Comparative Evaluation of Waste Export and Conversion Technologies Disposal Options

King County

Department of Natural Resources and Parks

Solid Waste Division

June 2007

R·W·BECK

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CERTIFICATE OF ENGINEER

The technical material and data contained in this document were prepared under the supervision and direction of the undersigned, whose seal, as a professional engineer licensed to practice as such, is affixed below.

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Abbreviations and Acronyms

BNSF	Burlington Northern Santa Fe
Btu	British thermal unit
C&D	construction and demolition (debris)
CDD	chlorinated dibenzo-p-dioxins
CDF	chlorinated dibenzofurans
CDL	construction, demolition and land-clearing (debris)
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
EPA	United States Environmental Protection Agency
HAP	hazardous air pollutant
HCl	hydrochloric acid
HDPE	high density polyethylene
HHW	household hazardous waste
hp	horsepower
IPCC	International Panel on Climate Change
ISWA	Integrated Waste Services Association
kWh	kilowatt-hour
LandGEM	Landfill Gas Emissions Model
LDPE	low density polyethylene
MACT	maximum available control technology
MMBtu	million British thermal units
MWh	megawatt-hour
N_2O	nitrous oxide
NAAQS	National Ambient Air Quality Standards
NMOC	nonmethane organic compounds
NO_X	oxides of nitrogen
NPV	net present value
O&M	operation and maintenance
OCC	old corrugated cardboard
ONP	old newspaper (newsprint)
PAH	polycyclic aromatic hydrocarbons
PCDD	polychlorinated dibenzo-p-dioxin
PCDF	polychlorinated dibenzofuran

PETE	polyethylene terephthalate
PM_{10}	particulate matter less than 10 micrometers in mass-mean diameter
$PM_{2.5}$	particulate matter less than 2.5 micrometers in mass-mean
diameterPSD	Prevention of Significant Deterioration
PVC	polyvinylchloride
RCW	Revised Code of Washington
RDC	Regional Disposal Company
RDF	refuse-derived fuel
SNCR	selective non-catalytic reduction
SO_2	sulfur dioxide
TCLP	Toxicity Characteristic Leaching Procedure
TEF	Toxic Equivalency Factor
TPD	tons per day
TPY	tons per year
TSP	total suspended particulate matter
ug/kg	micrograms per kilogram of solid material
UP	Union Pacific
VOC	volatile organic compounds
WAC	Washington Administrative Code
WECC	Western Electricity Coordinating Council
WTE	waste-to-energy

EXECUTIVE SUMMARY

Introduction

This report presents the results of the review and analysis undertaken by R. W. Beck, Inc. ("R. W. Beck") of waste disposal options currently being considered by King County's Department of Natural Resources and Parks, Solid Waste Division. The Solid Waste Division is charged with the proper management of solid waste generated in the County and has developed a comprehensive solid waste management system that includes recycling, collection, transfer, and disposal components.

At the present time, the County's principal means of disposal is the County-owned Cedar Hills Regional Landfill, which the County currently estimates will have useful remaining life until around 2016. With approximately nine years of remaining disposal capacity, the County is considering long-term alternative disposal options that would be available by 2016. The County is currently focused on evaluating the following options:

1. The intermodal transfer and long-haul transport via rail haul to privately owned landfills located outside the County (the "Waste Export Disposal Option").
2. The development of a solid waste conversion facility that would be capable of converting municipal solid waste into a form of recoverable energy (the "Conversion Technology Disposal Option").

This report sets forth the results of our review of certain issues related to these two disposal options during the 20-year study period of 2016 to 2036.

Purpose of the Report

It is important to note that at the County's current stage of planning for future disposal capacity, it does not intend to make a final decision based on the results of this report. This report has focused on: 1) providing information to assist decision-makers in their understanding of the two disposal options; 2) explaining the interrelationship of the disposal options to the County's recycling program and its transfer station and transfer fleet; and 3) providing planning estimates of capital costs, operating expenses, and operating revenues associated with the two disposal options under consideration.

Overview of the System

At the present time, the County is responsible for the proper management of the estimated 1,775,000 tons per year of solid waste that are currently being generated within the County. The County is managing this situation through two principal means:

1. Recycling – Approximately 770,000 tons of solid waste are currently being recycled by means of a series of recycling programs the County has implemented as described in Appendix A. The County estimates that it is currently recycling approximately 44.6 percent of the total waste being generated.
2. Landfilling – Approximately 1,005,000 tons of waste are being disposed of in the County, with most of this material being disposed of at the Cedar Hills landfill. This represents approximately 55.4 percent of the solid waste being generated in the County. Most of this waste is suitable for disposal by either of the two options considered in this report.

The portion of the solid waste stream requiring disposal is currently being collected by both private and public haulers and then delivered to either one of the County's eight transfer stations or directly to the Cedar Hills landfill.

Overview of Waste Export Disposal Option

While there are several options available to the County related to intermodal capacity, in order to estimate costs and other factors for the purpose of this report, we have assumed the Waste Export Disposal Option would involve an intermodal waste transfer facility developed, operated, and owned by the County, and located on a site accessible to one or both of the railroad mainlines that serve King County. "Intermodal" refers to the fact that the containerized solid waste will be transferred from trucks to rail cars as part of the transfer operation. Solid waste collected in the County will be delivered to a County transfer station, compacted into intermodal containers, and then transferred to the intermodal facility via transfer trailer trucks. At an intermodal facility, all of the solid waste will be loaded onto intermodal container rail cars. When a full train of rail cars has been loaded, the train will transport the waste to a privately owned regional landfill. At the landfill, the containers will be unloaded at the working face of the landfill and the empty containers will be placed back on the rail cars and returned to the intermodal facility.

The transfer and transportation of solid waste via an intermodal facility is a well-proven method of solid waste disposal with relatively low risk of technology failure.

Overview of Conversion Technology Disposal Option

For the purpose of this report, "Conversion Technology" refers to a process which converts solid waste from a waste product to a useful form of energy and/or useable byproduct, generally with some residual, unusable component that must be sent for disposal.

As is discussed in Section 3 of this report, a number of different Conversion Technologies are currently being promoted by various vendors. The Conversion Technologies can generally be subdivided as follows based on the type of process:

1. Thermal
2. Biological
3. Chemical

The County directed R. W. Beck to review currently available information on all Conversion Technologies for the purpose of identifying the Conversion Technologies that merit the County's further review and consideration. In order to qualify for further review, a Conversion Technology had to be "commercially proven." The County defined commercially proven as facilities that have been constructed and successfully operated for at least three years at an operating size or scale suitable for the quantity and composition of the County's projected solid waste stream.

With these criteria in mind, we reviewed the following Conversion Technologies, all of which are described in detail in Section 3:

1. Thermal-based
   a. Pyrolysis
   b. Gasification
   c. Plasma Arc
   d. Mass Burn
      i. Modular starved-air
      ii. Modular excess-air
      iii. Waterwall
   e. Refuse-Derived Fuel (RDF)
   f. Advanced Thermal Recycling
2. Biological and Chemical
   a. Anaerobic Digestion
   b. Waste-to-Ethanol
   c. Aerobic Digestion/Municipal Solid Waste Composting
   d. Thermal Depolymerization/Plastics-to-Oil
   e. Steam Classification/Autoclave
   f. Catalytic Cracking

Of these 14 Conversion Technologies, we identified three as having sufficient operating experience in the size required to meet the County's waste disposal requirements. These three commercially proven technologies are evaluated in depth in this report:

- Mass Burn – Waterwall

- RDF
- Advanced Thermal Recycling

These three Conversion Technologies are well-proven methods of solid waste disposal with a manageable risk of technology failure if the Conversion Facility is designed, constructed, operated, and maintained by a vendor with proven capabilities in the operation of such Conversion Facilities.

Of the 11 remaining Conversion Technologies, we identified five technologies that we believe merit further monitoring by the County in the event that a large, operating facility comes on-line. In such an event, the County would have additional information and data to evaluate. The five technologies that we believe merit further monitoring by the County are:

- Gasification
- Plasma Arc
- Anaerobic Digestion
- Waste-to-Ethanol
- Steam Classification/Autoclave

In our opinion and for the reasons discussed in Section 3, the balance of the Conversion Technologies do not merit further monitoring by the County at this time.

Number and Size of Conversion Facilities

Selecting the correct number and capacity of Conversion Facilities involves a number of different trade-offs that will require consideration by the County. The arguments in favor of smaller Conversion Facilities in multiple locations throughout the County are as follows:

1. Greater redundancy for the solid waste management system as a whole, both in terms of waste disposal and energy generation.
2. Reduced cost of transporting waste from the point of collection to the point of disposal.
3. Reduced impact on just one geographic area of the County associated with traffic, noise, odors, and litter.
4. Smaller facilities make it possible to add additional disposal capacity in smaller increments as it becomes necessary.
5. Increased annual availability of the disposal capacity of the entire solid waste management system by having a greater number of processing lines.

Arguments for larger Conversion Facilities in fewer locations are as follows:

1. Due to economies of scale, larger facilities will experience:
    a. lower capital costs on a dollar per ton of installed capacity basis
    b. lower operating expenses on a dollar per ton of waste basis

This in turn should result in a lower overall cost to the County

2. Siting fewer Conversion Facilities will be less expensive and time-consuming for the County.

Because of the significant cost savings, the ability of a single Conversion Facility to meet the disposal capacity requirements, and the projected quantities of waste in the County, we have concluded for the purpose of this report that the County would implement a single facility sized at 3,200 TPD. Nevertheless, for the reasons cited above, this is a decision the County would want to carefully consider.

Effect of Recycling on Conversion Technologies

The County has identified plans to increase its recycling rate above the current level of 44.6 percent. For the planning purposes of this report, the County advised that R. W. Beck should assume the percentage of recycled material will increase by an average of 0.3 percent per year (the "Base Case" recycling level). The County's recycling goal is a critical factor that would need to be addressed in greater detail before making any decision regarding the actual implementation of a Conversion Technology.

As is discussed in Sections 6 and 7 of this report, we have assumed the County will take the steps required to reach the Base Case recycling level. Our analysis indicates that if the County is able to achieve its goals and increase the Base Case level of recycling from 44.6 percent in 2007 to 47.3 percent in 2016 and 53.3 percent by 2036, the County will be able to reduce the size of a Conversion Technology in 2016 from 3,700 tons per day (TPD) to 3,200 TPD and in 2036 will require disposal capacity of 4,700 TPD instead of 5,600 TPD. This has the potential to save the County hundreds of millions of dollars in capital costs and operating expenses over the useful operating life of a Conversion Facility or during the study period for the Waste Export Disposal Option.

In developing the information on the potential impact of recycling on a Conversion Facility, our analysis concluded that:

1. Based on the Waste Characterization Study that the County prepared in 2003, there are currently additional recyclable items in the County waste stream that if recovered should allow the County to reach the Base Case recycling level.
2. There is a sufficient quantity of solid waste being generated in the County that would allow the County to reach its Base Case recycling level while implementing a Conversion Facility at 3,200 TPD.
3. The County could increase the level of recycling above the Base Case to eventually achieve 60 percent by 2036 and there would be a sufficient quantity of waste for a 3,200 TPD Conversion Facility. Under such a scenario, there may be a small effect on the net amount of energy the Conversion Facility could generate, depending upon the types of materials that are actually targeted by the County for recycling.

4. If the County increased the level of recycling from the Base Case to 70 percent, there would be a small shortfall in the amount of waste required to operate a 3,200 TPD Conversion Facility. Under this scenario, it should be anticipated that there would be a modest impact on the net amount of energy the Conversion Facility could generate. The County might address this shortfall by accepting waste from other jurisdictions or by deciding to construct a smaller Conversion Facility that would be compatible with the increased level of recycling.

Decisions the County makes regarding the level of future recycling will be very important for the following reasons:

1. If the County targets a recycling level that is lower than what it actually achieves, the County could have unutilized disposal capacity at a Conversion Facility, thereby potentially underutilizing millions of dollars of investment.
2. If the County targets a recycling level that is higher than what it actually achieves, the County could find itself in a situation where it does not have sufficient disposal capacity to meet its needs.
3. The timing of when additional disposal capacity may be required after 2016 could be impacted by the actual level of recycling that is achieved.

Need for Backup Disposal Capacity

It is important to note that if the County proceeds with a Conversion Facility at some future time, it will not eliminate the need for access to some landfill disposal capacity. Landfill disposal capacity would be required for the following reasons:

1. Disposal of non-processible waste (construction and demolition material, oversized items, etc.) that the Conversion Facility cannot process. We estimate that this could range from 5 to 9 percent of the waste stream in the County's transfer system.
2. Disposal of solid waste during periods when the Conversion Facility, or a portion thereof, is down for scheduled or unscheduled maintenance, or when the waste quantity exceeds the storage and processing capacity in the transfer and Conversion Facility disposal system. Properly designed, constructed, and operated Conversion Facilities can be expected to have an annual availability factor of approximately 90 percent. In addition, the Conversion Facilities should be designed to have a minimum of three days' storage capacity in addition to the storage capacity in the transfer system. The amount of bypassed waste will vary each year dependent upon the total amount of solid waste requiring disposal (which is projected to increase each year) and the installed capacity of the Conversion Facility.
3. Disposal of residue material from the conversion process. Any of the three identified Conversion Technologies should be able to reduce the volume of waste by approximately 90 percent meaning the remaining residue will be equal to 10% of the waste on the basis of volume. However, the remaining residue material will likely be equal to 25 to 30 percent of the weight of the incoming waste. Unless

and until a beneficial use can be found for such residue material, it will have to be landfilled. Section 9 of this report discusses different approaches to the management of residue material in Washington State.

4. Due to seasonal fluctuations in the generation of solid waste throughout the year, the County may have to bypass solid waste during peak waste generation months depending upon policy decisions the County makes regarding the size of a Conversion Facility.

Energy Generation

Both of the disposal options that are considered in this report have the potential to generate some form of energy.

For the Waste Export Disposal Option, we have assumed the County will deliver its solid waste to a privately owned regional landfill. As the County's waste decomposes in a landfill, it will produce methane gas which can be captured, cleaned, and used to generate electricity. Based on a series of planning assumptions described in Section 12, we estimate that under the Waste Export Disposal Option the County solid waste could generate approximately 39 million British thermal units (MMBtu) of energy during the study period 2016 to 2036. We further estimate that the value of such gas to a private electricity generator could be approximately $118 million (2007 dollars) during that 20-year study period.

It is important to note that it is highly likely that the landfill could continue to generate gas from County waste for at least 40 years after the County stops delivering solid waste to the landfill. We have not included the additional 40 years of gas generation after 2036 in our comparative analysis in order to facilitate the comparison between options.

It should be further noted that the County may or may not experience any financial benefit from the sale of landfill gas. Because the landfill itself, the landfill gas collection equipment, and the power generation equipment would all be owned by private parties, no landfill gas revenue will accrue directly to the County. We are not able to determine whether such landfill gas revenues will be reflected in a lower disposal fee to the County.

However, the County would realize the benefits of electricity generation from a Conversion Facility that the County owns and operates. Based on the planning assumptions set forth in Section 12 regarding power generation, heating value of the solid waste, and annual plant availabilities, we estimate that a Conversion Facility could generate approximately 11.6 million MWh of electrical energy between 2016 and 2036. We further estimate that the value of such energy would be approximately $662 million, expressed in 2007 dollars. Assuming a 3,200 TPD Conversion Facility processes approximately 1,050,000 tons of waste per year, the net value of the Conversion Facility energy revenues to the County would be approximately $31.50 per ton. These revenues would be available to help offset the capital and operating expenses of the Conversion Facility.

Similar to the Waste Export Disposal Option, a Conversion Facility should be expected to be capable of generating electricity well beyond the initial 20-year planning period of this report. In our opinion, a properly designed, constructed, and operated Conversion Facility could have a useful life approaching 50 years assuming the timely renewal and replacement of required items of equipment.

Comparative Costs

While a Conversion Facility may be expected to generate considerable revenue over the 20-year planning period of this report, it will have a substantial capital cost and operating and maintenance expenses. As discussed in Section 11 of this report, the last new Conversion Facility constructed in the United States came on-line in 1995, so much of the construction cost information is dated. Based on our discussions with the vendors of Conversion Facilities, we estimate that the capital cost of the three Conversion Technologies discussed in this report could range as follows:

Conversion Technology	2007 Capital Cost Range ($ millions)
Mass Burn WTE	$460–$520
RDF WTE	$560–$610
Advanced Thermal Recycling	$520–$560

It should be noted that such estimates do not include the capital cost of a County-owned intermodal facility for the transfer and transportation of residue ash and bypass waste from the Conversion Facilities

The capital cost of an intermodal facility necessary for the Waste Export Disposal Option is estimated to be in the range of $15 million to $20 million (2007 dollars), or approximately 4 percent of the capital cost of the least expensive Conversion Facility. None of these capital cost estimates includes either the cost of property or the cost of capital (debt service).

The development of detailed construction cost estimates for three Conversion Technologies and the Waste Export Disposal Option was well beyond the scope of this report. Such estimates would require three to six months to develop and would cost well in excess of $100,000 to prepare.

Based on estimates of capital cost, cost of residue ash disposal, revenues from energy production, operation and maintenance costs, and transport and disposal fees, we developed a net present value (NPV) calculation for each option to assist the County in its evaluation of the comparative costs. The results of the NPV calculation for each disposal option are shown in the following table.

Disposal Option	Total Net Present Value ($2016 millions)	Net Present Value per Ton ($2016)
Mass Burn	$1,116 – $1,550	$42 – $58
RDF	$1,570 – $1,967	$59 – $74
Advanced Thermal Recycling	$1,443 – $1,875	$54 – $70
Waste Export	$1,136 – $1,263	$43 – $47

It is important to recognize that the NPV is not an estimate of the actual cost to the County of each disposal option; it is an estimate of the value of the option considering the time value of money. Further discussion of the concepts and limitations of this analysis is included in Section 15 of this report.

Net Emissions

The air quality implications of the disposal options were evaluated through a review of rates of emission of various air pollutants. Pollutants were divided into three categories: 1) criteria pollutants – those with published ambient air quality standards; 2) air toxic pollutants – human health pollutants with no ambient standards; and 3) greenhouse gases – pollutants that are not normally considered toxic, but thought to contribute to the earth's climate change. Conversion Technologies would emit pollutants directly during the study years. Developing an estimate of emission rates for criteria pollutants and air toxic pollutants is straightforward, based on the quantity of waste converted and an assumed emission factor for each pollutant. For the landfill gas technologies associated with the Waste Export Disposal Option, however, since the gases continue to be generated for many years after the 20-year study period has ended, the estimation of emission rates considered gases derived from the wastes generated during the study period out to the year 2200.

For greenhouse gases, we used an EPA method, based on international scientific consensus, where emission rate estimation for Conversion Technologies includes only those emissions that do not come from sustainably harvested biogenic sources. For Conversion Technologies this essentially means that the majority of greenhouse gas emissions are carbon dioxide resulting from the combustion of plastics and materials of mixed origin. Wood, paper, food scraps, and other biogenic materials would decompose naturally and ultimately produce the same greenhouse gas emissions, so they are not counted in the emission inventory. For the disposal of solid waste in landfills, plastics do not decompose appreciably, so they do not produce greenhouse gases. However, the organic materials do decompose in landfills and produce methane, a much more potent greenhouse gas than the carbon dioxide produced by combustion. Since the methane would not occur under natural aerobic decomposition, methane emissions are included in the inventory, even if the original source is biogenic. The majority of the landfill gas, 80 percent, is assumed to be captured and burned. This produces carbon dioxide, which is treated the same as for the Conversion Technology alternatives.

Two other important concepts considered in the analysis of net emissions are "avoided emissions" and "carbon storage." Any of the options involving energy recovery are given credit for emissions that are avoided from other sources that would be needed to generate the same electricity. Carbon storage only applies to landfill alternatives, where a certain percentage of the carbon that was in the natural biogenic cycle of growth and decay is now locked beneath the surface and will not decompose in the time period being considered. Books and some other forms of paper are examples of biogenic materials that decompose very slowly.

The results of the analysis concluded that criteria pollutant emissions from all options would be expected to be well controlled and not produce any significant human health or human welfare impacts. The Conversion Technologies are estimated to generally have higher criteria pollutant emissions than landfill gas technologies, with the exception that volatile organic compound emissions from landfills are much higher than from the Conversion Technologies.

Air toxic pollutant emissions from all options would be expected to be able to be well controlled and not pose any significant human health impacts. However, landfills would be expected to have significantly higher air toxic emissions than Conversion Technologies due to the large volumes of fugitive landfill gas that are unavoidable with even the best landfills.

Solid waste is a product of human civilization and results in greenhouse gas emissions. Any properly developed solid waste management plan should be able to reduce the potential global impact of the gases that could be produced by this waste. The modern landfill alternatives considered here, with active gas collection systems and estimated 80 percent gas capture, are estimated to produce less greenhouse gas emissions than the Conversion Technologies. This conclusion disagrees with information provided by some other researchers, who have found greenhouse gases from Conversion Technology alternatives to be on par or better than landfill alternatives. We believe the difference in conclusions is explained by: 1) the modern design of the landfills considered here, compared with national average landfills that do not collect as much of the landfill gas; and 2) the relatively low avoided emissions in Washington State compared with other states where a higher percentage of the electricity is generated from coal combustion.

The potential impact of net emissions from a Conversion Facility located in the County may differ from the potential impact in other parts of the United States because of the significant amount of hydro-based power in the northwest

Major Report Conclusions

This report resulted in more than 30 principal findings as listed in Section 16. The key conclusions derived from these findings are as follows:

- The three Conversion Technologies and the Waste Export Disposal Option are each capable of handling the quantity and composition of the King County waste stream while meeting all applicable permit requirements.

- The Conversion Technologies are compatible with increased County recycling efforts up to a 70% recycling rate.
- In general, the Conversion Technologies are slightly more expensive than the Waste Export Disposal Option.
- An informed decision on disposal options will require a more detailed analysis to refine conclusions and evaluate specific characteristics not covered in this report.

Section 1
INTRODUCTION

Section 1
INTRODUCTION

This report presents the results of the review and analyses undertaken by R. W. Beck, Inc. (R. W. Beck) on behalf of King County's Department of Natural Resources and Parks, Solid Waste Division. Portions of the report were prepared by the following firms working as subconsultants to R. W. Beck:

- Sound Resource Management
- Geomatrix
- Power Waste Recovery

Purpose

The purpose of this report is to review available information regarding current and emerging technologies for the processing of solid waste ("Conversion Technologies") as potential disposal alternatives to the landfilling of the County's solid waste at an out-of-county landfill ("Waste Export"). The County currently disposes of most of its municipal solid waste at the Cedar Hills Regional Landfill, which is located in the County. Based on the current rate of disposal and the use of land at the Cedar Hills landfill that is currently permitted for the disposal of solid waste, the County estimates that the Cedar Hills landfill will reach the end of its useful operating life in 2016. The County has determined that it does not want to continue landfilling waste in the County after the Cedar Hills landfill has been closed. Therefore, the County is currently considering two options:

1. Disposal at a solid waste conversion facility to be constructed in the County (the "Conversion Technology Disposal Option").
2. Intermodal transfer and long-haul transport via rail to an out-of-county landfill for disposal (the "Waste Export Disposal Option").

More specifically, the purpose of this report is to: 1) identify commercially proven Conversion Technologies in the size range required by the County; 2) identify how large a Conversion Technology facility ("Conversion Facility") would be required to meet the County's waste disposal requirements; 3) consider the potential impact on a Conversion Facility as the County proceeds with the implementation of its proposed recycling programs; 4) identify the potential range of capital and operating costs of the Conversion Technology and Waste Export options; 5) identify the amount of energy a Conversion Facility could be expected to generate and the level of revenues the County could receive through the sale of that energy; and 6) compare the estimated range of net air emissions of the Waste Export Disposal Option with the Conversion Technology Disposal Option during the 20-year planning period of this report.

We used criteria provided by the County to select Conversion Technologies for more in-depth consideration, after an initial review of all potential Conversion Technologies. These criteria required that the Conversion Technology had to be "commercially proven." The County defined commercially proven as facilities that have been constructed and successfully operated for at least three years at a scale similar to the County's projected waste stream.

Scope

In preparing this report, R. W. Beck performed the work pursuant to the terms and conditions set forth in the *Agreement for Professional Services for Work Order Multidisciplinary Engineering Services for SWD Planning and Implementation*, Contract No. E53023E dated September 5, 2005. The specific scope of services for this work was identified in *Work Order No. 6 – Comparative Evaluation of Waste Export and Conversion Technologies Disposal Options – Scope of Work* dated December 19, 2006. The scope of work included subtasks that called for R. W. Beck to undertake research and analysis on the following topics in order to compare the disposal options:

- Type and Quantity of Acceptable Waste
- Conversion Technology Review and Selection
- Annual Availability of Conversion Facilities
- Compatibility of Recycling Programs and Conversion Technologies
- Number and Size of Conversion Facilities and Waste Export Facilities
- Percent of Waste That is Unacceptable at Conversion Facilities
- Backup Disposal Capacity
- Composition of Residue Ash from Conversion Facilities
- Current Classification of Residue Ash in Washington
- Estimate of Net Air Emissions
- Estimated Capital and Operating Costs
- Projected Energy Revenues
- Transfer Station Collection/Transportation Infrastructure
- Estimated Facility Siting and Permitting Costs

Following the execution of Work Order No. 6, the County directed R. W. Beck to also prepare a comparative cost analysis that summarized the planning estimates developed in various sections of the report.

Nature of Review

In undertaking the analysis associated with completing the 15 subtasks identified above, R. W. Beck undertook the following efforts:

1. Contacted vendors who offer different types of Conversion Technologies to obtain information on historical level of performance and estimated capital and operating costs.
2. Reviewed available reports prepared by others regarding the Conversion Technologies.
3. Relied upon our own previous experience in reviewing Conversion Technologies for other clients.
4. Visited Germany to review the actual operation of the advanced thermal recycling Conversion Technology.
5. Utilized data and information we have developed during the last 25 years regarding the operation of mass burn and refuse-derived fuel (RDF) Conversion Technologies.
6. Contacted the operator of the Spokane, Washington Conversion Facility to obtain historical operating data.
7. Contacted the Washington State Department of Ecology to obtain information on permit requirements and the classification of residue ash.
8. Developed long-range planning estimates of the price of power in the Northwest.
9. Undertook an analysis which developed planning estimates of the potential air emissions from the Waste Export and Conversion Technology disposal options.
10. Reviewed the County's proposed recycling goals up to 2036, the County's Waste Characterization Study, and the County's estimate of future waste generation.
11. Prepared a summary comparative cost analysis of the disposal options.

Section 2
SOLID WASTE QUANTITY AND COMPOSITION

Section 2
SOLID WASTE QUANTITY AND COMPOSITION

This section of the report presents the results of the review R. W. Beck has performed regarding the quantity and composition of solid waste currently being disposed of by the County at the Cedar Hills Regional Landfill. The quantity and composition of the solid waste are important in identifying:

1. What percentage of the waste stream is actually processible by any particular Conversion Technology.
2. The amount of non-processible waste that will have to be landfilled.
3. What portion of the waste stream currently being sent for disposal might be able to be recycled in the future and how the Conversion Technologies would impacted by increased recycling.

At the end of this section is a summary table (Table 2-3) that outlines the projected tonnage and composition of waste in select future years. This projection is a snapshot based on the assumption that the composition of the waste stream has not significantly changed between 2003 and now, and that it will not change between now and 2036. The information in Table 2-3 is used in subsequent sections of this report as a basis for assumptions about future recycling efforts and is a starting point for determining the projected quantities and composition of waste disposed of in future years. To arrive at the projection of waste requiring disposal by a Conversion Facility, future additional levels of recycled material will be subtracted from the estimated quantities shown in Table 2-3.

Solid Waste Composition

In order to develop an estimate of the amount of municipal solid waste which would potentially be acceptable for each Conversion Technology, R. W. Beck reviewed the results of the Waste Characterization Study performed by the County in 2003. We believe the Waste Characterization Study provides sufficient breakdown of waste categories for the planning purposes of this report. Table 2-1 presents a summary of the results of the Waste Characterization Study. Since this information represents the composition of waste that was delivered to the Cedar Hills landfill, after the County removed waste categorized as “unacceptable” waste, Table 2-1 is assumed to show the composition of future “acceptable” waste at a Conversion Facility. To determine the composition and quantity of waste that would actually be processed by a Conversion Facility in King County, future recycling efforts (Section 7) and non-processible waste based on the particular Conversion Technology (Section 6) are subtracted from this composition.

Table 2-1
Results of King County's 2003 Waste Characterization Study

Category	Tons	Percent by Weight	Category	Tons	Percent by Weight
Paper	218,452	23.24%	**Metal**	65,271	6.94%
Newspaper	25,362	2.70%	Aluminum cans	3,532	0.38%
OCC/Kraft paper	43,338	4.61%	Other aluminum	1,995	0.21%
Low-grade recyclable paper	58,606	6.23%	Tinned food cans	6,973	0.74%
High-grade printing paper	15,277	1.63%	Other ferrous metal	22,367	2.38%
Bleached polycoat paper	2,981	0.32%	Other nonferrous metal	690	0.07%
Paper/other materials	15,278	1.63%	Mixed metals/materials	29,180	3.10%
Compostable paper	52,054	5.54%	Gas metal cylinders	534	0.06%
Gift wrapping paper	415	0.04%	**Other Wastes**	100,358	10.68%
Other paper	5,141	0.55%	Construction/demolition wastes	38,826	4.13%
Plastic	101,465	10.79%	Ashes	1,429	0.15%
PET #1 plastic bottles	5,981	0.64%	Nondistinct fines	10,584	1.13%
HDPE #2 plastic bottles	4,739	0.50%	Gypsum wallboard	8,483	0.90%
Other plastic containers	6,674	0.71%	Furniture/mattresses	25,572	2.72%
Polystyrene foam	3,974	0.42%	Small appliances	7,765	0.83%
Plastic film and bags	47,027	5.00%	Printers/copiers/faxes	1,103	0.12%
Other plastic packaging	5,812	0.62%	Office electronics	1,208	0.13%
Plastic products	13,919	1.48%	Miscellaneous inorganics	5,388	0.57%
Foam rubber/padding	2,978	0.32%	**Household Hazardous**	5,607	0.60%
Plastic/other materials	10,361	1.10%	Used oil	411	0.04%
Organics (wood/yard/food)	320,230	34.07%	Vehicle batteries	0	0.00%
Dimensional lumber	35,741	3.80%	Household batteries	238	0.03%
Treated wood	8,854	0.94%	Alkaline/button cell batteries	475	0.05%
Contaminated wood	17,699	1.88%	Latex paint	313	0.03%
Roofing/siding	6,045	0.64%	Oil-based paint	105	0.01%
Stumps	1,722	0.18%	Solvents/thinners	44	0.00%
Large prunings	1,847	0.20%	Adhesives/glues	478	0.05%
Yard Wastes	47,127	5.01%	Cleaners and corrosives	184	0.02%
Other wood	13,371	1.42%	Pesticides/herbicides	200	0.02%
Food wastes	187,824	19.98%	Gas/fuel oil	66	0.01%
Other Organics	100,340	10.67%	Antifreeze	35	0.00%
Textiles/clothes	18,748	1.99%	Medical waste	481	0.05%
Carpet/upholstery/other textiles	25,192	2.68%	Computer monitors	172	0.02%
Disposable diapers	25,754	2.74%	Televisions	1,621	0.17%
Rubber products	2,379	0.25%	Cell Phones	176	0.02%
Tires	3,553	0.38%	Laptops/LCD monitors	85	0.01%
Animal carcasses	52	0.01%	Other Hazardous	523	0.06%
Animal feces	18,443	1.96%	**Total**	**940,027**	**100.00%**
Miscellaneous organics	6,219	0.66%			
Glass	28,304	3.01%			
Clear glass containers	9,674	1.03%			
Green glass containers	4,281	0.46%			
Brown glass containers	5,057	0.54%			
Other colored glass containers	45	0.00%			
Other glass	9,247	0.98%			

Source: King County Department of Natural Resources and Parks, Solid Waste Division.

Waste Disposal Quantity Projections

We reviewed information provided by the County regarding the County's projection of the quantity of waste it anticipates will be generated in the County during the period of 2016 to 2036. These projections were created from a regression model used by the County and assume an average increase in the recycling rate of 0.3% per year. Selected years from the County's projections are presented in Table 2-2.

Table 2-2
Projected Waste Disposal Quantities

Year	Projected Waste Disposal Quantity (thousands of tons)
2016	1,164
2021	1,255
2026	1,324
2031	1,439
2036	1,555

Projected Waste Composition

To determine the waste composition and tonnages for the planning period, we applied the general categorical waste composition percentages from the Waste Characterization Study in 2003 to the waste projections for the planning period. This methodology assumes that little or no change to the composition of the waste stream will occur between 2003 and 2036. The resulting composition presented in Table 2-3 is a snapshot of the projected King County waste stream and is used as a basis for future assumptions in this report, including increases in the level of recycling.

Table 2-3: Projected Waste Category Tonnages

Assumed County Waste Composition 2016–2036		Projected Tons by Year				
Category	Percent	2016	2021	2026	2031	2036
Total	100	1,164,301	1,255,030	1,324,286	1,438,772	1,554,841
Paper	23.24	270,584	291,669	307,764	334,371	361,345
Plastic	10.79	125,628	135,418	142,890	155,243	167,767
Organics (wood/yard/food)	34.07	396,677	427,589	451,184	490,190	529,734
Other Organics	10.67	124,231	133,912	141,301	153,517	165,902
Glass	3.01	35,045	37,776	39,861	43,307	46,801
Metal	6.94	80,802	87,099	91,905	99,851	107,906
Other Wastes	10.68	124,347	134,037	141,434	153,661	166,057
Household Hazardous	0.6	6,986	7,530	7,946	8,633	9,329

Section 3
REVIEW OF CONVERSION TECHNOLOGIES

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The County is evaluating waste conversion technologies ("Conversion Technologies") as a possible disposal alternative to rail haul from the County to landfills located outside the County. For the purpose of this report, Conversion Technologies are defined to include both commercially demonstrated combustion technologies as well as emerging technologies which utilize thermal, biological and chemical conversion. In recent years, various venders have proposed a number of new Conversion Technologies as potentially viable waste management alternatives. R. W. Beck conducted a review of these technologies which included: 1) reviewing published information regarding both commercially demonstrated and emerging Conversion Technologies; 2) contacted the vendors of certain emerging Conversion Technologies; 3) relying upon information R. W. Beck had previously developed; and 4) visiting several types of facilities under review. Based on selection criteria developed by the County, R. W. Beck has classified each of the Conversion Technologies we reviewed into one of three categories:

1. Proven technology that meets the County's selection criteria.
2. Commercially unproven technology that appears to have potential and that merits ongoing monitoring by the County during the next three to five years.
3. Unproven technology that does not currently merit ongoing monitoring by the County.

This section of the report presents a summary of our review, the County's selection criteria that we applied, a description of the various Conversion Technologies we reviewed for the purposes of this report, our recommendations regarding the categorization of each Conversion Technology, and a discussion of additional criteria the County may wish to consider if and when it decides to procure one of the recommended Conversion Technologies.

Nature of Review

To review the Conversion Technologies, R. W. Beck: 1) relied upon our own experience working on waste-to-energy projects in the solid waste industry, 2) reviewed pertinent literature, and 3) contacted vendors of specific technologies to gather data for our review. These approaches are briefly described in the following paragraphs.

R. W. Beck has extensive experience evaluating different solid waste processing technologies. Facilities that we have evaluated include the following technologies:

- Waste-to-energy
    - Mass burn, including
        - Modular starved air
        - Rotary combustors
        - Field erected
    - Refuse-derived fuel and material recovery plants including
        - Ferrous recovery – pre-incineration
        - Aluminum recovery – eddy current separators
        - Sorting and sizing – trommels, shredders, air classifiers
        - Glass recovery systems
    - Circulating fluidized bed combustors
- Co-disposal – sewage sludge and municipal solid waste in a multiple hearth furnace
- Composting of municipal solid waste
- Co-composting of municipal solid waste and sewage sludge
- Pyrolysis of municipal solid waste
- Pyrolysis of tires
- Municipal solid waste to ethanol
- Plasma arc

Not all of the technologies listed above were included as part of this review for the County, as they are not all applicable for the County's stated purposes. Specifically, co-disposal with sewage sludge, co-composting with sewage sludge, and pyrolysis of tires were not included as part of this review.

R. W. Beck also reviewed published information developed by others. The publications reviewed as part of this report include:

1. Evaluation of New and Emerging Solid Waste Management Technologies prepared for the New York City Economic and Development Corporation and New York City Department of Sanitation – September 16, 2004.
2. Summary Report: Evaluation of Alternative Solid Waste Processing Technologies prepared for the City of Los Angeles – September 2005.
3. Evaluation of Alternatives to and Identification of the Preferred Residuals Processing System Recommendations Report for Durham/York Region – May 30, 2006.
4. The Municipal Waste Combustion Industry in the United States-7th Edition Resource Recovery Yearbook and Directory.

5. Conversion Technology Evaluation Report prepared for the County of Los Angeles – August 18, 2005.
6. European Union documentation provided by Councilmember Kathy Lambert.
7. Solid Waste Management and Greenhouse Gases: a Life Cycle Assessment of Emissions and Sinks. U.S. Environmental Protection Agency.

Finally, R. W. Beck contacted vendors of different Conversion Technologies. In our telephone contact with vendors, we used a data request form that asked for the following information:

- Process description
- Number of facilities where technology is employed
- Year the facility went into commercial operation
- Size of facility
- Type of waste processed
- Need for front-end processing
- Amount of process residue requiring disposal (as a percent of incoming waste)
- Annual plant availability
- Type of recovered products
- Net energy produced
- Capital cost of the facility ($/ton of daily waste disposal capacity)
- Operating and maintenance expenses ($/ton of waste processed)
- Type of air pollution control equipment installed
- Results of air emissions tests
- For technologies still in the developmental stage, date the technology is expected to be commercially available.

Criteria for Determining Conversion Technologies for Further Review

Vendors are currently proposing a large number of emerging solid waste Conversion Technologies. It would be prohibitively expensive for the County to request an in-depth review of all the solid waste processing technologies currently being offered in the marketplace. Therefore, the County identified four basic criteria that any Conversion Technology was required to meet in order to qualify for further consideration and review. Those criteria are as follows:

1. Previously demonstrated continuous capability of the technology, over a minimum three-year period, to process the approximate quantities and

composition of waste being managed by the County at the Cedar Hills Regional Landfill.

2. Demonstrated capability of the technology to produce energy or another byproduct for which there is a proven market and which could be sold in the quantities that the facility will produce.
3. Demonstrated capability of the technology, over a minimum three-year period, to operate within the permit requirements that will be imposed by the state of Washington.
4. Demonstrated capability, over a minimum three-year period, to produce a residue product which can be disposed of or reused in accordance with state solid waste handling requirements

In addition to these four basic criteria, the County also advised that R. W. Beck should consider the following issues:

1. The facilities must utilize a technology which assures that they will be able to be in operation by 2016.
2. The report should discuss the minimum level of processible material which a technology must accept.
3. Consideration must be given to the challenges that will be presented with trying to obtain sites for multiple facilities to be located in the County. There will be some practical limit on the number of facilities that can be sited so individual unit size should be a consideration.
4. A reasonable level of “scale-up,” (i.e., increased plant size required for the County’s waste over the largest size plant now in operation) should be allowed. However, the amount of scale-up that would be required to meet the County’s requirements should not be excessive.
5. The technologies should allow for the possible installation of additional processing lines as the County’s waste quantities increase over time. The processing lines should be of sufficient size so that such installations do not have to be undertaken on too frequent a basis, allowing the units to be operated efficiently.

Conversion Technologies Reviewed

For the purpose of this report, we have subdivided the Conversion Technologies as follows:

- Thermal technologies
  - Emerging thermal technologies
  - Proven thermal technologies
- Biological and Chemical technologies

Presented below is a discussion of each of the Conversion Technologies R. W. Beck reviewed and our recommendation on which technologies meet the County's criteria for further review.

Thermal Conversion Technologies

Thermal-based Conversion Technologies utilize higher temperatures and have higher conversion rates when compared to other conversion processes. For the purpose of this report, our review of thermal technologies included proven and emerging thermal technologies. The proven thermal Conversion Technologies we reviewed are mass burn combustion, refuse-derived fuel burned in dedicated boilers, and advanced thermal recycling as employed in Germany. The emerging thermal Conversion Technologies we reviewed are pyrolysis, gasification, and plasma arc.

Emerging Thermal Conversion Technologies

The following paragraphs present a discussion of the three emerging thermal Conversion Technologies R. W. Beck reviewed and our recommendation regarding whether each technology should be further reviewed based on the County's criteria.

Pyrolysis and gasification, though we deem them "emerging" technologies in the context of this report, are not new technologies. These two technologies have been used to process coal since the early 20th century. Attempts were made in the 1970s to apply pyrolysis to the processing of municipal solid waste at several facilities in the United States but those projects failed, primarily due to difficulties with the front-end waste processing of the solid waste. While the application of these technologies to solid waste feedstocks is only emerging in the United States, these technologies have been applied for the management of solid waste in other parts of the world such as Japan and Europe.

Pyrolysis

Pyrolysis is a process that produces pyrolytic oils and fuel gases that can be used directly as boiler fuel or refined for higher quality uses such as engine fuels, chemicals, adhesives, and other products. Solid residues from pyrolysis contain most of the inorganic portion of the feedstock, as well as large amounts of solid carbon or char. Pyrolysis typically occurs at temperatures in the range of 750°F to 1,500°F and thermochemically degrades the feedstock without the addition of air or oxygen. Because air or oxygen is not intentionally introduced or used in the reaction, pyrolysis requires thermal energy that is typically applied indirectly by thermal conduction through the walls of the containment reactor. The reactor is usually filled with an inert gas to aid in heat transfer from the reactor walls and to provide a transport medium for removal of the gaseous products.

The composition of the pyrolytic product is changed 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 is 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 to 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.

Combustion of the gases produced during the pyrolytic reaction in a separate reaction chamber release significant thermal energy. The thermal energy can produce steam for electricity generation, heat the pyrolytic reaction chamber, or dry the feedstock entering the reaction chamber. If pyrolytic gases are combusted to produce electricity, air emission control equipment will be needed to meet regulatory standards.

The municipal solid waste feedstock requires shredding to a 12-inch maximum size prior to charging the pyrolysis reactors.

To learn more about the status of the pyrolysis Conversion Technology, R. W. Beck attempted to contact Graveson Energy Management and WasteGen UK Ltd., two of the major suppliers. The U.S. representative of Graveson Energy Management was not reachable. Graveson Energy Management has not built a full-scale facility in the United States and their technology requires an extremely high size reduction of the feedstock to less than one inch. Due to this significant technical constraint, R. W. Beck eliminated this pyrolysis Conversion Technology from further consideration. Since a response was not received from WasteGen, our assessment relied upon published data. Other suppliers of the pyrolysis Conversion Technology have pilot or demonstration experience processing municipal solid waste, but no full-scale facilities are in commercial operation.

The net energy generation rate for the pyrolysis Conversion Technology can reportedly approach 700 kWh per ton of waste processed. Two facilities with WasteGen technology are operating in Germany, the oldest facility having operated continuously for 22 years. The largest operating unit with over three years of experience processing municipal solid waste and similar waste is rated at 175 TPD and is located in Hamm-Uentrop, Germany. The large scale-up of this technology for application in King County represents a potential area of risk. Brightstar Environmental constructed a single 30,000 TPY (2 units at estimated 50 TPD each) facility in Wollongong, New South Wales, Australia. The commercial-scale facility operated in test phase from 2000 to 2004 and was shut down in April 2004. The Brightstar facility reportedly had problems with the char gasification component of the process and corresponding financial problems with the plant. A proposed facility in the United States with the same conversion technology in Collier County, Florida was canceled.

Furthermore, no facilities employing pyrolysis to process MSW are commercially operating in the United States. Based on the lack of commercial application at the size and service duration required to process the County’s waste, R. W. Beck does not recommend the County pursue the pyrolysis technology at this time. We further recommend the County should not consider pyrolysis as a viable conversion technology either currently or in the future unless and until this technology is demonstrated at a commercially proven scale appropriate to the County’s needs.

Gasification

Two types of gasification technologies exist: 1) fluid bed gasification and 2) two-stage (pyrolysis-gasification) fixed bed. These technologies involve the thermal conversion of organic carbon-based materials in the presence of internally produced heat, typically at temperatures of 1,400°F to 2,500°F, and in a limited supply of air/oxygen (less than stoichiometric, or less than is needed for complete combustion) to produce a synthetic gases ("syngas") composed primarily of hydrogen and carbon monoxide. Inorganic materials are converted either to bottom ash (low-temperature gasification) or to a solid, vitreous slag (high-temperature gasification that operates above the melting temperature of inorganic components). Some of the oxygen injected into the system is used in reactions that produce heat, so that pyrolysis (endothermic) gasification reactions can initiate, after which the exothermic reactions control and cause the gasification process to be self-sustaining. Like pyrolysis, most gasification systems are closed systems and do not generate waste gases or air emission sources during the gasification phase. An important aspect of gasification is that the chemical reactions can be controlled for the production of different products. The gases produced by gasification can be cleaned to remove any unwanted particulates and compounds prior to use as fuel. After cooling and cleaning in an emission control system, the syngas can be utilized in boilers, gas turbines, or internal combustion engines to generate electricity, or the syngas can be used to make chemicals. Synthetic gases can produce methanol, ethanol, and other fuel liquids and chemicals.

All gasification technologies require preprocessing to reduce the size of the MSW feedstock, generally to a size of between 2 and 12 inches.

In low-temperature gasification, which takes place below the melting point of most inorganic constituents, a powdery to clinker-type of bottom ash is formed. In high-temperature gasification, the inorganic ash materials exit the bottom of the gasifier in a molten state, where the slag falls into a water bath, and is quenched and crystallized into a glassy, non-hazardous slag. The slag is crushed to form grit that can be easily handled. Slag can be used in the manufacture of roofing tiles or it can be used as sandblasting grit or asphalt filler. Bottom ash may require landfilling, although some suppliers have been able to use it to manufacture ceramic-like bricks or paving stones. One system that utilizes oxygen injection creates extremely hot temperatures in the bottom of the gasifier, reaching the melting temperature of some metals. In that process, metals can be recovered in ingot form. Reuse of the slag after this metal recovery would result in a very high MSW reduction rate. Fly ash from the air emission control system is the primary process residue. A facility with the gasification Conversion Technology reportedly can reduce the feedstock by weight by more than 90 percent. If this rate of reduction is correct, it would represent an improvement over traditional thermal conversion technologies, which can reduce the volume of MSW by 90 percent, but the weight by only 75 percent. The reduction rate of the gasification technology can reportedly vary from almost 80 percent to over 90 percent by weight.

As part of this review, R. W. Beck requested information from Ebara Corporation, Global Energy Solutions, Ntech Environmental (Entech Renewable Energy System licensee), and Interstate Waste Technologies (Thermoselect licensee). We received responses from Global Energy Solutions and Interstate Waste Technologies, and for the other potential suppliers we relied on published data. Twelve facilities employing Ebara technology are reported to be operating worldwide. Global Energy Solutions claims 23 operating facilities worldwide, of which four facilities process MSW. Forty-seven facilities employing technology by Entech Renewable Energy System are reported to be operating worldwide, of which 12 small facilities process MSW. Seven smaller facilities using Thermoselect technology are reported to be operating worldwide. Several Thermoselect facilities are in the development stage. Furthermore, no facilities employing gasification to process MSW are commercially operating in the United States.

For fluid bed technologies, the net energy generation rate can vary from almost 400 to 450 kWh per ton of waste processed, which is somewhat lower than the conversion rate of traditional thermal Conversion Technologies. For two-stage (pyrolysis-gasification) fixed bed technologies, the net energy generation rate reportedly can vary from almost 700 to over 900 kWh per ton of waste processed, which is significantly higher than traditional thermal Conversion Technologies. Global Energy Solutions has the largest operating unit, a facility in Tokyo, Japan, rated at 180 TPD with over three years of experience processing MSW. Scale-up of this technology for application in the County represents a potential area of risk. A facility in Karlsruhe, Germany, a Thermoselect system, had problems that led to considerable delays in commissioning. That 792-TPD facility was finally commissioned in 2001 at a reduced processing capacity and was shut down in 2004 due to environmental, economic, and litigation issues.

The current unit capital cost for a new facility is estimated to range from around $146,000 to $181,000 per TPD of installed capacity. The current unit operating and maintenance (O&M) cost is approximately $57 to $65 per ton of waste processed. The capital cost is somewhat lower than a proven thermal Conversion Technology and the O&M costs are somewhat higher.

Based on the lack of successful commercial application at the size required by the County, R. W. Beck does not recommend the County pursue gasification technology at this time. However, further improvements in gasification in general are currently underway and we recommend the County continue to monitor the gasification technology for future advancement and applicability.

Plasma Arc

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 19th century. Plasma arc technology uses very high temperatures to break down the feedstock into elemental byproducts.

Plasma is a collection of free-moving electrons and ions that is typically formed by applying a large voltage across a gas volume at reduced or atmospheric pressure. When the voltage is high enough, and the gas pressure low enough, electrons in the gas molecules break away and flow toward the positive side of the applied voltage. The gas molecules, losing one or more electrons, become positively charged ions that are capable of transporting an electric current and generating heat when the electrons drop to a stable state and release energy. This same is inherent in atmospheric lightning.

Plasma arc devices or "plasma torches" can be one of two types: 1) the transferred torch; and 2) the non-transferred torch. The transferred torch creates an electric field between an electrode, at the tip of the torch, and the reactor wall or conducting slag bath. When the field strength is sufficiently high, an electric arc is created between the electrode and reactor, much like an automotive spark plug. 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.

Very high temperatures are created in the ionized plasma. The plasma can reach temperatures of 7,000ºF and higher; the non-ionized gases in the reactor chamber can reach 1,700ºF to 2,200ºF; and the molten slag is typically around 3,000ºF. For applications in processing MSW, the intense heat actually breaks up the molecular structure of the organic material to produce simpler gaseous molecules such as carbon monoxide, hydrogen, and carbon dioxide. The inorganic material is vitrified to form a glassy residue. A main disadvantage of the plasma arc systems used in power generation is that a large fraction of the generated electricity is required to operate the plasma torches, which reduces net electrical output of the facility.

The MSW feedstock requires shredding to a 6-inch maximum size prior to charging the plasma arc reactors.

Byproducts of plasma gasification are similar to those produced in high-temperature gasification, as noted previously. Due to the very high temperatures produced in plasma gasification, carbon conversion nears 100 percent.

The net energy generation rate reportedly can vary significantly depending on the facility throughput. The parasitic load of the torches at plasma arc facilities is significant.

Hitachi Metals, Inc. has developed two commercial solid waste plasma arc facilities with the Westinghouse Plasma system in Japan. The facility in Utashinai has the largest operating unit, rated at 83 TPD with over three years of experience while processing MSW and auto-shredder residue. Existing systems use two operating and one spare torch per reactor. This scale of plasma arc technology has also been used in a General Motors plant in Defiance, Ohio, since 1989. The General Motors facility melts scrap metal for engine block castings. The plasma heating elements there have logged more than 500,000 hours of operation.

A leading supplier of the plasma arc Conversion Technology using the Westinghouse Plasma system is a company named Geoplasma. R. W. Beck relied upon published data about the plasma arc Conversion Technology offered by Geoplasma. Several other suppliers that were not evaluated in this report offer this Conversion Technology for small-scale facilities. Each gasification unit at Geoplasma's proposed facilities would use approximately the same size plasma-heated cupola as the one installed at the Ohio plant. For a larger facility, Geoplasma proposes that it would add more processing lines in parallel. Geoplasma has not developed any plasma arc facilities. Geoplasma was selected to build a 3,000-TPD MSW facility in St. Lucie County, Florida. St. Lucie County is currently negotiating an agreement with Geoplasma to develop the project.

No MSW facilities employing the plasma arc Conversion Technology are commercially operating in the United States. Scale-up of this technology for application in King County represents a potential area of risk to the County. R. W. Beck does not recommend that the County pursue the plasma arc technology at this time due to the lack of commercial applications in the size and service duration required to process the County's waste. We further recommend the County monitor the plasma arc technology for future advancement and applicability, particularly if the 3,000-TPD facility in Florida actually proceeds.

Summary of Emerging Thermal Technologies

Note that all three of the emerging thermal Conversion Technologies require front-end processing of the waste and two require reducing the waste to a size of 6 inches or less. As discussed previously in this section, R. W. Beck has found that such processing of MSW can result in significant technical challenges. We also note that the reported energy generation potential of pyrolysis and gasification are significantly higher than more proven thermal Conversion Technologies such as mass burn or RDF. The reported capital cost of the gasification Conversion Technology is slightly lower than, and the O&M expenses are comparable to or higher than, proven thermal Conversion Technologies.

Proven Thermal Conversion Technologies

R. W. Beck has identified three proven thermal Conversion Technologies, mass burn, RDF, and advanced thermal recycling. These technologies employ both modular (prefabricated) and field-erected systems, refractory and waterwall combustors, and starved air and excess air combustion technologies, in the appropriate combinations. In the following subsections we also discuss the rotary combustor technology, since a number of such facilities are in operation domestically. We have not included facilities in this discussion that have no current application in the waste-to-energy industry (for example, an RDF facility with modular, starved air combustion systems).

Mass Burn Waste-to-Energy Systems

Mass burn waste-to-energy systems can be basically divided into three separate technologies: 1) modular starved air systems, 2) modular excess air systems, and 3) field-erected excess air systems. The modular starved air systems were historically used for small applications (under 400 TPD). These facilities typically combine several refractory lined combustors, each rated for around 90 TPD, in the number necessary to dispose of the quantities of waste available in the area. These refractory lined combustors generally have two chambers in which the municipal solid waste is introduced and pushed through several steps, during which the fuel is first dried, then combusted, and then completely burned with the ash removed into a submerged conveyor. The combustion is conducted without adequate amounts of oxygen (starved); additional air is introduced in the secondary chamber where the combustion is fully completed. Many of these modular starved air systems are used in small applications for incineration only. If energy recovery is desired, a separate waste-heat boiler is included to convert the hot gases from incineration into steam to drive a steam turbine connected to an electric generator.

The modular excess air waste-to-energy system can be described as the rotary combustor systems in use in several facilities in the United States. These facilities use a rotating cylindrical combustor in combination with a waste-heat boiler to create steam for electrical production. The combustors are constructed with tube material that circulates water to absorb the heat of combustion and heat the water being used in the waste-heat boiler to create the steam for use in the steam turbine-generator. The municipal solid waste tumbles through the inclined combustor and falls out of the combustor onto an after-burning grate system which allows for the complete burnout of the municipal solid waste fuel.

The type of waste-to-energy facility most prevalent in the United States uses the field-erected, excess air technology. With this technology, the incinerator and boiler are one system; the walls of the incinerator are constructed of tubing in which water circulates as part of the steam generation process. The mass burn technology typically utilizes an overhead crane to feed municipal solid waste from a pit into a chute that deposits it onto an inclined surface upon which the material burns in the presence of more than enough (excess) air to achieve complete combustion. The heat generated during combustion is transferred through the waterwalls to create steam. In addition, the waterwall boilers are typically provided with additional tubing in other sections of the boiler to create superheated steam, which improves the generation of electricity, and other tubes to preheat the feedwater, which improves the efficiency of the boiler process. The superheated steam is sent to a steam turbine connected to an electric generator to create electric power. Some facilities use steam turbines that allow for extraction of steam at some specific pressure level to be sold to an adjacent industry that may require process steam.

RDF Systems

Refuse-derived fuel systems have been employed as a means to improve the quality of the municipal solid waste prior to combustion and to provide a means to recover materials prior to combustion. All RDF systems operating in the United States today are being used in combination with field-erected waterwall boilers. There are no RDF systems being used in combination with modular starved air combustion systems. RDF systems can be used to prepare fuel to be used with different types of combustors, including fluid bed combustors or other industry boilers (cement kilns, pulverized coal units, etc). For the purposes of this report, we have assumed that an RDF plant for the County must be provided with its own combustion unit and that the County would not prepare RDF with the intention of selling it as fuel to some existing boiler unit.

RDF systems can be arranged in several different forms. There are several material processing systems that are typically used in an RDF plant, including shredders, magnets, eddy current separators, trommels, and picking stations. What differentiates each RDF system is the combination of preprocessing systems that it uses, and the order in which these systems are arranged. Several types of shredders can be employed, including slow speed shear-type shredders, bag-breaking “flail mill”–type shredders, and size-reducing hammermill-type shredders. Magnets can be used to remove ferrous metals like steel cans and other iron. Eddy current separators can be used to remove non-ferrous metals such as aluminum, brass and tin. Trommel systems can be used to separate materials by size by using rotating cylindrical drum screens with holes of a certain size. For example, a two-stage trommel may have small holes for the first one-third of the drum to remove dirt and small debris from the municipal solid waste, followed by screens with larger holes to remove material appropriately sized for the combustion unit; the remaining oversized material then flows out the end of the trommel and is conveyed to a shredder for size reduction. On a single-stage trommel all the screens would have the same size holes and would be used to target only one size of material (for example, small holes for glass and grit removal). Manual picking stations can be used to provide a means to pick targeted items determined to be worth the extra effort.

In the United States, three types of RDF systems are normally employed, including the “shred and burn” system, the trommel-first systems, and the shred-first systems. The shred and burn system in use at the SEMASS facility in Rochester, Massachusetts removes the non-processible waste, shreds everything else, removes ferrous metals, and burns the rest. The trommel-first system, in use at the SPSA facility in Portsmouth, Virginia and in one facility in Miami, Florida, uses trommels to open bags and remove glass and grit, then sends the material into another trommel to separate those items already sized appropriately for the combustor (which also tends to concentrate the aluminum cans), then shreds the oversized material for use in the boiler. These systems typically use magnets to remove ferrous metal from each stream and eddy current separators to remove aluminum prior to the size-reducing shredder. The shred-first systems in Maine, Connecticut, Hawaii, Michigan, and Florida use a flail mill to open the bags of municipal solid waste, then magnets and trommels to remove small residues and appropriate sized materials, then hammermills to size the remaining material. The operating characteristics of the different systems are presented in Table 3-1.

Table 3-1
RDF Shredding Options

RDF System	Non-Processible Waste	Ferrous Removed	Aluminum Recovered	Residue Removed (1)
Shred and Burn	5%	3%–4%	Less than 1%	0%
Trommel-First	5%	3%–4%	Less than 1%	18%–25%
Shred-First	5%	3%–4%	Less than 1%	18%–25%

(1) There has been a trend in the RDF plants to cease the removal of residue (small debris from the trommel) to increase the amount of fuel available to the combustion unit and to decrease the amount of material destined to be disposed of in the landfill.

All of the RDF systems operating in the United States use field-erected, excess air grate combustion units, the boilers of which are very similar to those used by the modern mass burn system: field-erected waterwall units with superheaters and economizers.[1] The differences between mass burn and RDF combustion units are associated with the grate systems. The majority of RDF units use a horizontal grate system, compared to the inclined grate systems used by the mass burn facilities.

Advanced Thermal Recycling Systems

Advanced thermal recycling represents a second-generation advancement of technology which, similar to mass burn, uses complete combustion of organic carbon-based materials in an oxygen-rich environment, typically at temperatures of 1,300°F to 2,500°F, producing an exhaust gas composed primarily of carbon dioxide and water with inorganic materials converted to bottom ash and fly ash. The hot exhaust gases flow through a boiler, where steam is produced for driving a steam turbine-generator, generating electricity. The cooled waste gases flow through an advanced emission control system designed to capture and recover components in the flue gas, converting them to marketable byproducts such as gypsum (e.g., for wallboard manufacture) and hydrochloric acid (used for water treatment). Typical recovery rates of gypsum and hydrochloric acid from municipal solid waste on a weight basis are 0.3 and 1.3 percent, respectively. The bottom ash and fly ash are segregated, allowing for recovery/recycling of metals from the bottom ash, and use of the bottom ash as a road base and construction material provided such materials meet regulatory requirements. The post-combustion materials recovery and emissions control systems go beyond the technology utilized at conventional waste-to-energy plants such as the Spokane Regional Waste-to-Energy Facility.

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[1] In Europe, there are several RDF facilities that use fluidized bed combustion to burn RDF. Specifically, these involve circulating and bubbling bed technology. R. W. Beck has not focused on these technologies since there are no U.S. applications that meet the size and operating history requirements of the County. However, for the sake of completeness, we have provided this brief description.

Fluidized bed combustion is a method of burning solid fuel in suspension in a bed of small inert particles, which are kept in a state of agitation and fluidity by the upward flow of combustion air and gases of combustion. This technology makes it possible to efficiently burn a broad range of low-grade fuels, including MSW and RDF.

In the bubbling bed combustor, the particles of burning fuel and inert bed material are not intended to be carried out of the combustor, but to remain in the combustion chamber where combustion is accomplished in the 4 to 5 feet of bed depth. When the bubbling bed is at rest, before the high velocity air flow is started, the depth of the fuel and inert material is about 2 feet. With re-circulation of fly ash, the bubbling bed combustor approaches the circulating fluidized bed in operating characteristics.

The circulating fluidized bed differs from the bubbling bed type in that the circulating fluidized beds have a significant amount of partially burned fuel and inert material particles that are carried out of the combustion section and into a cyclone-type separator. The cyclone-separator permits the hot combustion gas, along with particles too fine to be retained by the cyclone-separator, to pass into the steam generator section of the assembly. The cyclone-separator is a device with a gas pass arrangement which produces a high velocity spiral flow of the gases and entrained particles. Centrifugal force causes the particles greater than a certain predetermined size to be recirculated back into the combustion chamber for increased residence time, which improves fuel burnup. We are aware of only two circulating fluid bed units burning 100 percent RDF (most systems burn a combination of fuels); both of those are in Europe and neither approaches the size criteria of the County.

The feedstock for advanced thermal recycling systems can be unprocessed municipal solid waste or RDF. Using lower moisture content and removal of non-combustible materials, RDF improves the heating value of the feedstock, resulting in higher efficiency and lower throughput per kWh of electricity generated. To improve economics and efficiency, facilities can incorporate preprocessing to remove marketable recyclables such as paper, plastics, metals, and glass.

Materials handling involves extensive recycling and reuse of solid and liquid residues, which can include various marketable byproducts, as described in the previous paragraphs. These materials handling innovations reportedly result in disposal of less than 5 percent of process residues, which will be inert. With these innovations, the disposed weight reduction rate of the advanced thermal recycling technology can reportedly vary from 80 percent to over 95 percent.

R. W. Beck conducted a telephone conversation and received a written response from a representative of Waste Recovery Seattle International LLC, a licensee of the advanced thermal recycling Conversion Technology. This technology is proven in two full-scale, commercial facilities in Hamburg, Germany. Muellverwertung Borsigstrasse Damm (MVB), the oldest facility, has been operational since 1994. The Muellverwertung Rugenberger Damm (MVR) facility has reportedly operated at over 90 percent annual availability.

The net energy generation rate is on the order of 550 kWh per ton of waste processed. The MVR facility has the largest operating unit, with over three years of experience processing MSW and rated at 580 TPD. Based on this size, significant scale-up of this technology for application in the County is not necessary. A new facility under construction in Berlin, Germany will employ a steam reheat cycle, increasing the anticipated net energy generation rate to 850 kWh per ton.

The present unit capital cost for a new facility is estimated to be around US$180,000 per TPD of installed capacity. The present unit O&M cost is reported to be approximately US$47 per ton.

No facilities employing the advanced thermal recycling Conversion Technology are commercially operating in the United States. Based on the sizes of the facilities that have been installed and the number of years the advanced thermal recycling technology has been in commercial operation, the advanced thermal recycling Conversion Technology was considered in depth.

Summary of Proven Thermal Technologies

Table 3-2 presents general information of representative facilities in the United States. Table 3-3 presents operating characteristics for proven thermal Conversion Facilities, including advanced thermal recycling facilities in Germany.

Table 3-2
Proven Thermal Conversion Facilities Operating in the United States

Facility	Technology(1)	Status	Initial Operation Date	Size (TPD of MSW)	Size (MW) (Gross/Net)
Marion County, Oregon	Mass burn - waterwall	Operational	1986	550	13.1/11
Spokane, Washington	Mass burn - waterwall	Operational	1991	800	26/22
Stanislaus, California	Mass burn - waterwall	Operational	1990	840	22.5/18.5
Long Beach, California	Mass burn - waterwall	Operational	1988	1,380	36/30
Norfolk, Virginia	RDF - waterwall	Operational	1988	2,000	40/35 steam sales
Kent County, Michigan	Mass burn - waterwall	Operational	1990	625	18.3/15.7
Lancaster County, Pennsylvania	Mass burn - waterwall	Operational	1991	1,200	36/30
Baltimore, Massachusetts	Mass burn - waterwall	Operational	1985	2,250	60/57
Millbury, Massachusetts	Mass burn - waterwall	Operational	1987	1,500	45/40
Honolulu, Hawaii	RDF - waterwall	Operational	1990	2,160	40/43.6
Detroit, Michigan	RDF - waterwall	Operational	1991	3,300	65/53 steam sales
Fairfax, Virginia	Mass burn - waterwall	Operational	1990	3,000	85/73

(1) There are no advanced thermal recycling facilities currently operating in the United States.

Table 3-3
Operating Characteristics of Proven Thermal Conversion Facilities

Facility	Capital Cost (US$)	O&M Cost (US$/yr) (not including debt service)	Annual Tons of Municipal Solid Waste Processed	Annual Availability	Recovered Materials
Marion County, Oregon	$47.5 million in 1986	O&M contract $4.7 million ('95) escalated	182,800	~90%	Post-combustion ferrous metal
Spokane, Washington	$110 million in 1991	$7.3 million in 1993	~305,000	>90%	Pre- and post-combustion ferrous metals, yard waste, C&D
Stanislaus, California	$82.2 million in 1985	O&M contract $7.3 million ('95) escalated	~300,000	>90%	Post-combustion ferrous metal
Long Beach, California	$106 million in 1987	$19.1 million in 1996	~470,000	>90%	Post-combustion ferrous metal
Norfolk, Virginia	$153 million in 1985	$26.4 million in 1996	400,000 tons of RDF burned	~85%	Pre- and post-combustion ferrous metal, aluminum
Kent County, Michigan	$62.2 million in 1989	$15.2 million in 1995	195,000	90%	Post-combustion ferrous metal
Lancaster County, Pennsylvania	$106 million in 1991	$12.7 million in 1995	394,000	90%	Post-combustion ferrous metal
Baltimore, Massachusetts	$185 million in 1983		730,000	88%	Post-combustion ferrous metal
Millbury, Massachusetts	$180 million in 1988		461,000	85%	Post combustion ferrous metal
Honolulu, Hawaii	$181 million in 1990	$17.8 million in 1995	640,000	88%	Pre-combustion ferrous metal, post-combustion non-ferrous metal
Detroit, Michigan	$245 million in 1986, plus $75 million in 1991	Est. $29 million in 2006	800,000	85%	Pre-combustion ferrous
Fairfax, Virginia	$195.5 million in 1988	$17.7 million in 1995	950,000	87%	Post-combustion ferrous and non-ferrous metal
Hamburg, Germany (MVR Advanced Thermal Recycling Facility)	Equivalent facility estimated at $186 million in 2007	$18 million in 2006	380,000	92%	Post-combustion ferrous and non-ferrous metal, hydrochloric acid, and gypsum

The proven Conversion Technologies described in this section have demonstrated that they are capable of processing the residential municipal solid waste and light industrial/commercial combustible waste being generated in the County. All three use very similar methods for combustion of the waste. In general, the mass burn and advanced thermal recycling Conversion Technologies have the capability to handle certain components of the waste stream that the RDF systems try not to process, such as carpet, mattresses, and other bulky residential materials. None of these Conversion Technologies generally accept any medical or hazardous wastes, or construction and demolition waste, although targeted loads of combustible fractions of demolition waste could be accepted at most well designed mass burn or advanced thermal recycling facilities. Waste-to-energy facilities do not process contaminated soil, bulk tires, white goods or other materials deemed detrimental to the process. Mass burn and advanced thermal recycling systems generally have approximately 3 percent non-processible waste from the acceptable waste stream, while RDF facilities have 5 to 7 percent non-processible material from the acceptable waste stream.

The Conversion Technologies described in this section generally create electricity by use of a steam turbine-generator. A well designed facility can generate approximately 500 to 550 net kWh per ton of fuel (municipal solid waste or RDF) burned. Facilities can be designed to generate steam for sale along with the electric power if there is an adjacent industry that can use the process steam. The most common recovered material from waste-to-energy facilities other than electricity or steam is the ferrous metals remaining after combustion. There is a trend to recover non-ferrous metals from the post-combustion ash stream as well. Where permitted by regulation, some facilities have processes to recover aggregate material from the ash that in some cases can be used as road sub-base material or as an aggregate substitute in concrete blocks.

There are a number of capable waste-to-energy vendors in the United States that can design, procure, construct, operate and maintain the facility(ies). The systems and components used in the waste-to-energy facilities can be procured domestically and are readily available. The County could expect to retain a contractor capable of providing performance and other project bonds, and able to guarantee performance of the system, construction schedule, project cost, and operating expenses.

Summary of Thermal Technologies

Table 3-4 presents a summary of the emerging and proven thermal Conversion Technologies.

Table 3-4
Comparison of Emerging and Proven Thermal Technologies

	Emerging Thermal Technologies			Proven Thermal Technologies		
Technology Characteristic	Pyrolysis	Gasification	Plasma Arc	Mass Burn	RDF	Advanced Thermal Recycling
Preprocessing requires size reduction (maximum size)	Yes (12 in.)	Yes (2–12 in. or compaction)	Yes (6 in.)	No	Yes	No
Volumetric Reduction of Feedstock	80%–95%	80%–95%	95+%	90%	90%	80%–95%
Net Energy Generated (kWh per ton of waste processed)	<700 kWh	<400–>900 kWh	<400–600 kWh	525–550 kWh	525–550 kWh	550 kWh
Largest daily processing capacity of a unit/line at a facility with more than three years of commercial operation that processes MSW or similar feedstock (tons/day)	175 TPD	180 TPD	83 TPD	3,000 TPD	3,000 TPD	580 TPD
Number of operating facilities with MSW worldwide	2	90–100	2	100+	~15	2
Typical unit capital cost of new facility in the US (US$ Thousand/ton of daily waste processing capacity)	NA	$146–$81	NA	$180–$200	$180–$200	~$180
Typical operating and maintenance (O&M) unit expenses in the US, not including process residue disposal (US$/ton of waste processed)	NA	$57–$65/ton	NA	$35–$50/ton	$40–$55/ton	$47/ton

NA – information not available

Biological and Chemical Conversion Technologies

Biological and Chemical Conversion Technologies utilize biological and/or chemical processes to reduce waste volumes, encourage breakdown of molecules, and create byproducts that can be reused beneficially. These technologies may use heat, agitation and many other forms of waste manipulation to control the reduction environment and stimulate the desired reactions. The biological technologies we reviewed were anaerobic digestion, aerobic digestion/composting, thermal depolymerization and steam classification. The chemical technologies we reviewed were waste-to-ethanol and catalytic cracking.

Anaerobic Digestion

Anaerobic digestion is a biological process that entails microbial breakdown of large organic molecules into methane and carbon dioxide in the absence of oxygen. A useful product of anaerobic digestion is biogas (methane and carbon dioxide), which can be burned to generate steam and electricity. In addition to generating gas, anaerobic digestion produces a residue that contains inorganics, non-degradable organics, and other materials. Following the digestion process, these solids may be cured in standard composting type processes to produce a usable compost product.

For the processing of mixed municipal solid waste streams similar to that of the County, an anaerobic digestion facility has significant drawbacks. While anaerobic digestion has been used for decades to process solids removed at wastewater treatment plants, it has been used more recently, mostly in Europe, to process source-separated organics from municipal solid waste. However, the non-degradable materials that exist in municipal solid waste which has not been source-separated are very problematic for this technology, and this shortcoming is a major obstacle for the use of this technology in the County's general waste stream. These contaminants, if not removed from the feedstock, will remain in the solid byproduct and significantly reduce the value and usability of the resulting compost. Furthermore, some of these materials pose an operational problem as they can damage the equipment in the digester. For the County's mixed municipal solid waste, an anaerobic digestion facility would require significant preprocessing of the waste prior to digestion and a significant portion of the waste stream would require landfilling or recovery (roughly 32 percent of the County's waste stream). If this preprocessing step is not successful at removing contaminants, it is likely that the compost material would not be usable and would also have to be landfilled, resulting in significant decreases in waste reduction and significant increases in the County's cost of waste disposal. Finally, R. W. Beck was not able to find any operating data that shows that anaerobic digestion facilities can preprocess and digest a waste stream with characteristics or tonnages equivalent to those of the County. Based on these limitations we did not attempt to estimate possible operating parameters, capital costs, and operation and maintenance expenses for an anaerobic digestion facility in the County. Anaerobic digestion was not reviewed further for this report.

In our opinion, however, the County should monitor this technology for future developments and breakthroughs because certain methods of preprocessing employed at anaerobic digestion facilities have shown promise in the management of mixed municipal solid waste. Furthermore, if the County decides in the future to implement source-separation of its organics, the County should look at anaerobic digestion as a potentially viable waste conversion alternative. Its ultimate viability will depend on the expected quality of the organic feedstock and the ability of the local compost market to handle the byproducts.

Waste-to-Ethanol

Waste-to-ethanol is a new technology that uses hydrolysis and other processes to break down the organic fraction of the waste (paper, food waste, yard waste, etc.) into sugars which are then distilled into ethanol. For implementation in the County, a waste-to-ethanol facility would have to include a preprocessing step, likely a materials recovery facility, to remove contaminants from the organic portion of the waste stream.

There are no waste processing facilities in operation that convert municipal solid waste into ethanol, and therefore no available operating or cost data; however, one such facility is currently being planned in Middletown, New York by Masada Oxynol LLC. Masada employs a process that uses strong acid hydrolysis to convert the cellulosic fraction of waste to sugars. The sugars are then fermented to ethanol using conventional yeasts. The non-cellulosic fraction of the waste (plastics, metals, glass, etc.) is either recycled from a front-end materials recovery plant or is converted to energy to provide energy to the process. R. W. Beck previously reviewed the proposed technology at the Masada facility. The developer proposed to co-dispose of municipal solid waste and sewage sludge. The Masada project has been in development stage for over six years. The potential for the technology holds some promise for the future because of the projected size of the Middleton facility (753 TPD), the modular nature of the technology, the small amount of residuals requiring landfilling (theoretically less than 10 percent), and the expected market for ethanol. We recommend that the County monitor the progress of this technology, and specifically the Masada facility, if and when that facility is further developed.

Aerobic Digestion/Municipal Solid Waste Composting

Aerobic digestion, when employed for the management of municipal solid waste, is also called aerobic municipal solid waste composting. It involves the decomposition of large organic molecules in the presence of oxygen. Aerobic digestion uses biological processes to break down the organic portion of the municipal solid waste stream to reduce the volume of waste and to produce compost for soil amendment or fertilizer. The quality of the compost is sensitive to both the process and the degree to which undesirable material has been excluded from the waste.

To process a municipal solid waste stream similar to the County's, an aerobic digestion facility would require a preprocessing step to remove non-compostable materials and to prepare the remaining materials for composting. Aerobic composting includes a variety of technologies, both enclosed (in-vessel) and open systems. Open systems commonly use windrows that can either be static piles with forced aeration or piles that are turned with specialized equipment to expose the material to air. In-vessel systems, though higher in capital cost, provide the best control of the composting process and limit the odor issues that may arise.

While aerobic digestion has been widely implemented, especially in Europe, about a quarter of the aerobic facilities located in the United States were shut down between 1992 and 1995 due to public opposition and technical problems, especially with odor control. No additional aerobic digestion facilities for municipal solid waste have been developed in the United States in the last six years and the commercial viability of the technology is currently in question because most vendors are unwilling to provide performance guarantees, especially for odor control, when using municipal solid waste as the primary feedstock. Most of the new composting facilities are using source-separated organics from the residential and/or commercial solid waste streams for feedstock. They do not process mixed municipal solid waste as would be the case in King County. Due to the technical limitations, we did not attempt to compile operating and cost data for aerobic digestion facilities. We do not think the aerobic digestion technology qualifies for further review at this time.

Thermal Depolymerization/Plastics-to-Oil

Thermal depolymerization is a process to reduce complex organic materials into crude oil. It is similar to the processes that occur in nature to create fossil fuels, but this process requires only hours to be completed. In thermal depolymerization, feedstock materials, currently agricultural and animal waste, are ground into chunks and mixed with water. They are then subjected to heat and pressure for about 15 minutes. The pressure is then released rapidly and the water is boiled off. The remaining materials are separated into hydrocarbons and other materials. The hydrocarbons are then broken down and distilled to produce crude oil. Also produced in the process are fatty acid oils used in various cleaners and pharmaceuticals, and minerals used in fertilizer products.

Since 2005, a 200-TPD facility has been operating in Carthage, Missouri that processes the feathers, heads, legs, and other unsaleable parts of turkeys from a nearby ConAgra turkey processing plant. The facility reports it is capable of producing 500 barrels of oil a day. Because that facility using agricultural and food processing waste as the feedstock, there are no residuals which must be landfilled. The vendor plans to develop a plant that uses municipal solid waste as a feedstock for this technology, but no such plants are currently in existence. That vendor deems most other details of the process and its operation (specifically, efficiency and economics) to be confidential information and was unwilling to provide any information to R. W. Beck.

Because the current focus of the technology is on agricultural waste and there are only a few plants that are operating or in the planning stages, we did not attempt to compile or estimate operating or cost data for a thermal depolymerization facility in the County. In our opinion, this technology is many years away from being feasible for processing a waste stream of the size and composition of the County's. For these reasons, we did not conduct any further review of thermal depolymerization for this report.

Steam Classification/Autoclave Technology

Autoclave technology is currently used for the management of medical waste and has seen some limited use in the disposal of mixed municipal solid waste. With this technology, waste is placed into large sealed containers called autoclaves. Through exposure to a specific combination of temperature, moisture, pressure and agitation, the waste is sterilized and its volume reduced. Once processed, some of the remaining waste can be separated and recovered. Specifically, pulp from paper and other fiber-based waste can potentially be reused by box-makers or combusted as refuse-derived fuel. Most non-recoverable waste is reduced in volume by 50 to 60 percent and is intended to be safe for landfilling.

Since the technology has shown volume reduction and resource recovery benefits, it is being employed experimentally with mixed municipal solid waste as a feedstock. The County's most important considerations for the application of this technology include the strength of markets for the cellulose pulp (either box-makers or an RDF facility) and the fact that the process consumes energy. Several companies are involved in developing the technology and others have expressed interest. World Waste Technologies, Inc. recently constructed a facility in Anaheim, California which, once fully operational, is planned to be able to process 500 tons of residue from a materials recovery facility each day. World Waste Technologies reports than it is also planning to build another facility in Anaheim that will process 2,000 TPD. Currently, the first Anaheim facility is reported to be operating, but not at its full capacity, as World Waste Technologies continues to look for ways to increase efficiency and improve the process.

While other public entities, specifically Salinas Valley, California, have reportedly expressed an interest in steam classification, the lack of operating record with municipal solid waste as a feedstock at the size necessary for King County makes it an untested process for the County at this time. The first Anaheim facility has not operated for sufficient duration or at the scale required for the County. In addition, the energy required to operate the facility at the temperatures and pressures required to autoclave the waste results in lower net energy production than other technologies. For these reasons, we did not conduct any further review of steam classification/autoclave technology for this report.

In our opinion, the County should monitor this technology because it does show some promise for the management of municipal solid waste, but it is currently unproven in the processing of waste in the quantities required by the County. The development of the Anaheim facilities by World Waste Technologies and the progress of Salinas Valley are specific projects that the County should watch closely.

Catalytic Cracking

Catalytic cracking is a thermochemical conversion process that uses catalysts to accelerate the breakdown of polymers such as plastics into their basic unit, called a monomer. The monomers can then be processed using typical cracking methods, often used in oil refinery operations, to produce fuels such as low-sulfur diesel and gasoline.

A facility using this process has reportedly been operating in Poland at commercial scale, reportedly at 260 TPD, for a number of years. This process can complement conventional plastic recycling, especially for low-quality co-mingled plastic streams that often end up in the landfill.

Based on the results of the County's Waste Characterization Study as discussed in Section 2, plastics would represent only about 11 percent by weight of the County's solid waste feedstock for a Conversion Facility(ies). This technology may be suitable for only a limited fraction of the County's solid waste. Since catalytic cracking processes only a small portion of the County's waste stream, we did not conduct any further review of this technology for this report.

Additional Criteria for the County's Consideration

As discussed previously, the County selected a set of criteria to be applied for the initial screening of different Conversion Technologies. In the event the County eventually determines to proceed with the procurement of a vendor of one of the Conversion Technologies, we recommend that the County consider using some additional criteria as part of its procurement process. These recommendations are based on our previous experience in assisting public entities in the procurement of private vendors of solid waste management facilities. The additional criteria for consideration by the County are as follows:

1. Demonstrated capability of the vendor to operate a facility of the size required to meet the County's needs. There have been examples where Conversion Technologies that were successfully applied in one situation, failed to operate as expected because of the failure of the operator.
2. Presence in the United States of the personnel who will design, operate, and maintain a facility of the size proposed. In our experience, it is important to have the required personnel immediately accessible to the project.
3. Presence in the United States of the ability to manufacture or supply all required replacement parts that are unique to the proposed technology. Delays in international shipments of necessary parts can have a serious impact on the annual availability of any Conversion Technology.
4. Demonstrated ability of the vendor to obtain and maintain the required performance bonds and any credit enhancement facilities, such as a letter of credit or a line of credit. A vendor's inability to obtain such bonds is indicative that some other party is reluctant to step into the place of the vendor.
5. Demonstrated creditworthiness of the vendor. The County could be looking at a facility or facilities that cost between $500 million and $1 billion. The County will be looking to the vendor to provide meaningful performance guarantees, including:
   - Annual plant availability
   - Maximum capacity rating
   - Tons processed

- Energy generation
- Waste reduction
- Residue generation
- Ability to meet permit requirements
- Fixed construction price
- Fixed operating and maintenance expenses.

Such operating guarantees will be backstopped by financial guarantees in the form of liquidated damage payments or penalties. It will be critical for the County to have a vendor who has the financial capability to stand behind such financial guarantees.

Recommendation of Technologies for Further Review

Table 3-5 presents the results of R. W. Beck's review using the four basic evaluation criteria selected by the County.

It is important to note that all but four of the Conversion Technologies identified in Table 3-5 have not been commercially demonstrated in sizes anywhere close to what the County will require during the 20-year planning period. We estimate that by 2016, the County will need approximately 3,000 TPD of disposal capacity. All of the emerging Conversion Technologies are currently operating at sizes of approximately 170 TPD or less. In our opinion, significant scale-up challenges will have to be addressed if any of these technologies were to be pursued, and we are concerned that such issues could not be properly addressed by 2010, which is the latest date that permitting and construction of a Conversion Facility would have to commence to meet a 2016 on-line date.

With respect to Criterion 3, which is related to the Conversion Facility's ability to meet state permit requirements, we have identified a potential concern regarding the ability of the rotary combustor technology and the RDF technology to meet the air permit requirements in Washington State. The ability of these two technologies to meet such requirements will depend on the permit requirements that would be imposed on the Conversion Facility. For example, the rotary combustor technology has historically had a problem with meeting a combustion temperature of 1,800°F for 1 second residence time; if this requirement was part of the air permit, then that technology may not be a suitable choice. In the case of the RDF system, a 50 parts per million carbon monoxide limit, if required as part of the air permit obtained by the County, would be very difficult for an RDF system to comply with. For these reasons, we have noted that Criterion 3 presents a possible problem for these two technologies. The feasibility of the rotary combustor technology (Mass Burn – modular with excess air) is also in question because, while there is one facility in existence utilizing the technology, the County would have difficulty finding a vendor offering it. For this reason Mass Burn modular excess air was not reviewed further.

Based on our review and the County's criteria, we selected the following Conversion Technologies for further review and to serve as the basis of the remaining sections of this report to be compared to the Waste Export Disposal Option:

1. **Mass burn waste-to-energy waterwall.** This technology has been commercially demonstrated in the United States for 30 years. Individual facilities have been constructed and operated to receive and process 3,000 TPD. These facilities are able to accept approximately 90 to 97 percent of the municipal solid waste generated. They generate net electricity at a rate of approximately 500 to 550 kWh per ton of waste processed. The facility in Spokane has met its air permit requirements of the state of Washington since going on-line in 1991. These facilities generate a residue product which can be disposed of or resized in accordance with the current solid waste handling requirements of the state. These facilities have demonstrated the ability to reduce the volume of solid waste by 90 percent and the weight of solid waste by 70 percent.
2. **RDF waste-to-energy.** This technology has been commercially demonstrated in the United States for 20 years. Individual facilities have been sized to accept and process more than 2,500 TPD. These facilities are able to accept approximately 90 to 93 percent of municipal solid waste. They generate electricity for sale. A careful review will have to be undertaken of the ability of the RDF technology to meet the air permit requirements of the state of Washington.
3. **Advanced thermal recycling.** Although this technology has not yet been constructed in the United States, it has been in successful commercial operation in Germany for more than three years and has operating units which could be sized to meet the County's waste disposal requirements. The technology is capable of generating power for sale and the vendor makes claims for improved emissions control. If the claims prove to be correct, this technology should represent limited technical risk to the County.

Table 3-5
Evaluation of Criteria for Conversion Technologies

Conversion Technology	Criterion 1 [(1)] At Least Three Years of Operation	Criterion 1 [(1)] Commercially Demonstrated Size to Process King County Waste	Criterion 2 [(2)] Demonstrated Capability to Produce a Useful Byproduct	Criterion 3 [(3)] Demonstrated Capability to Meet Permit Requirements	Criterion 4 [(4)] Demonstrated Capability to Produce Acceptable Ash or Residue	Recommendation
Emerging Thermal						
Pyrolysis	Yes	No	Yes (electricity)	Yes	Yes	Do not pursue
Gasification	Yes	No	Yes (electricity)	Yes	Yes	Monitor
Plasma Arc	Yes	No	Yes (electricity)	Yes	Yes	Monitor
Proven Thermal						
Mass burn WTE – modular with starved air	No	No	Not applicable	Not likely	Yes	Do not pursue
Mass burn WTE – modular with excess air	Yes	Yes	Yes (electricity/steam)	Perhaps/ Yes	Yes	Do not pursue
Mass burn WTE – waterwall	Yes	Yes	Yes (electricity/steam)	Yes	Yes	Pursue further
RDF WTE	Yes	Yes	Yes (electricity/steam)	Perhaps/ Yes	Yes	Pursue further
Advanced Thermal Recycling	Yes	Yes	Yes (electricity/steam)	Yes	Yes	Pursue further
Biological and Chemical						
Catalytic Cracking	No	No	Yes (fuel oil)	No	No	Do not pursue
Anaerobic Digestion	Yes	No	Yes (electricity, compost)	No	No	Monitor
Waste-to-Ethanol	No	No	Yes (ethanol)	No	No	Monitor
Steam Classification/Autoclave	No	No	Yes (cellulose fiber)	No	No	Monitor
Aerobic Composting	Yes	No	Yes (compost)	No	No	Do not pursue
Thermal Depolymerization	Yes	No	Yes (oil)	No	No	Do not pursue

(1) Criterion 1: Previously demonstrated capability of the technology, over a minimum three-year period, to process the approximate quantities and composition of waste being managed by the County at the Cedar Hills Regional Landfill

(2) Criterion 2: Demonstrated capability to produce energy or another byproduct for which there is a proven market and which can be sold in the quantities that the facility will produce

(3) Criterion 3: Demonstrated capability of the technology, over a minimum three-year period, to operate within the permit requirements that will be imposed by the state

(4) Criterion 4: Demonstrated capability, over a minimum three-year period, to produce a residue product that can be disposed of or reused in accordance with state solid waste handling permit requirement

Section 4
ANNUAL FACILITY AVAILABILITY OF CONVERSION TECHNOLOGIES

Section 4
ANNUAL FACILITY AVAILABILITY OF CONVERSION TECHNOLOGIES

The Conversion Technologies under evaluation must provide reliable processing of King County's solid waste stream by 2016. Annual availability for a Conversion Facility represents the percentage of time the Conversion Facility is able to perform during the year. Processing unit availability has a direct effect on the amount of MSW that a Conversion Facility can process and the amount of energy it can generate. Downtime due to lack of MSW deliveries is not counted against annual availability, but instead is taken into account when calculating the annual plant capacity factor, which takes into account both the amount of time the facility is available and how much of the available capacity is consistently utilized for processing waste.

This section focuses on the key aspects of the annual availabilities of Conversion Facilities including:

- General concepts;
- Scheduled and unscheduled outages;
- Important applications; and
- Reported historical availabilities of currently operating Conversion Facilities.

This section also discusses, based on these concepts, the assumed annual availabilities we have used in subsequent sections for evaluating the three selected Conversion Technologies.

General Concepts

Conversion Facilities are intended to maintain very high overall availabilities due to the constant need for both disposal capacity and electricity generation. They are capital-intensive units designed to operate every hour of every day except when they require maintenance or repair. The two critical components of Conversion Facilities are the Conversion Technology processing units and the energy generation units. In general, existing Conversion Facilities each have at least two processing units or lines, so that the facility can continue to accept and process waste even when one of the processing units is down. Since the energy generation component, the steam turbine-generator, is able to realize very high annual availabilities and requires relatively little maintenance, only one energy generation unit is typically included in a Conversion Facility.

The annual plant capacity factor for a Conversion Facility is calculated by dividing the actual processing capacity experienced by that facility during the year by the maximum processing capacity of the facility. The annual availability, on the other hand, is determined by first dividing the number of hours each processing line was available to operate by the number of hours in a year. The annual availability factors for the processing lines are combined to produce the annual availability factor for the Conversion Facility.

Processing unit and energy generation unit availability have a direct effect on the amount of waste that a Conversion Technology facility can process and the amount of energy it can generate, so facilities are intended to be operated at as high an annual availability as practical.

Scheduled and Unscheduled Outages

Scheduled outages at Conversion Facilities occur when facility operators deem it necessary to take either the processing units or turbine-generators off-line to perform preventative maintenance. For example, with the mass burn waste-to-energy waterwall Conversion Technology, major scheduled outages for each processing unit typically require 18 to 20 days of downtime per year. This is equivalent to approximately 5 percent of the available time in any year. To minimize the need to bypass processible waste to backup disposal facilities, operators review monthly MSW generation and deliveries and, based on such review, schedule major outages to occur during minimum waste delivery periods of the year.

Unscheduled outages at Conversion Facilities occur when operators shut down a processing unit or turbine-generator due to an unscheduled equipment or system failure. For properly operated and maintained facilities, the percentage of scheduled outages should be greater than the unscheduled downtime. While it is nearly impossible to avoid unscheduled downtime, it is important to minimize the number and duration of unscheduled outages because they not only result in lost production but also result in increased repair costs, often due to the overtime labor charges incurred.

For existing mass burn waste-to-energy waterwall and advanced thermal recycling facilities, the most common reasons for scheduled and unscheduled outages include boiler tube leaks and cleaning, grate bar replacements, and combustion residue extractor plugs. While grate bar replacements and residue extractor failures result in relatively short outages compared to boiler tube leaks, they adversely affect performance nonetheless and result in the need to consume auxiliary fossil fuel.

For existing RDF waste-to-energy facilities, the front-end waste processing of MSW (prior to introduction as fuel to the boilers) causes the most scheduled and unscheduled downtime. Failure and blockage of the shredders and the trommel screens are common reasons for unscheduled downtime of RDF facilities. Since the processed RDF is generally a more homogeneous fuel than unprocessed MSW, the boiler and combustion residue conveying systems of RDF facilities can potentially operate more reliably than mass burn waste-to-energy waterwall systems and advanced thermal recycling facilities.

Unscheduled outages will vary from year to year due to the age of equipment and the preventative maintenance program, but for the purposes of this report, we have assumed unscheduled outages will be equal 16 to 18 days per year, which is supported by industry experience. A single unscheduled outage can range from as little as one or two days to as much as a week or more, depending on the nature of the problem. Combustion units have to be allowed to cool down sufficiently so that, if necessary, workers can enter the unit to undertake repairs. Following the repair, the unit must be brought back on-line. The amount of downtime can be impacted by the availability of spare parts, the availability of skilled labor, and the extent of the repair.

Steam turbine-generator units are extremely reliable and generally have a very high annual availability of 98 to 99 percent. The turbine-generators are taken off-line once per year generally for a short scheduled adjustment and fine-tuning. Also, turbine generators are taken off-line approximately once every five years for major inspection and preventative maintenance services. During that year, the annual availabilities of the turbine-generators are slightly lower.

The total amount of scheduled and unscheduled outages can reasonably be expected to be equal to approximately 10 to 15 percent of the total year, resulting in an annual availability of approximately 85 to 90 percent. Some facilities have reported annual availabilities of up to 92 to 93 percent, but we believe that is a very optimistic assumption for the 20-year planning period used in this report.

Applications of Availability

The effects of high or low availabilities at Conversion Facilities are the increased or decreased opportunities, respectively, to process waste and create energy. The ability to operate reliably is important for recovering the cost of constructing and operating the Conversion Facility and handling the constant stream of waste. Also, since availability assumptions are used extensively in planning and contracting, maintaining a high availability is important for the overall economies of the Conversion Facility.

For example, in order to obtain revenue bond financing for a Conversion Technology project, the owner/operator of the facility will need to demonstrate: 1) an adequate waste supply to support the project, 2) the ability to process waste, 3) the ability to collect tipping fees, and 4) the ability to execute energy sales agreements as one source of revenues to pay the bonds. These agreements will be based to a significant degree on the expected operation of the facility and will include consideration of the anticipated annual plant availability.

In addition, the County must make arrangements for backup disposal capacity based on an assumed annual plant availability. If a Conversion Facility fails to process the guaranteed waste tonnage, the County will have to ensure an environmentally sound and proper disposal of the bypassed waste.

Finally, in energy sales agreements, the owner of the Conversion Facility may be required to guarantee to deliver to the energy purchaser a certain quantity of electric power or thermal energy either annually, hourly, or daily. Such level of guarantees will depend upon the Conversion Facility's expected annual plant availability. In electricity sales agreements, an electric utility may provide a Conversion Technology facility with two types of payments—an energy charge and a capacity charge. The electric utility will provide energy payments for the electricity actually delivered to the grid over the year. Capacity charges are provided to facilities that can deliver and guarantee a base load of electricity to the grid. If the annual availability of the facility is too low, the facility may not meet the contractual obligations for the energy capacity payments. Also, if the annual availability of a facility decreases to the point where the minimum energy delivery rates are not satisfied, this could also adversely affect the payment provisions.

Ultimately, most of the contractual obligations related to the operation of a Conversion Facility are tied to an expected level of availability to process MSW and generate electricity. For this reason, it is crucial for the Conversion Facility to be operated to maintain the highest level of availability possible.

Reported Plant Availability at Reference Facilities

As part of our review regarding annual availability for Conversion Technologies, R. W. Beck contacted the owners and/or operators of currently operating Conversion Facilities and obtained data on the recent annual availabilities for the three selected Conversion Technologies. We also reviewed historical data regarding annual availability. Table 4-1 lists the annual availability data for the reference facilities utilizing the three selected Conversion Technologies.

The information in Table 4-1 indicates that the annual availabilities for the reference facilities of the mass burn waste-to-energy waterwall and advanced thermal recycling technologies averaged in the low 90 percent range. The annual facility availabilities for reference RDF waste-to-energy facilities were slightly lower, averaging around 86 percent.

Table 4-1
Annual Facility Availability for Three Selected Conversion Technologies

Location	No. of Processing Units (1)	Rated Facility Processing Capacity (1) (TPD)	Range (%) Minimum	Range (%) Maximum	Average (%)	No. of Years Reviewed
Mass Burn Waste-To-Energy Waterwall						
Spokane, WA	2	835	92	94	93	3
Marion Co., OR (2)	2	550	92	95	93	6
Stanislaus, CA	2	840	84	89	87	3
Kent Co., MI	2	625	91	93	92	16
Lancaster Co., PA	3	1,200	91	94	92	8
RDF Waste-To-Energy						
Norfolk, VA	4	2,000	79	87	83	2
Detroit, MI (3)	3	3,300	88	89	89	3
Honolulu, HI	2	1,708	78	90	85	3
Advanced Thermal Recycling						
MVR Hamburg, Germany	2	1,100	92	93	92	4
MVB Hamburg, Germany	2	1,100	92	94	93	4

(1) The number of units and rated processing capacities for U.S. plants were obtained from *The 2004 IWSA Directory of Waste-to-Energy Plants* (Washington, D.C.: Integrated Waste Services Association, 2004).
(2) Marion County determines the annual availability data on a fiscal year beginning July 1. Data for 2005 was not included due to an anomaly occurring in operations.
(3) The third unit is a standby and the environmental permit allows only two units to operate simultaneously.

Summary

For the purpose of this report and based on our review of the data presented in Table 4-1, we have developed planning estimates of the annual availabilities for the three Conversion Technologies, as listed in Table 4-2.

Table 4-2
Annual Facility Availability for Three Selected Conversion Technologies

Conversion Technology	Annual Facility Availability (%)
Mass Burn Waste-To-Energy Waterwall	90
RDF Waste-To-Energy	87
Advanced Thermal Recycling	90

Based both on the data we have reviewed and our previous experience, we believe that these assumed annual plant availability rates are reasonable for the planning purposes of this report. As discussed previously, we believe availability estimates above 90 percent for the entire 20-year planning period would be overly optimistic.

We have used these assumed annual availability factors in Section 6, "Conversion Technology and Waste Export Facility Considerations," Section 8, "Backup Disposal Capacity for Conversion Facilities," and Section 12, "Projected Energy Revenues."

Section 5
NON-PROCESSIBLE WASTE AT CONVERSION FACILITIES

Section 5
NON-PROCESSIBLE WASTE AT CONVERSION FACILITIES

It is important to note that none of the Conversion Technologies will be able to process 100 percent of the municipal solid waste currently delivered to the Cedar Hills Regional Landfill. Because of solid waste size or composition constraints, some portion of that municipal solid waste will require disposal by some other means, most likely landfilling. In such an event, the County must arrange for disposal of such material. This section of the report presents a discussion of the estimated type and amount of non-processible waste, for each Conversion Technology, that would require alternate disposal.

What Constitutes Non-Processible Waste

Many of the currently operating waste-to-energy facilities have operating agreements that categorize waste as either “acceptable” or “unacceptable” depending on whether or not such types of waste can even be delivered to the facility. Examples of unacceptable waste could include contaminated soils, sludges, ashes, large dead animals, construction and demolition material, and large quantities of yard waste. What constitutes unacceptable waste is impacted by, among other things, the type of Conversion Technology used. Also included as “unacceptable” is the category currently deemed “Special Waste” by the County. This category makes up less than 1 percent of the waste currently delivered to the Cedar Hills landfill and includes waste such as asbestos, large amounts of spoiled food, dead animals, and oversized items like boats and trailers. We have assumed that all items currently identified by the County as unacceptable waste would not be delivered to the Conversion Facility and would require alternate disposal.

The operators of Conversion Facilities may further categorize the “acceptable” waste, which is delivered to the Conversion Facility, as either “processible” or “non-processible.” For example, the operator of a Conversion Facility may accept such items as rolled carpet, white goods (refrigerators, stoves, etc.), or engine blocks, but the operator may segregate such items after they have been delivered and classify them as “non-processible.” While such non-processible items are delivered and accepted at the Conversion Facility, they are not introduced into the conversion process and are instead sent to alternate disposal, such as landfilling or recycling.

For the purpose of this report, because “unacceptable” waste generated in the County is assumed to be diverted prior to delivery to the Conversion Facility (or Cedar Hills landfill), all waste delivered to the Conversion Facility is assumed to be “acceptable” and any waste diverted from the Conversion Facility to alternate disposal prior to processing is considered "non-processible." Furthermore, it is assumed that any "unacceptable" waste was either recycled, recovered or disposed of using alternate, in-county methods, and that only "non-processible" waste accepted by the Conversion Facility will require disposal by the County at a landfill. Our primary focus in this section of the report is to develop an estimate of the amount of non-processible waste that must be disposed of at a landfill or by some other means.

Generally speaking, non-processible waste is municipal solid waste that, if received and processed by the specific Conversion Technology, could potentially adversely affect the operation of the facility, be a threat to health or safety, and/or violate permits or other regulations.

Municipal solid waste can be deemed non-processible due to its size, chemical composition, moisture content, or thermal properties, or because of regulatory constraints. Examples of typical non-processible materials for the three Conversion Technologies under consideration are listed in Table 5-1.

Table 5-1
Typical Non-Processible Materials

Material Categories7
Hazardous material
Asbestos
Rocks, dirt, concrete
Large dead animals
Construction and demolition debris
Batteries (vehicle, household, alkaline/button cell batteries)
Paint (latex and oil based)
Computer monitors, televisions, cell phones
White goods
Large machinery and equipment
Motor vehicles and parts
Sludge, sewage, wastewater and other liquid wastes
Thermometers, fluorescent lights, oil, acids, caustics, poisons and other household hazardous waste

In addition, there are some differences between the different Conversion Technologies in the materials that are considered non-processible. Most of these differences are due to the capabilities of the front-end processing equipment required at RDF facilities. RDF technology employs separation and shredding equipment that is not capable of processing large items such as oversized bulky items and larger metal items. Conversely, large items may be considered processible at mass burn or advanced thermal recycling facilities as long as the items will fit into the boiler and have heating value.

An important consideration in determining what waste is processible is the list of materials that are prohibited from combustion by the regulatory agencies. Typically, it is desirable that household hazardous waste, such as paints, batteries, used oils, thermometers, and electronic equipment, is not disposed of at Conversion Facilities either because these items may be a hazard to the Conversion Facility and its operators, or because their combustion will result in air emissions or residue ash that may affect human health and safety. Also, operators may deem some materials such as gypsum scrap (drywall) to be non-processible because, when combusted, it results in significant increases in specific types of air emissions or residue contamination. While the operators are still required to accept such material and should be prepared to process it, they can deem it non-processible and divert it.

Materials that have little or no heating value are also often considered non-processible and may be diverted prior to processing. Examples of these materials are dirt, rocks, concrete, and other inerts. The introduction of these materials to a thermal process results in little if any energy generation and will just take up space in a boiler and cause erosion of the equipment. Also, once these materials are put through the process they become residue of the facility and must be handled as such. By diverting such materials prior to their being processed, the operator can often dispose of them more easily, decreasing the amount of ash residue which may have to be disposed of differently, and potentially more expensively, than dirt and inerts. In general, these materials are diverted based on the ease with which they can be removed prior to processing. It is common for materials such as ferrous metals and large pieces of concrete to be removed because the level of effort is reasonable. Alternatively, objects such as broken glass and non-ferrous metals are usually sent through the process because, while they add little or no heating benefits, their presence does not result in significant inefficiencies and their removal would be very difficult. Operators have found that in the case of both ferrous and non-ferrous metals, these can often be removed more easily from the residue once the solid waste has been processed.

Estimated Quantity of Non-Processible Waste

In order to develop an estimate of the amount of non-processible waste to be disposed of by the County, we considered:

1. The reported percentages of non-processible waste at existing waste-to-energy facilities;
2. The differences in types of waste that can be processed between the three Conversion Technologies being considered in this report; and
3. The composition of the County's municipal solid waste as quantified in the County's Waste Characterization Study (discussed in Section 3) and the County's estimate of projected future recycling rates (discussed in Section 7).

Amount of Non-Processible Waste at Existing Facilities

As part of this report, we contacted the operators of several Conversion Facilities to obtain data on the amount of non-processible waste they currently receive at their facilities. Based on these conversations, the amount of non-processible waste reported by mass burn operators ranged from 1 to 11 percent. We expect that the average range for an RDF facility will be slightly higher because of the more complicated front-end processing.

Non-Processible Waste in King County

We reviewed the results of the County's Waste Characterization Study to identify what components in the waste stream we would expect to be non-processible at the Conversion Facilities. It should be noted that the Waste Characterization Study was based on waste delivered to the Cedar Hills landfill, which by rule is not supposed to receive construction and demolition material, biosolids, sludges, and yard waste. As discussed above, since these components of the waste stream represent a significant portion of the material that would be considered unacceptable waste at a Conversion Facility, we have assumed that all of the waste currently being received at the Cedar Hills landfill would be accepted at a Conversion Facility, but that not all of it would be classified as processible.

Presented in Table 5-2 is a summary of our estimate of the processible and non-processible portions of the King County waste stream for 2016, based on the County's assumed recycling program and waste generation projections. This information is generally comparable to the reported results of the existing waste-to-energy facilities with which we are familiar. Therefore, for the purposes of this report, we have assumed that 5 to 9 percent of the County's waste stream will be deemed non-processible by the Conversion Facilities and will require disposal at an alternate disposal facility.

Table 5-2
Assumed King County Processible Percentages and Tonnages by Conversion Technology
(2016 Tons)

	Mass Burn		RDF		Advanced Thermal Recycling	
Category	Percentage	Tons	Percentage	Tons	Percentage	Tons
Paper	100%	270,571	100%	270,571	100%	270,571
Plastic	100%	125,673	100%	125,673	100%	125,673
Wood/Yard/Food Organics	100%	396,631	100%	396,631	100%	396,631
Other Organics	100%	124,279	100%	124,279	100%	124,279
Glass	100%	35,057	100%	35,057	100%	35,057
Metal	100%	80,844	100%	80,844	100%	80,844
Other Wastes	60%	74,173	19%	24,045	60%	74,173
Household Hazardous	0%	0	0%	0	0%	0
Total Processible Percentage	95%		91%		95%	
Total Processible Tons	1,107,228		1,057,099		1,107,228	
Total Non-Processible Tons	57,073		107,202		57,073	

Impact of Recycling on Non-Processible Waste

It should be expected that the current recycling programs in King County will change over time. In undertaking this analysis, we have included consideration of the County’s proposed increase in the current level of recycling. In developing the information and discussion of a possible Conversion Facility, we assumed that the Conversion Facility would complement the County’s current recycling goals. There are certain recyclable materials that have strong and long-standing markets for sale. Portions of these types of materials continue to be disposed of at the Cedar Hills landfill and they are categories of waste that are considered processible in the three Conversion Technologies we are considering. King County has highlighted organics as a particular category of the waste stream that will likely see an increase in recycling attention by the County. In addition, the County has advised that it plans to take steps to maximize existing efforts to recycle glass and plastic. For these reasons, we expect that any changes in the County’s recycling rate will affect only the Total Processible Tons shown in Table 5-2. Therefore, we anticipate that changes in recycling will have very little, if any, effect on the Total Non-Processible Tons shown in Table 5-2.

Section 6
CONVERSION TECHNOLOGY AND WASTE EXPORT FACILITY CONSIDERATIONS

Section 6
CONVERSION TECHNOLOGY AND WASTE EXPORT FACILITY CONSIDERATIONS

In this section of the report, we discuss the specific facility considerations for the implementation both the Conversion Technology Disposal Option and the Waste Export Disposal Option. For the Conversion Technology Disposal Option, this entails making specific assumptions about the operational aspects of each of the commercially proven Conversion Technologies and creating a theoretical facility that will be used in analyses in later sections of this report. For the Waste Export Disposal Option, this involves discussion of contracting with disposal companies and specific considerations related to intermodal capacity and operation.

Conversion Technology Considerations

For the purposes of organization and simplification of the information, we separately discuss the "capacity" and the "number" of Conversion Facilities. By "capacity" we mean the total amount of disposal or processing capacity the County needs in any year to accommodate the amount of waste that requires disposal in that year. The "number" of facilities refers to the number of different sites that will be required or recommended in order to meet the determined capacity. These two issues are discussed separately because their key issues and considerations are fairly distinct.

The capacity of the Conversion Facilities is mainly a function of waste stream characteristics and specific operating aspects of the Conversion Technologies themselves. Specifically, to determine the capacity, the County must evaluate: 1) projected quantity of waste generated; 2) projected quantity of waste to be recycled, with the remainder to be disposed of; 3) projected quantity of non-processible waste for each type of Conversion Technology; 4) expected annual availability of each Conversion Technology; 5) the heating value of the waste; 6) monthly and seasonal fluctuations in the generation of waste; 7) the timing of additional disposal capacity; and 8) the number and size of processing lines to be used.

Alternatively, the determination of the number of Conversion Facilities is more a function of siting and permitting considerations. Included in these considerations are: 1) the cost and ease of siting and permitting; 2) varying development, construction, and operations costs; 3) maximizing economies of scale; 4) the flexibility and robustness of the system; 5) the maximization/utilization of existing and planned solid waste system infrastructure (transfer stations, collection equipment); and 6) impacts on the immediate geographic area of the site(s) of the facility(ies).

Below, we discuss all of these considerations and, based on the County's priorities established in discussion with County staff, identify various issues for the County to consider.

The information in this section relies upon and builds upon information developed in the following other sections of this report:

- Section 2 – Solid Waste Quantity and Composition
- Section 4 – Annual Facility Availability of Conversion Technologies
- Section 5 – Non-Processible Waste at Conversion Facilities

Identification of County Priorities

Decisions related to the capacity and number of Conversion Facilities are complicated by the fact that so many of the parameters are interrelated. Different parameters may have positive and negative ramifications for costs, level of effort, and risks to the County. For this reason it is important to establish and understand the County's priorities related to these parameters. The following decision-making criteria are based on directions provided by the County. Recognizing that the criteria are interrelated, they are listed in two groups, high priority and lower priority:

High Priority

- Minimize capital and operating costs.
- Maximize the ability to recover energy and other beneficial products.
- Minimize the number of sites that will have to be obtained and permitted.

Lower Priority

- Minimize the amount of bypass waste.
- Minimize the expense of local solid waste transport.

We have applied these five criteria in developing our analysis of the assumed capacity and number of facilities.

Factors Impacting the Capacity of a Conversion Facility

Projected Base Case Quantities of Waste Requiring Disposal

For the purpose of this analysis, and based on data provided by the County, we developed projections for waste generation, recycling, and disposal. These projections are based on the County's assumption of a consistent increase in the recycling rate of 0.3 percent per year from a benchmark of 43.7 percent in 2004. These projections are presented in Table 6-1 for the planning period of 2016 to 2036.

Table 6-1
Projected Annual Quantity of Waste Requiring Disposal

Year	Recycling Rate(1)	Projected Generation (Tons)	Projected Recycling (Tons)	Projected Disposal (Tons)
2016	47.3%	2,209,300	1,044,999	1,164,301
2017	47.6%	2,263,510	1,077,431	1,186,079
2018	47.9%	2,319,650	1,111,112	1,208,538
2019	48.2%	2,365,610	1,140,224	1,225,386
2020	48.5%	2,426,490	1,176,848	1,249,642
2021	48.8%	2,451,230	1,196,200	1,255,030
2022	49.1%	2,510,700	1,232,754	1,277,946
2023	49.4%	2,521,050	1,245,399	1,275,651
2024	49.7%	2,584,390	1,284,442	1,299,948
2025	50.0%	2,649,650	1,324,825	1,324,825
2026	50.3%	2,664,560	1,340,274	1,324,286
2027	50.6%	2,732,280	1,382,534	1,349,746
2028	50.9%	2,775,610	1,412,785	1,362,825
2029	51.2%	2,847,020	1,457,674	1,389,346
2030	51.5%	2,920,180	1,503,893	1,416,287
2031	51.8%	2,985,004	1,546,232	1,438,772
2032	52.1%	3,051,270	1,589,712	1,461,558
2033	52.4%	3,119,007	1,634,360	1,484,647
2034	52.7%	3,187,625	1,679,878	1,507,747
2035	53.0%	3,257,753	1,726,609	1,531,144
2036	53.3%	3,329,423	1,774,583	1,554,841

(1) Assumes level of recycling increases 0.3% per year.

Non-Processible Waste at Conversion Facilities

As discussed in Section 5, the quantity of non-processible waste delivered to a Conversion Facility can influence the amount of waste that requires landfilling or disposal through an alternate method. In Section 5, we discuss the annual tonnages of processible waste estimated for King County for each Conversion Technology based on the projections in Table 6-1. Based on the information presented in Section 5, we have used the assumed percentages of non-processible waste as shown in Table 6-2 for each Conversion Technology.

Table 6-2
Assumed Non-Processible Percentage by Conversion Technology

Technology	Non-Processible Waste (%)
Mass Burn Waste-to-Energy Waterwall	5
RDF Waste-to-Energy	9
Advanced Thermal Recycling	5

Annual Availability of the Conversion Facilities

As outlined in Section 4, the expected annual availability of a Conversion Facility is anticipated to vary slightly depending on the Conversion Technology employed. Table 6-3 summarizes the reported range of annual facility availabilities for each of the technologies considered in this report.

Table 6-3
Reported Annual Facility Availability for each Conversion Technology

Conversion Technology	Facility Availability (%)
Mass Burn Waste-to-Energy Waterwall	87–93
RDF Waste-to-Energy	83–89
Advanced Thermal Recycling	92–93

As discussed in Section 4, we believe it would be overly aggressive to assume for this report that any of the Conversion Technologies will be able to realize a 92 to 93 percent average annual availability over the 20-year planning period. While we recognize that in some years facilities may be able to reach these reported levels, in our experience average availabilities over multi-year operating periods are generally lower than the reported numbers shown in Table 6-3. The assumptions we have used in the report are summarized in Table 6-4.

Table 6-4
Assumed Annual Facility Availability for each Conversion Technology

Conversion Technology	Facility Availability (%)
Mass Burn Waste-to-Energy Waterwall	90
RDF Waste-to-Energy	87
Advanced Thermal Recycling	90

Note: This table summarizes assumptions used by R. W. Beck in its planning analysis of capacity of Conversion Facilities.

Expected Variations in Waste Generation

The expected annual waste generation quantity is the primary determinant in identifying the amount of disposal capacity the County will require. The extent to which this waste generation varies from month to month is also an important consideration in determining the capacity of the Conversion Facility(ies) because it can impact the amount of waste that will have to be bypassed. This means that the County must determine whether, in order to meet the peak waste generation months, it wants to construct a Conversion Facility that is larger than the size necessary to meet the annual average monthly waste generation rate. By constructing a larger Conversion Facility, the County would:

1. Incur additional capital cost;
2. Have additional capacity that it could "grow into" in future years as waste generation increases; and
3. Reduce bypass waste in peak waste generation months.

As can be seen in Table 6-5, the monthly variation in the quantity of waste that was disposed of between 2003 and 2006 is not significantly different from month to month. June is the busiest month with nearly 88,000 tons on average, but the slowest month, February, still accounts for nearly 75,000 tons on average after making an adjustment for the fact that February has only 28 days. This means there is a difference of approximately 17 percent between the peak waste generation month (June) and the lowest waste generation month (February). The policy decision the County would have to consider if it chose the Conversion Technology Disposal Option is whether to: 1) size the Conversion Facility for the lowest waste generation month (February), which assures the Conversion Facility is always operated at its maximum capacity; 2) size the Conversion Facility for the maximum waste generation month (June), which assures there is no bypass waste; or 3) size the Conversion Facility for the average month.

The relatively narrow range of difference between the peak month of June and the lowest month of February should allow the Conversion Facility to operate reasonably efficiently throughout the course of the year if the County determines to size the Conversion Facility to meet the annual average monthly amount of waste generation.

Table 6-5
Average Monthly Disposal Quantities
(2003–2006)

Month	Average Disposed (Tons)	Percent of Total
January	78,809	8.02%
February	69,810	7.10%
March	79,840	8.12%
April	82,072	8.35%
May	87,000	8.85%
June	87,958	8.95%
July	86,099	8.76%
August	86,263	8.77%
September	83,347	8.48%
October	82,783	8.42%
November	78,399	7.97%
December	80,700	8.21%
Total	**982,887**	**100.00%**

Source: King County Solid Waste Division

In addition to considering monthly fluctuations in waste generation, the County would need to consider the significant differences between what would constitute a “busy” day and what would constitute a “slow” day, in terms of the quantity of waste generated on a daily basis. The County would have to address the differences in waste deliveries between busy and slow days through the operation of both the entire solid waste management system and the Conversion Facility:

1. The design of the Conversion Facility should allow for a storage pit or tipping floor that will accommodate a minimum of three days storage capacity to allow for long weekends and interruption of waste deliveries such as might be caused by bad-weather driving conditions.

2. Scheduled outages of the Conversion Facility should be taken during low waste generation months.

3. The County should operate other solid waste management facilities in the system to allow for the “busy days” when waste deliveries could significantly exceed the operating and storage capacity of the Conversion Facility.

Timing of Additional Disposal Capacity

A key consideration in determining the best approach to sizing the Conversion Facility(ies) is the County's preferred timing for constructing additional disposal capacity after 2016. These policy decisions would have a significant impact on the amount of bypassed waste which must be landfilled each year as a result of peak waste periods and the growth of the waste stream. There are several different approaches the County could consider related to the timing of increasing the capacity of the Conversion Facility(ies) after 2016. These different approaches and the resulting impact are summarized in Table 6-6.

Table 6-6
Approaches to Timing Disposal Capacity Additions

Approach	Impact
1. Add disposal capacity as early as is required to avoid the need to bypass any waste.	This is the most expensive approach in terms of capital cost and having waste disposal and energy generation capacity that may not be fully utilized throughout the year. It would minimize the amount of backup disposal capacity required.
2. Add disposal capacity when such capacity would meet the annual average disposal requirements during the year.	This would result in better utilization of the disposal capacity/energy capability of the Conversion Facility and would be more cost effective than Approach 1. It would result in the need to bypass waste during certain months in the early years until the additional capacity came on line.
3. Add disposal capacity only when the disposal capacity would be fully utilized throughout the year.	This is the most cost efficient approach in terms of fully utilizing the disposal capacity/energy generation capability of the Conversion Facility. It would result in the need to bypass waste during busier months from the outset of operation, with increasing quantities of bypassed waste until the additional capacity came on line.

Number of Processing Lines

The number of processing lines can influence the flexibility of operation and therefore impact the amount of bypassed waste and overall efficiency of the Conversion Facility. In general, the more processing lines there are in the Conversion Facility, the easier it is to phase the scheduled downtimes and maintain a high level of efficiency during unscheduled downtimes. For example, if a 3,000 TPD Conversion Facility has four processing trains (750 TPD each), the outage of one processing train represents 25 percent of the processing capacity of the Conversion Facility and leaves a running capacity of 2,250 TPD. If, on the other hand, the Conversion Facility has two larger processing trains (1,500 TPD each) and one of them is taken out of operation, 50 percent of the processing capacity of the Conversion Facility is not available, leaving only 1,500 TPD of capacity and potentially increasing the amount of bypassed waste.

When considering the number of processing lines, it is important to consider the expected economies of scale and the expected variation of the waste stream. As is typical with many aspects of Conversion Facilities, the larger the processing line that can be constructed, the greater the economies of scale. Based on demonstrated performance at existing Conversion Facilities, our opinion is that the County should consider individual processing lines sized at no more than 1,000 TPD. As this size is decreased, the unit costs for construction, operation, and maintenance of the line can be expected to increase. However, as discussed above, with larger processing lines comes reduced scheduling flexibility and less capability to handle variations in the amount of waste generated. The County would need to consider the trade-off of lower costs against increased bypass waste.

Waste Simulation Model

To help evaluate all of the above factors, we prepared a model of the operation of a Conversion Facility (the “Waste Simulation Model”) that uses historic daily tonnages from the County waste stream, projects them for future years, and produces estimated tonnages of the amount of waste requiring landfilling (bypassed, non-processible, and residue) and processing.

The Waste Simulation Model was developed to allow the County to evaluate the effect of making changes to certain of the assumed operational metrics of a Conversion Facility. The Waste Simulation Model allows the user to modify the values of a variety of parameters related to the estimated quantities of solid waste and the design of the Conversion Facility. Using this information, the model calculates an estimate of the amounts of processed waste, bypassed waste, residue, and plant efficiency under different operating assumptions. Presented below is a brief discussion of the specific inputs and outputs of the Waste Simulation Model.

Tonnages

In order to simulate the operation of a Conversion Facility, the Waste Simulation Model projects daily tonnages assumed to be delivered to the Conversion Facility for an entire calendar year. To do this, the Waste Simulation Model uses the actual waste delivery data for the Cedar Hills landfill for 2003 through 2006. It calculates the four-year average for each day of one year, lining up weekdays and weekends, to create an expected weighted average schedule of waste delivery for the year. The user can then enter a “Projected Total Annual Tonnage” for a future year and the Waste Simulation Model will create a waste schedule for the simulated year by increasing the average daily tonnages by a “Projection Factor.” The Projection Factor is calculated as:

Projection Factor = Future Year Tonnage ÷ Four-Year Average Tonnage

Assumed Operational Inputs

For the Waste Simulation Model to develop an estimate of a Conversion Facility's operation for a particular quantity of "Projected Waste Deliveries," the model requires the user to make assumptions about the operation and number of processing lines of the assumed Conversion Facility. These assumptions and their use in the model are discussed in detail below.

Number and Size of Processing Lines

The Waste Simulation Model requires an assumption be made regarding the number and size of the processing lines employed at the simulated Conversion Facility. This allows the user to simulate facilities with similar rated capacities (the number of processing lines multiplied by their size in tons per day) but with different processing line configurations to determine how much of a difference changes in the number and size of processing lines make in the operational efficiency of the Conversion Facility.

Facility Availability

Facility availability is used by the Waste Simulation Model to create an outage schedule (scheduled and unscheduled) that is used to simulate the actual processing capacity of the Conversion Facility when a processing line is not operating due to maintenance or repair. The Waste Simulation Model allows the user to enter the number of days that each processing line is assumed to be off-line for both scheduled and unscheduled outages. The Waste Simulation Model assumes that scheduled outages take place during the months of the year when the waste deliveries are lowest, and, to be conservative, assumes that unscheduled outages occur when the waste deliveries are highest.

Percentage of Non-Processible Waste

The Waste Simulation Model requires a user to make an assumption regarding the percentage of non-processible waste delivered to a Conversion Facility since this metric varies depending on the selected Conversion Technology and the quantity of waste. During the simulation, the Waste Simulation Model removes this percentage of the waste prior to processing, assuming that non-processible waste will not be introduced into the conversion process. Therefore, non-processible waste is not considered as part of the processing capacity of the Conversion Facility. The amount, expressed in tons, of non-processible waste is also one of the outputs of the Waste Simulation Model.

Residue Production

Residue production is defined as the amount, expressed as a percent by weight, of material that results from the processing of the solid waste compared to the amount of processible waste that is introduced into the conversion process. This metric can vary depending on the type of Conversion Technology, the operation of the facility, and specific characteristics of the waste stream.

Facility Storage

Facility storage refers to the number of tons that a Conversion Facility can store in its pit, or in other parts of the County's solid waste management system, when the processing components are either at capacity or not operating. Facility storage is a part of the design of every Conversion Facility and is used to increase its operational flexibility. Storage is used when the Conversion Facility is receiving more waste than it can currently process and allows the Conversion Facility to accommodate variations in the amount of waste that is received from day to day. In the Waste Simulation Model, if more waste is delivered than the facility has capacity to process, the excess waste is assumed to be stored. If the amount of stored waste reaches the assumed facility storage amount, then the Waste Simulation Model assumes that excess waste will start to be bypassed. However, in reality, some of this excess waste could possibly be held in the storage areas at the transfer stations for short periods of time.

Model Outputs

The Waste Simulation Model uses the Assumed Operational Inputs provided by the user and runs a hypothetical year of facility operation based on the Projected Waste Delivery Schedule for that particular year. Outputs of the simulation include "Tonnage Processed," "Tonnage Non-Processible," "Tonnage and Percent Bypassed" (percent of "Total Tonnage Delivered"), "Residue Tonnage," and the "Plant Capacity Factor" ("Total Utilized Capacity" ÷ "Rated Capacity"). These outputs can help the user evaluate changes in waste processing capability and quantity of bypassed waste under different assumed operational and design aspects of the Conversion Facility.

Simulation Results

Tables 6-7, 6-8, and 6-9 show the results of simulations for each Conversion Technology with four processing lines, each with an assumed capacity of 800 TPD per processing line. The results of simulations for 2016, 2026, and 2036 are presented in the tables. These results demonstrate the effect of the growing waste stream and the estimated operating differences between each Conversion Technology at identical sizes.

Table 6-7
Simulation Results
2016 Projected Tonnage

Conversion Technology	Mass Burn	RDF	Advanced Thermal Recycling
Inputs			
Processing Lines	4	4	4
Line Capacity (tpd)	800	800	800
Facility Availability	90%	87%	90%
Non-Processible Percentage	5%	9%	5%
Residue Production	25%	20%	22%
Facility Storage (tons)	10,000	10,000	10,000
Outputs			
Tonnage Processed	1,042,993	999,216	1,042,993
Tonnage Non-Processible	58,215	104,787	58,215
Tonnage By-Passed	58,528	54,733	58,528
Total Waste Landfilled	116,743	159,520	116,743
Residue Tonnage	260,748	199,843	229,458
Percent Landfilled	10.07%	13.77%	10.07%
Plant Capacity Factor	89%	86%	89%

Table 6-8
Simulation Results
2026 Projected Tonnage

Conversion Technology	Mass Burn	RDF	Advanced Thermal Recycling
Inputs			
Processing Lines	4	4	4
Line Capacity (tpd)	800	800	800
Facility Availability	90%	87%	90%
Non-Processible Percentage	5%	9%	5%
Residue Production	25%	20%	22%
Facility Storage (tons)	10,000	10,000	10,000
Outputs			
Tonnage Processed	1,050,400	1,015,200	1,050,400
Tonnage Non-Processible	66,214	119,186	66,214
Tonnage By-Passed	199,939	182,746	199,939
Total Waste Landfilled	266,154	301,932	266,154
Residue Tonnage	262,600	203,040	231,088
Percent Landfilled	20.22%	22.92%	20.22%
Plant Capacity Factor	90%	87%	90%

Table 6-9
Simulation Results
2036 Projected Tonnage

Conversion Technology	Mass Burn	RDF	Advanced Thermal Recycling
Inputs			
Processing Lines	4	4	4
Line Capacity (tpd)	800	800	800
Facility Availability	90%	87%	90%
Non-Processible Percentage	5%	9%	5%
Residue Production	25%	20%	22%
Facility Storage (tons)	10,000	10,000	10,000
Outputs			
Tonnage Processed	1,050,400	1,015,200	1,050,400
Tonnage Non-Processible	77,742	139,936	77,742
Tonnage By-Passed	416,699	390,261	416,699
Total Waste Landfilled	494,441	530,197	494,441
Residue Tonnage	262,600	203,040	231,088
Percent By-Passed	32.01%	34.31%	32.01%
Plant Capacity Factor	90%	87%	90%

The results of this analysis demonstrate that a Conversion Facility originally sized at 3,200 TPD is projected to have a minimal amount of bypass waste in 2016, estimated to be between 1 and 5 percent. However, the model calculates that by 2026, the County will have between 150,000 TPY and 200,000 TPY of bypassed waste depending on the technology employed. This would require approximately 400 TPD to 600 TPD of additional disposal capacity in 2026.

By running a simulation for the entire 20-year operating period the Waste Simulation Model can also estimate the timeline for adding additional disposal capacity to the County's system. For a Conversion Facility with four processing lines with capacities of 800 TPD, we estimate that a fifth processing line of 800 TPD would be fully utilized by between about 2026 and 2030, depending on the technology employed.

Factors Impacting the Number of Conversion Facilities

While the siting of multiple Conversion Facilities can result in some efficiencies in the hauling of waste and some sharing of waste management impacts, the County must carefully consider several issues in evaluating this decision.

Economies of Scale

One advantage of fewer Conversion Facilities with larger individual capacities is the utilization of economies of scale. This refers to the fact that the capital and operating costs associated with processing waste are not linear. As the amount of waste processed by a single Conversion Facility increases, the unit cost and effort to process each additional ton decreases. This is because some activities require the same level of expenditure and complexity regardless of the amount of waste processed, making it more cost effective to maximize the amount of waste related to that activity. When considering multiple Conversion Facilities, the County must consider the financial benefits of these economies of scale to ensure that each Conversion Facility is sufficiently sized to reduce its overall cost.

Siting Considerations

The County must evaluate the difficulty in siting and permitting multiple Conversion Facilities. Historically, Conversion Facilities have not been a welcomed neighbor by residents and stakeholders and the County can reasonably expect to experience similar objections. As discussed in Section 14, it is likely that proceeding through the siting and permitting of a Conversion Facility will be a long, difficult, and expensive process.

The County is likely to find it a challenge to identify sites of the size and with the infrastructure and land use requirements that will allow Conversion Facilities to be constructed and operated efficiently. Considerations such as access to major roadways, power lines, other utilities, and rail lines will dictate whether the Conversion Facility can be sited and meet the required functions. A specific example would be if the site does not have access to rail lines, requiring all transport of waste and residual to occur by use of trucks.

Transportation Costs

Another aspect for the County to consider when siting a Conversion Facility is the cost of transportation incurred by solid waste collection vehicles and long-haul vehicles. In the system's current configuration, collection vehicles generally bring collected waste to transfer stations where it is loaded and compacted into trailers that haul the waste to the Cedar Hills landfill. Proper siting of a Conversion Facility should attempt to minimize the distances that collection vehicles and haul vehicles have to travel in order to reduce the total cost of the County's solid waste management system. It is also possible that one or more Conversion Facilities could replace one or more existing or planned transfer stations as the destination for collection trucks. Decisions by the County to replace a transfer station must be made carefully to ensure system efficiencies are maintained and the County's investment in transfer station development is considered.

Advantages and Disadvantages of each Scenario

The advantages and disadvantages for both a single facility, and two facilities or more, are shown in Tables 6-10 and 6-11, respectively.

Table 6-10
Advantages and Disadvantages of a Single Facility

Advantages	Disadvantages
■ Siting and permitting costs would be less than for multiple-facility options and potentially easier due to the likely public resistance, location of interconnection and other utilities, etc. ■ Residue transfer to disposal site is more consolidated than for the multiple-facility options and therefore is likely less expensive ■ Takes greater advantage of economies of scale in larger facility in terms of development and operating and maintenance costs ■ Depending on location, could displace one or more existing or planned transfer stations and the required investment in these facilities ■ Demands on internal County resources during development and operation likely to be less than for multiple-facility options ■ If County chooses to contract with a private operator, the single-facility option would result in fewer operating contracts and possibly lower administrative cost than multiple-facility options where each facility would likely have its own operating contract	■ Siting and permitting of a single large facility may be more challenging size of plant footprint and because of issues of inequitable distribution of impacts in County ■ In-county backup or redundant disposal capacity centered at one location which could prove a vulnerability if facility becomes isolated in a catastrophe or if facility goes off-line because of some local plant event ■ Longer collection haul routes to facility from some areas of the County than in multiple-facility options and therefore higher hauling costs from transfer stations ■ Results in a potentially inequitable distribution of impacts because one geographic section of the County is the recipient of all the solid waste ■ Depending on location, could make redundant one or more existing transfer stations and the investment made in these facilities

Table 6-11
Advantages and Disadvantages of Multiple Facilities

Advantages	Disadvantages
■ Siting of multiple smaller facilities versus a single large facility may be less challenging because of the reduced size of plant footprints and because of issues of inequitable distribution of impacts to County ■ Shorter haul routes to facilities from some areas of the County compared to routes for a single facility, therefore lower hauling cost ■ Distributed facilities more likely to result in more equitable distribution of impacts than single facility ■ Multiple facilities result in more redundancy than a single facility, making the system less vulnerable to disruption ■ Depending on facility locations, could displace one or more planned transfer stations and the required investment in these facilities	■ Siting and permitting are more expensive than for a single facility ■ Higher development and operating and maintenance costs than single facility due to reduced economy of scale ■ Residue transfer to disposal site is less consolidated than for a single facility, likely to be more expensive ■ Depending on facility locations, could make redundant one or more existing transfer stations and the investment made in these facilities ■ Demands on internal County resources during development and operation likely to be more than for single facility ■ If County chooses to contract with a private operator(s), would likely involve separate operating contracts for each facility, resulting in a greater administrative burden on the County than for single facility

Conclusions Regarding Capacity and Number of Conversion Facilities

We have identified a planning estimate of the capacity and number of Conversion Facilities based on the County's priorities, as discussed above. Our analysis is based on the assumption that the County will generate waste and realize an escalating recycling rate as outlined in Table 6-1. Using these criteria, we estimate that the County will require approximately 3,200 TPD of disposal capacity in 2016. The County's three higher priorities could be met by siting a single Conversion Facility consisting of four conversion processing lines each sized at approximately 800 TPD. This configuration would represent the least expensive option in terms of capital cost and operating expenses; it would be the most efficient in terms of generating power, and it would result in the smallest number of sites that would have to be permitted.

This Conversion Facility should be designed to accommodate the future addition of a fifth conversion line also sized at 800 TPD. We recommend the County consider having any additional processing lines sized the same as the first four lines. We believe that this will help in terms of scheduling downtime, ordering replacement parts and supplies, and operator familiarity with the units. It should be noted that an additional conversion line of 800 TPD is large and our analysis estimates that it would not be fully utilized until around 2030. On the other hand, if the County decides to wait to build a fifth processing line until enough waste is generated to use the full capacity of an additional 800 TPD line, it could result in the landfilling of significant quantities of bypass waste prior to the commencement of its operation. The County could consider a scenario in which it would install the additional disposal capacity earlier than would be required for its own disposal needs and accept solid waste from outside of the County on a short-term basis until the County requires all of the capacity itself. This would provide a source of tipping fee revenues to the County while assuring that the additional capacity is operated at its most efficient energy-generation level.

The construction of a single Conversion Facility of 3,200 TPD does not address the County's two lower priorities—to minimize bypass waste and to minimize system hauling costs—as well as a scenario with more processing lines and multiple facilities would. In addition, the construction of a single Conversion Facility means that one geographic area of the County would assume the full impact of the County's waste disposal solution.

It is important to recognize that the purpose of this analysis is not to arrive at one optimal solution but rather to indicate the many different parameters that the County will have to consider if it selects the Conversion Technology Disposal Option. There are a large number of possible combinations of processing line configurations and sizes. The discussion of a single Conversion Facility initially sized at 3,200 TPD with four processing lines is based on reasonable planning assumptions regarding the County's waste and the state of the technologies. Our intent is for the County to use this discussion to further consider the benefits and drawbacks of different sized Conversion Technologies so that the County can gain an understanding of its options. Our intent is not to suggest that the Conversion Facility discussed here is the only, or most preferable, method for implementation of a Conversion Facility.

Size of Facility Sites

The size of the required site for a Conversion Facility will be dependent upon its processing capacity and plans for future expansion. Private waste haulers are particularly concerned about unloading their collection vehicles as quickly as possible in order to return to the collection route. Therefore, it will be important for the Conversion Facility to have a sufficient number of tipping bays allowing vehicles to unload efficiently. In addition, the Conversion Facility should have a storage pit or tipping floor that is sized to store a minimum of three days of waste supply. Further, the County will want a facility site large enough to allow collection and transfer vehicles to queue up on-site rather than back up onto public roads.

The required size of the site will be different for construction-related activities as compared to the actual operation of the Conversion Facility. The County may need to consider using adjacent parcels of land for laydown area during the construction phase.

Based on these requirements, our opinion is that the County should consider facility sites of at least approximately 15 to 20 usable acres for the operation of a single Conversion Facility sized at 3,200 TPD. A larger site results in greater flexibility in accepting solid waste deliveries and general operation of the Conversion Facility. The size of the site would also be impacted by decisions the County makes regarding the types of vehicles that can access the site. If collection vehicles deliver directly to the Conversion Facility, more space and tipping bays will be required for the larger number of vehicles. This could be reduced if the County only allows transfer vehicles to access its site. If the County should opt for multiple facilities of smaller size, our opinion is that the County would need a facility site of approximately 10 to 12 usable acres for the operation of a Conversion Facility sized at 1,000 TPD. It should be noted that at most sites, the number of usable acres may be less than the total area of the site due to potential constraints such as wetlands, streams, slopes, and sensitive area buffers. For estimating purposes we have assumed that the actual site size for a Conversion Facility will be approximately 125% of the estimated usable size required.

Combination of Facilities Required

In addition to the Conversion Facility discussed in this section, Table 6-12 lists other solid waste management facilities the County would need to ensure proper operation of a Conversion Facility. This assumes that the non-processible waste is not recycled or reused, and that no beneficial use is found for the resulting residue ash. If such uses are implemented these requirements will be significantly less than shown in Table 6-12. Also inherent in this discussion is the assumption that the Conversion Facility will operate as expected and that the composition and quantity of the waste stream will not change significantly from that discussed in this report. If the waste processing capabilities of the Conversion Facility are reduced or if waste generation is greater than expected, for example, due to natural disaster or lower-than-assumed recycling rates, the requirements may be significantly greater than the ranges shown in Table 6-12.

Table 6-12
Other Facility Requirements

	Required in 2016
Bypass and Non-Processible Disposal Capacity at a Landfill	115,000–160,000 TPY
Residue Ash Disposal Capacity at a Landfill or through Beneficial Reuse	200,000–260,000 TPY

Truck-to-rail intermodal capacity will be required for the disposal of these bypass and non-processible wastes as well as the residue ash. Due to the smaller tonnages requiring disposal at a landfill, the Conversion Technology Disposal Option is not as taxing on the existing truck-to-rail intermodal capacity in King County (see discussion below). For this reason, it is likely more cost effective for the County to obtain these services through a contract as opposed to building its own dedicated intermodal facility.

Waste Export Disposal Option Facility Considerations

Truck-to-rail intermodal capacity will be required to a significantly greater extent for the Waste Export Disposal Option than for the Conversion Technology Disposal Option. This capacity could be provided through contract with private industry or it could be constructed by the County with the option of County operation or contracted operation. An important aspect of intermodal rail operation is that it requires very close cooperation with, and dependence on, the serving railroad company(ies) to which the waste hauling is being consigned. Long hauling of waste by truck to the regional landfills in eastern Washington and Oregon, or even farther to Idaho, is not considered practical or cost competitive with rail due to the long distances involved and the increasing cost of diesel fuel.

Currently there is insufficient developed truck-to-rail intermodal capacity in King County to handle the quantity of County waste forecast in the years 2016 through 2036, and there is a growing demand for what intermodal capacity does exist. Therefore, under the Waste Export Disposal Option it will be necessary for either the County or a private entity to site and build additional intermodal capacity to satisfy the County's needs. If the County adopts a Conversion Technology that produces residue ash, there may be sufficient intermodal capacity to handle the smaller quantities of ash that would likely need to be shipped to a remote landfill. For this latter option, we would suggest that the County consider obtaining those intermodal services through a contract.

The County's transfer station system will be an integral part of the Waste Export Disposal Option. Depending on the siting of the intermodal facility, one of these stations might be co-located at the intermodal facility if the County is the owner of the intermodal facility. Since the most likely site for a new intermodal facility would be in the South County area where some sufficiently large parcels of land still exist with potential access to the two railroad mainlines, the South County transfer station proposed in the draft Waste Export Plan would be a likely candidate facility to co-locate at an intermodal facility built by the County.

Siting of Intermodal Facilities

Siting an intermodal rail facility requires a site that can accommodate a full train and that provides access, either direct or via one of the two railroad companies, Burlington Northern Santa Fe (BNSF) and Union Pacific (UP), to both of the mainlines that serve King County.

Ideally, the intermodal site must allow a full train (approximately 6,500 lineal feet) to completely exit the mainline without uncoupling and conversely must allow the makeup of a full train, including brake testing, before it enters the mainline.

Truck-to-rail intermodal sites must obviously be sited with access to a rail line. To provide the County with cost competitive access to all of the regional landfills in the Northwest (Washington, Oregon and Idaho), the intermodal facility will need access to both the BNSF and UP railroads. Depending on the location in the County, some intermodal sites could access both railroad companies' mainlines even if they only have access to one of the mainlines, due to the existence of reciprocal switching agreements between the two railroad companies. At other locations where a reciprocal switching agreement does not exist, the cost to switch from one line to the other could be prohibitively high, effectively denying the County access to one or more of the regional landfills.

The intermodal site will also require good access from one or more major arterial highways to facilitate rapid transfer truck access.

Since the intermodal facility is likely to be operated as much as 24 hours a day, seven days per week, the site should be located where it does not have sensitive noise receptor neighboring properties such as properties zoned Rural.

Sizing of Intermodal Facilities

Based on our previous experience with conceptual design and site evaluations for an intermodal facility for King County at two other sites, we estimate that at a minimum a site of 30 to 40 usable acres will be required and the site will need a 6,500-foot running track/lead and three pairs of intermodal loading tracks 14 feet on center with 70- to 80-foot aprons between the track pairs.

The sizing of the intermodal facility should take into account that there will be times when there may need to be a significant number of empty and/or full export containers stored on the site due to upset conditions either along the railroad or at the landfill end of the disposal system. Laydown area for storing up to two days of full or empty containers is recommended. Approximately 140 containers will be required to store one day's waste generation at the current recycling rate of 43 percent. It may also be advisable to consider having laydown room for waste containers from other jurisdictions as well if the County's site is large enough to accommodate these additional containers.

If the site will also host a new transfer station, the site area should be increased by at least an additional 10 usable acres.

Other Facility Requirements

The transfer station requirements for the waste export system have been identified by the County in the draft Waste Export Plan. We do not foresee a need to modify the suggested station requirements set forth in the Waste Export Plan. A single truck-to-rail intermodal facility is also discussed in the Waste Export Plan with the possibility of multiple facilities under certain circumstances. Intermodal facilities are like Conversion Facilities in that there is an economy of scale both in capital cost and in operation and maintenance costs in a single large facility versus two or more smaller facilities.

For the purposes of this report, we have assumed that a single truck-to-rail intermodal facility, publicly or privately owned, would be located in the South County area, where access to both railroad companies' mainline tracks is most likely, and would operate in conjunction with the transfer/recycling stations defined in the County's draft Waste Export Plan.

Section 7
POTENTIAL IMPACTS OF RECYCLING ON CONVERSION TECHNOLOGIES

Section 7
POTENTIAL IMPACTS OF RECYCLING ON CONVERSION TECHNOLOGIES

King County has proven to be a leader in recycling and waste diversion efforts and its programs rank among the most successful in the nation. This section of the report discusses the potential impacts of the County's current and proposed recycling programs on the operations of the recommended Conversion Technologies. This section also discusses the potential impact on the energy generation function of the Conversion Technologies if, in the future, the County increases the quantities of recycled materials currently being removed from the waste stream.

King County Code, Chapter 10.14, states that "it is recognized that waste reduction and recycling are the highest priority of the viable solid waste management options" and that the County has adopted the goal "to achieve zero waste of resources by 2030." This shows that the County hierarchy of solid waste options places greater emphasis on waste reduction and recycling than it places on the permitting, siting, and development of a Conversion Facility.

Current Recycling Program

The County has numerous programs in place to divert and recycle specific materials from the waste stream. County programs serve the residents of the unincorporated areas of the County as well as 37 of the 39 cities, excluding Seattle and Milton. These programs include the residential curbside, multi-family, commercial, drop-box and construction recycling, as well as programs for hazardous waste management and other problem materials. A description of County programs and historical recycling rates is provided in Appendix A.

Future Recycling Program

Public entities can attempt to increase the amount of material they recycle through some combination of the following: increased types of materials that are targeted for recycling, increased levels of participation and/or separation efficiency, or changes in the methods in which the material is collected. The following discussion identifies potential changes the County could consider and the potential impact that each change could have on the County's current level of recycling.

Level of Participation

Current Curbside Participation

According to the Solid Waste Division's 2005 Waste Reduction & Recycling Telephone Survey, approximately 87 percent of King County single-family households, and 94 percent of multifamily households say they use their on-site recycling services. This very high level of participation in the curbside program may represent limited opportunities for significant future increases in participation. However, significant quantities of targeted recyclable materials still remain in County-disposed wastes, so there may be more substantial opportunities to increase the efficiency with which current households, as well as businesses, separate targeted recyclables from their garbage.

Current Drop-Off Participation

While the exact level of participation at the transfer station drop-offs is not known, the County does have some statistics as a result of a 2006 survey of customers bringing recyclable materials to King County transfer stations:[1]

- Loads of recyclable materials came predominantly (90%) from single-family residences; and
- The majority (74%) of customers surveyed did not subscribe to recycling collection service.

Programs Proposed to Be Added

Solid Waste Division staff believe that if additional programs and policies are adopted as part of the Comprehensive Plan Update, such as mandatory paper recycling and bans on yard waste disposal by self-haulers at transfer stations, recycling quantities are likely to increase.

Certain recycling programs may see an increase in tonnage due to the expanded availability of the service. For example, according to the County's website, there are currently 10 communities in the County that offer residents the opportunity to divert food waste with their yard waste set out for curbside collection. Because residential organics (wood/yard/food waste) make up a large portion of the waste stream, Division staff deem it likely that these materials will be targeted by the County for increased recycling opportunities.

[1] Source: "Waste Monitoring Program, 2006 Transfer Station Recycling Survey Final Report," August 2006, prepared by Cunningham Environmental Consulting.

Goals and Objectives

Projected Types and Quantities of Material to Be Recycled in the Future

The County developed an estimate of future recycling quantities based on estimated municipal solid waste generation and assuming a 44.6 percent recycling rate in 2007 with a 0.3 percent annual increase each year through 2036, as shown below in Table 7-1. We have identified this scenario as the "Base Case."

Table 7-1
Projected Quantities of Materials to be Recycled and Disposed of in King County through 2036 Based on Current Recycling Rate (Base Case)

Year	Projected MSW Generation (Tons)	Projected Recycling Rate(1)	Projected Tons Recycled	Projected Tons Disposed
2007	1,775,000	44.6%	769,700	1,005,000
2016	2,209,300	47.3%	1,044,999	1,164,301
2026	2,664,560	50.3%	1,340,274	1,324,286
2036	3,329,423	53.3%	1,774,583	1,554,841

Source: King County Solid Waste Division.

(1) Projected annual recycling rate, provided by the County, is assumed to be 44.6% in 2007 with an increase of 0.3% per year thereafter.

Using the projected quantities of tons recycled shown in Table 7-1 and applying the percentages of each commodity based on 2003 waste and recycling composition data, R. W. Beck developed a planning-level estimate of the quantities of each commodity which could be recycled for the period 2016 through 2036. These recycled material breakdowns for the Base Case are shown in Table 7-2. In developing the numbers shown in Table 7-2, we assumed each type of recycled material would increase at a rate of 0.3 percent per year.

Table 7-2
Projected Quantities of Material Recycled by Commodity in King County
2016 through 2036 (in Tons)
(Base Case)

	2016	2026	2036
Aluminum Cans	8,914	10,751	13,433
Tin Cans	6,459	10,127	15,574
OCC	204,925	247,153	308,822
High Grade Paper	30,741	38,400	49,637
Mixed Paper(1)	134,280	167,735	216,815
Newspaper	130,491	157,381	196,650
HDPE	5,699	8,019	11,451
PETE	6,375	8,970	12,810
LDPE	11,341	13,678	17,091
Other Plastic(2)	3,562	5,012	7,157
Container Glass	54,061	65,202	81,471
Food Waste(3)	86,970	140,001	218,804
Yard Waste	257,051	329,117	435,101
Wood Waste	8,218	19,823	37,153
Ferrous Metals	80,375	100,169	129,201
Nonferrous Metals	15,536	18,737	23,412
Total	1,044,999	1,340,274	1,774,583

OCC = old corrugated cardboard; HDPE = high density polyethylene; PETE = polyethylene terephthalate; LDPE = low density polyethylene

Note: The Base Case includes an assumed recycling rate increase of 0.3% per year for each material, with a beginning rate of 44.6% in 2007.

(1) Mixed paper includes bleached polycoat paper.
(2) Other plastic includes polystyrene foam
(3) Food waste includes compostable paper.

For the purpose of identifying the potential impact on the heating value of the MSW being delivered to a Conversion Facility under the Base Case, we have developed planning estimates of the quantities of all material that will be delivered to a disposal facility under the Base Case recycling scenario. The results of that comparison are presented in Table 7-3.

Table 7-3
Comparison of Material Being Delivered to a Conversion Facility
(Base Case)

	2003		2016		2036	
Type of Material	Quantity (Tons)	% of Total	Quantity (Tons)	% of Total	Quantity (Tons)	% of Total
Aluminum Cans	3,532	0.38%	2,228	0.19%	3,358	0.22%
Tin Cans	6,973	0.74%	6,459	0.55%	3,894	0.25%
Newspaper*	25,362	2.70%	32,623	2.80%	49,163	3.16%
OCC*	43,338	4.61%	51,231	4.40%	77,206	4.97%
Low Grade Paper*	58,606	6.23%	57,549	4.94%	72,272	4.65%
High Grade Paper*	15,277	1.63%	13,175	1.13%	16,546	1.06%
Compostable Paper*	52,054	5.54%	58,037	4.98%	71,063	4.57%
Other Paper*	23,815	2.53%	33,191	2.85%	50,018	3.22%
PETE*	5,981	0.64%	4,250	0.37%	3,203	0.21%
HDPE*	4,739	0.50%	3,799	0.33%	2,863	0.18%
LDPE*	47,027	5.00%	64,267	5.52%	96,851	6.23%
Other Plastic*	43,718	4.65%	59,938	5.15%	88,538	5.69%
Glass	28,304	3.01%	26,465	2.27%	39,884	2.57%
Yard Waste	47,127	5.01%	63,748	5.48%	48,345	3.11%
Food Waste	187,824	19.98%	217,381	18.67%	256,253	16.48%
Other Woody Organics*	85,279	9.07%	110,634	9.50%	141,957	9.13%
Textiles*	43,940	4.67%	61,238	5.26%	92,286	5.94%
Disposable Diapers	25,754	2.74%	35,893	3.08%	54,091	3.48%
Other Organics*	30,646	3.26%	42,711	3.67%	64,365	4.14%
Ferrous Metals	22,367	2.38%	26,792	2.30%	32,300	2.08%
Nonferrous Metals	690	0.07%	818	0.07%	1,232	0.08%
Other Metals	31,709	3.37%	44,192	3.80%	66,598	4.28%
C&D	47,309	5.03%	65,934	5.66%	99,362	6.39%
Furniture and Mattresses	25,572	2.72%	35,639	3.06%	53,708	3.45%
Other Waste	27,477	2.92%	38,294	3.29%	57,709	3.71%
HHW	5,607	0.60%	7,814	0.67%	11,776	0.76%
Total	940,027	100.00%	1,164,301	100%	1,554,840	100.00%

OCC = old corrugated cardboard; HDPE = high density polyethylene; PETE = polyethylene terephthalate; LDPE = low density polyethylene; C&D = construction and demolition debris; HHW = household hazardous waste

* Represents a component of the waste stream with high energy content.

Based on a review of the information in Table 7-3 and the quantities and percentages of combustible MSW assumed to be delivered to a Conversion Facility in 2016 and 2036, it appears that reaching the Base Case recycling goals would not have any significant impact on a Conversion Facility (assumed to be sized at 3,200 TPD, as discussed in Section 6) in terms of either sufficient waste supply or the heating value of the waste delivered to the facility. The data in Table 7-3 indicate that in 2016, more than 1,164,000 tons of waste are projected to be available to a Conversion Facility. In 2036 that number grows to approximately 1,555,000. Since the assumed 3,200 TPD Conversion Facility would process approximately 1,151,000 tons per year (considering the assumed facility availability), the supply projected to be available throughout the study period is more than adequate. In reviewing the assumed composition of the waste stream in 2036, we note that there are still significant quantities of the waste stream that are identified as having high energy content and what they represent as a percent of the waste stream has not been significantly reduced.

Based on this data, our opinion is that if the County reaches the Base Case recycling goals, this should not have any significant impact on the operation of a Conversion Facility of the size assumed in this report.

Increased Levels of Recycling

For comparative purposes, we developed two analyses which assumed the County increased its total level of recycling above the Base Case.

The 60 Percent Level

We developed an estimate of future recycling quantities based on the same estimated MSW generation as the Base Case and assuming that a 60 percent recycling rate would be achieved by 2036. The results of the 60 percent projections are shown in Table 7-4.

Table 7-4
Projected Quantities of Materials to be Recycled and Disposed of in King County through 2036 at a 60% Recycling Rate

Year	Projected MSW Generation (Tons)	Projected Recycling Rate	Projected Tons Recycled	Projected Tons Disposed
2007	1,775,000	44.6%	769,700	1,005,000
2016	2,209,300	47.3%	1,045,622	1,163,678
2026	2,664,560	53.7%	1,429,553	1,235,007
2036	3,329,423	60.0%	1,996,756	1,332,667

In order to increase the recycling rate from the Base Case amount of 53 percent to 60 percent by 2036, the County would have to recycle 60 percent of the projected waste generation of 3,329,423 tons (see Table 7-4), or approximately 1,996,756 tons in that year. This represents an increase of 222,173 tons above the 1,774,583 tons that would be required in 2036 in the Base Case.

Planning-level tonnage estimates were developed for each commodity which could be recycled for the period 2016 through 2036 at a 60 percent recycling rate. Estimates of the breakdown of recycled material are shown in Table 7-5.

Table 7-5
Projected Quantities of Material Recycled by Commodity in King County (in Tons)
2016 through 2036
(60% Recycling Rate)

	2016	2021	2026	2031	2036
Aluminum Cans	8,914	10,199	11,423	13,173	15,113
Tin Cans	6,459	8,600	10,906	13,963	17,521
OCC	204,925	235,891	265,689	308,024	355,146
High Grade Paper	30,741	36,544	42,373	50,435	59,564
Mixed Paper(1)	134,904	161,182	187,717	224,304	265,813
Newspaper	130,491	149,757	168,201	194,489	223,690
HDPE	5,699	7,113	8,591	10,587	12,882
PETE	6,375	7,958	9,611	11,844	14,411
LDPE	11,341	12,583	13,678	15,323	17,091
Other Plastic(2)	3,562	4,446	5,370	6,617	8,052
Container Glass	54,061	61,856	69,277	79,891	91,655
Food Waste(3)	86,970	126,649	170,451	227,671	294,899
Yard Waste	257,051	293,983	329,117	379,394	435,101
Wood Waste	8,218	14,436	21,474	30,534	41,281
Ferrous Metals	80,375	89,177	96,938	108,596	121,126
Nonferrous Metals	15,536	17,237	18,737	20,991	23,412
Total	1,045,622	1,237,612	1,429,553	1,695,835	1,996,756

OCC = old corrugated cardboard; HDPE = high density polyethylene; PETE = polyethylene terephthalate; LDPE = low density polyethylene

(1) Mixed paper includes bleached polycoat paper.
(2) Other plastic includes polystyrene foam.
(3) Food waste includes compostable paper.

The estimated quantities and types of materials that could be recycled at a 60 percent rate through 2036 are based on the following assumptions:

1. The County would work aggressively to increase the diversion rate of all the materials currently targeted for recycling. The percentages below refer to the amount recycled of the total quantities generated for each commodity.

- ONP (newspaper), OCC (corrugated cardboard), and mixed paper all reach a recycling rate of 90 percent or higher by 2036;
- Glass, metal, and plastic bottles (PETE and HDPE) all attain a 90 percent recycling rate by 2036;
- Bleached polycoat paper (aseptic containers such as milk and juice cartons) collected for recycling would dramatically increase. Fifteen percent of polycoat generated would be recycled by 2016 and by 2036, 90 percent would be recycled;
- Plastic containers (other than #1 and #2 bottles) attain a 30 percent recycling rate by 2016 and 45 percent by 2036;
- Plastic film and bags attain a 15 percent recycling rate by 2036;
- Yard waste recycling would reach 90 percent by 2036; and
- Food waste would attain a 25 percent recycling rate by 2016 and 55 percent by 2036.

2. The County would focus its efforts on recycling/diverting/composting additional organic materials such as dimensional lumber, stumps and large prunings beginning in 2016 and reaching a 50 percent recycling rate by 2036.
3. By 2036, 50 percent of the compostable paper generated would be diverted from disposal as part of the food waste recycling program.

For the purpose of identifying the potential impact on the heating value of the MSW being delivered to a Conversion Facility at a 60 percent recycling rate, we have developed planning estimates of the quantities of all material that will need to be sent to a disposal facility at a 60 percent recycling rate. The results of that comparison are shown in Table 7-6.

Table 7-6
Comparison of Material Being Delivered to a Conversion Facility
(60% Recycling Rate)

	2003		2016		2036	
Type of Material	Quantity (Tons)	% of Total	Quantity (Tons)	% of Total	Quantity (Tons)	% of Total
Aluminum Cans	3,532	0.38%	2,228	0.19%	1,679	0.13%
Tin Cans	6,973	0.74%	6,459	0.56%	1,947	0.15%
Newspaper*	25,362	2.70%	32,623	2.80%	22,123	1.66%
OCC*	43,338	4.61%	51,231	4.40%	30,882	2.32%
Low Grade Paper*	58,606	6.23%	57,549	4.95%	28,909	2.17%
High Grade Paper*	15,277	1.63%	13,175	1.13%	6,618	0.50%
Compostable Paper*	52,054	5.54%	58,037	4.99%	54,664	4.10%
Other Paper*	23,815	2.53%	32,567	2.80%	44,383	3.33%
PETE*	5,981	0.64%	4,250	0.37%	1,601	0.12%
HDPE*	4,739	0.50%	3,799	0.33%	1,431	0.11%
LDPE*	47,027	5.00%	64,267	5.52%	96,851	7.27%
Other Plastic*	43,718	4.65%	59,938	5.15%	87,644	6.58%
Glass	28,304	3.01%	26,465	2.27%	29,700	2.23%
Yard Waste	47,127	5.01%	63,748	5.48%	48,345	3.63%
Food Waste	187,824	19.98%	217,381	18.68%	196,556	14.75%
Other Woody Organics*	85,279	9.07%	110,634	9.51%	137,829	10.34%
Textiles*	43,940	4.67%	61,238	5.26%	92,286	6.92%
Disposable Diapers	25,754	2.74%	35,893	3.08%	54,091	4.06%
Other Organics*	30,646	3.26%	42,711	3.67%	64,365	4.83%
Ferrous Metals	22,367	2.38%	26,792	2.30%	40,375	3.03%
Nonferrous Metals	690	0.07%	818	0.07%	1,232	0.09%
Other Metals	31,709	3.37%	44,192	3.80%	66,598	5.00%
C&D	47,309	5.03%	65,934	5.67%	99,362	7.46%
Furniture and Mattresses	25,572	2.72%	35,639	3.06%	53,708	4.03%
Other Waste	27,477	2.92%	38,294	3.29%	57,709	4.33%
HHW	5,607	0.60%	7,814	0.67%	11,776	0.88%
Totals	940,027	100%	1,163,678	100.00%	1,332,667	100%

OCC = old corrugated cardboard; HDPE = high density polyethylene; PETE = polyethylene terephthalate;
LDPE = low density polyethylene; C&D = construction and demolition debris; HHW = household hazardous waste

* Represents a component of the waste stream with high energy content.

Based on a review of the information in Table 7-6 and the quantities and percentages of combustible MSW assumed to be delivered to a Conversion Facility in 2016 and 2036, it appears that reaching a 60 percent recycling level would not impact the quantity of waste required to operate a Conversion Facility sized at 3,200 TPD, as just under 1,164,000 tons are projected to be available in 2016 for a Conversion Facility assumed to process 1,051,000 tons per year. This tonnage also increases through the study period to approximately 1,330,000 tons in 2036. However, the amount of higher energy waste components assumed to be in the waste stream is reduced both in terms of total quantity as well as a percentage of the total waste stream. This is true for newspaper, old corrugated cardboard, low- and high-grade paper, compostable paper, and PETE and HDPE bottles. These seven materials are projected to represent approximately 19 percent of the total waste delivered to a Conversion Facility in 2016. By 2036, those components are projected to represent approximately 11 percent of the total waste delivered to a Conversion Facility. We also note, however, that the percentages of certain other high-energy components are projected to increase between 2016 and 2036. These components include other paper, LDPE, other plastic, other woody organics, textiles, and other organics. These materials are projected to represent approximately 32 percent of the incoming waste in 2016 and approximately 39 percent of the incoming waste in 2036.

Based on this data, our opinion is that the implementation of a 60 percent recycling level may have a relatively small effect on the heating value of the waste received at a Conversion Facility which, in turn, may have a relatively small effect on the amount of energy generated per ton of waste processed.

The 70 Percent Level

We undertook a similar analysis which assumed the recycling level increased from the Base Case to 70 percent by 2036. Projected quantities of materials recycled and disposed of based on a 70 percent recycling rate are shown in Table 7-7.

Table 7-7
Projected Quantities of Materials to be Recycled and Disposed of in King County through 2036 at a 70% Recycling Rate

Year	Projected MSW Generation (Tons)	Projected Recycling Rate	Projected Tons Recycled	Projected Tons Disposed
2007	1,775,000	44.6%	769,700	1,005,000
2016	2,209,300	52.0%	1,148,312	1,060,988
2026	2,664,560	61.0%	1,626,650	1,037,910
2036	3,329,423	70.1%	2,334,556	994,867

Planning level tonnage estimates per commodity at a 70 percent recycling rate are shown in Table 7-8.

Table 7-8
Projected Quantities of Material Recycled by Commodity in King County (in Tons)
2016 through 2036
(70% Recycling Rate)

	2016	2026	2036
Aluminum Cans	8,914	11,759	15,952
Tin Cans	7,751	12,074	18,494
OCC	215,171	276,502	366,726
High Grade Paper	32,937	45,021	62,873
Mixed Paper (1)	145,499	200,348	281,409
Newspaper	137,015	176,070	233,522
HDPE	6,649	9,450	13,598
PETE	7,438	10,572	15,212
LDPE	18,902	38,755	68,365
Other Plastic (2)	4,155	7,804	12,822
Container Glass	54,061	71,314	96,747
Food Waste (3)	132,633	243,881	409,590
Yard Waste	257,051	338,790	459,273
Wood Waste	13,696	33,038	61,922
Ferrous Metals	80,375	96,938	121,126
Nonferrous Metals	15,536	18,737	23,412
C&D (4)	1,012	3,663	7,628
Textiles (5)	3,062	11,079	23,072
Disposable Diapers	1,795	6,493	13,523
Furniture/Mattresses	1,782	6,447	13,427
Selected Other Wastes(6)	2,062	6,359	12,786
HHW (7)	537	1,556	3,078
Total	1,148,312	1,626,650	2,334,556

OCC = old corrugated cardboard; HDPE = high density polyethylene;
PETE = polyethylene terephthalate; LDPE = low density polyethylene;
C&D = construction and demolition debris; HHW = household hazardous waste

(1) Mixed paper includes gift wrapping paper and bleached polycoat paper.
(2) Other plastic includes polystyrene foam.
(3) Food waste includes compostable paper.
(4) C&D debris includes roofing and siding materials and gypsum wallboard.
(5) Textiles includes clothing, carpet, upholstery and other textiles.
(6) Selected Other Wastes includes small appliances, electronics, computer equipment, televisions, and cell phones.
(7) HHW includes used oil, household batteries, and latex and oil-based paint.

The estimated quantities and types of materials that could be recycled at a 70 percent rate through 2036 are based on the following assumptions, in addition to those listed for the 60 percent projections:

1. Gift wrapping paper would be added to the mixed paper category. By 2016, 30 percent would be recycled and by 2036, 95 percent of gift wrapping paper would be recycled.
2. Polystyrene foam would be accepted for recycling. Approximately 25 percent of polystyrene waste generated by 2036 would be recycled.
3. Plastic containers (other than #1 and #2 bottles) and plastic film and bags all attain a 60 percent recycling rate by 2036.
4. Yard waste recycling would reach 95 percent by 2036.
5. Food waste, including compostable paper, would attain a 75 percent recycling rate by 2036.
6. Additional construction and demolition (C&D) materials would be recycled, including 25 percent of all roofing and siding materials and gypsum wallboard by 2036.
7. Recycling opportunities would be available to divert approximately 25 percent of all textiles (including carpet and upholstery), disposable diapers, furniture and mattresses generated.
8. Increased efforts would be made to divert or recycle approximately 95 percent of selected other wastes (small appliances, electronics, and computer equipment) and household hazardous waste.

For the purpose of identifying the potential impact on the heating value of the MSW delivered to a Conversion Facility at a 70 percent recycling rate, we have developed planning estimates of the quantities of all material that will be delivered to a disposal facility at a 70 percent recycling rate. The results of that comparison are shown in Table 7-9.

Table 7-9
Comparison of Material Being Delivered to a Conversion Facility
(70% Recycling Rate)

Type of Material	2003 Quantity (Tons)	2003 % of Total	2016 Quantity (Tons)	2016 % of Total	2036 Quantity (Tons)	2036 % of Total
Aluminum Cans	3,532	0.38%	2,228	0.21%	840	0.08%
Tin Cans	6,973	0.74%	5,167	0.49%	973	0.10%
Newspaper*	25,362	2.70%	26,098	2.46%	12,291	1.24%
OCC*	43,338	4.61%	40,985	3.86%	19,301	1.94%
Low Grade Paper*	58,606	6.23%	47,957	4.52%	14,454	1.45%
High Grade Paper*	15,277	1.63%	10,979	1.03%	3,309	0.33%
Compostable Paper*	52,054	5.54%	47,155	4.44%	27,332	2.75%
Other Paper*	23,815	2.53%	31,563	2.97%	43,242	4.35%
PETE*	5,981	0.64%	3,188	0.30%	801	0.08%
HDPE*	4,739	0.50%	2,849	0.27%	716	0.07%
LDPE*	47,027	5.00%	56,706	5.34%	45,577	4.58%
Other Plastic*	43,718	4.65%	59,068	5.57%	82,873	8.33%
Glass	28,304	3.01%	26,465	2.49%	24,608	2.47%
Yard Waste	47,127	5.01%	63,748	6.01%	24,172	2.43%
Food Waste	187,824	19.98%	182,600	17.21%	109,198	10.98%
Other Woody Organics*	85,279	9.07%	104,734	9.87%	114,014	11.46%
Textiles	43,940	4.67%	58,176	5.48%	69,215	6.96%
Disposable Diapers	25,754	2.74%	34,098	3.21%	40,568	4.08%
Other Organics*	30,646	3.26%	42,711	4.03%	64,365	6.47%
Ferrous Metals	22,367	2.38%	26,792	2.53%	40,375	4.06%
Nonferrous Metals	690	0.07%	818	0.08%	1,232	0.12%
Other Metals	31,709	3.37%	44,192	4.17%	66,598	6.69%
C&D	47,309	5.03%	65,343	6.16%	94,908	9.54%
Furniture and Mattresses	25,572	2.72%	33,857	3.19%	40,281	4.05%
Other Waste	27,477	2.92%	36,948	3.48%	49,021	4.93%
HHW	5,607	0.60%	6,561	0.62%	4,601	0.46%
Total:	940,027	100%	1,060,988	100%	994,867	100%

OCC = old corrugated cardboard; HDPE = high density polyethylene; PETE = polyethylene terephthalate; LDPE = low density polyethylene; C&D = construction and demolition debris; HHW = household hazardous waste

* Represents a component of the waste stream with high energy content.

Based on a review of the information in Table 7-9 and the quantities and percentages of combustible MSW assumed to be delivered to a Conversion Facility in 2016 and 2036, it appears that reaching a 70 percent recycling level would impact both the quantity and heating value of waste required to efficiently operate a Conversion Facility sized at 3,200 TPD. The total quantity of waste assumed to require disposal in 2016 is approximately 1,061,000 tons, but by 2036 this number decreases to approximately 995,000 tons. This is somewhat less than the assumed annual processing capacity of 1,051,000 tons. The following high-energy waste components are forecast to decrease between 2016 and 2036: newspaper, old corrugated cardboard, low-grade paper, high-grade paper, compostable paper, PETE, HDPE, and LDPE. These materials are forecast to decrease from approximately 22 percent of the waste stream requiring disposal in 2016 to approximately 12 percent in 2036.

Based on this data, we believe the implementation of the 70 percent recycling level would have an impact on the heating value of the waste received at a Conversion Facility. This would affect decisions related to the size and operation of a Conversion Facility.

Recycling by Conversion Facilities

The following discussion provides background information on existing practices and potential opportunities to recover material from the three selected Conversion Technologies. Conversion Facilities recover some recyclables on the tipping floor or storage pit. In the waste receiving areas at Conversion Facilities, operators remove non-processable, bulky metal items (e.g., white goods, etc.) that are then recycled. Section 8 identifies materials in the County's MSW that the three selected Conversion Technologies cannot process. Section 10 reviews beneficial reuse potential in the state of Washington.

Mass Burn Waste-To-Energy Waterwall

Mass burn waste-to-energy facilities generally practice post-combustion materials recovery. In the United States, mass burn facilities combine the quenched bottom ash from the furnace-boiler and the fly ash from the upper boiler and economizer hoppers and the air emissions control system. Post-combustion material recovery consists of metals removal from the resulting residue. Possible processing steps include screening with a grizzly scalper, multiple stages of magnetic separation, and an eddy current separator for aluminum. The grizzly scalper separates the oversized bulky ferrous metal. The undersized ferrous metal and combustion residue fall for further processing. Metal recovery rates of over 80 percent are achievable. The recovered ferrous metal is entrained with ash and is highly oxidized, which reduces its market value. In the United States, beneficial reuse of the remaining combustion residue as alternative daily cover is widely practiced at MSW landfills.

Covanta Energy Corporation's Fairfax County Resource Recovery Facility in Virginia, Covanta's Niagara Falls Resource Recovery Facility in New York, and Wheelabrator Technologies' Pinellas Resource Recovery Facility in Florida all use eddy current separators and other methods to remove and recover nonferrous metals from post-combustion residue.

As described in Appendix B, the Spokane mass burn facility utilizes ferrous metal recovery from the residue ash and white goods recovery from the receiving floor to increase materials recovery. To the extent that a King County Conversion Facility would use similar methods, there is a potential for the County's overall recycling rate to be increased by an additional 3 to 4 percent.

RDF Waste-To-Energy

Front-end RDF processing generally results in converting 90 percent of the solid waste to a combustible fuel. The remaining 10 percent typically consists of recovered materials and process residue. Ferrous and nonferrous metals are recovered on the front-end using several processing steps which can include size reduction with shredders, screening with trommels, multiple stages of magnetic separation, and an eddy current separator for aluminum. Metal recovery rates of over 80 percent are achievable, but the recovered ferrous metal, which is contaminated with RDF products, has a lower market value than clean ferrous metal. To increase the RDF process yield and because of the minimal market value of mixed glass cullet, several RDF processing facilities in the United States have sealed the first-stage holes in the trommel screens.

The Southeastern Public Service Authority of Virginia's RDF Plant and Covanta's SEMASS Resource Recovery Facility in Massachusetts recover ferrous metal in the combined combustion residue. Based on the experiences at these facilities, it is clear that high recovery rates of metals in the combustion residue are achievable. In addition, beneficial reuse of the remaining combustion residue as alternative daily cover is practiced at many MSW landfills in the United States.

Advanced Thermal Recycling

Two advanced thermal recycling facilities, MVB and MVR, operate in Hamburg, Germany. Unlike waste-to-energy facilities in the United States, the bottom ash and fly ash streams are kept separate at the German facilities. This separation facilitates the beneficial use of the combustion residue. The bottom ash is used as construction fill in the port area of Hamburg. The fly ash is stabilized with cement and used to reclaim abandoned salt mines.

The bottom ash collects in a water bath at the bottom of the furnace-boiler units. After discharging from the removal system, the bottom ash is sieved and crushed followed by magnets and eddy current separators to remove ferrous and nonferrous metals. Riddlings (grate siftings), and floating and suspended solids are returned to the waste storage pit and mixed with the incoming waste. Soluble salts left in the wash water are pumped to the process water treatment system for cleaning and reuse. The washed, processed bottom ash is then conveyed to the storage area. Following removal and washing, the bottom ash is crushed, screened, and conveyed to the storage area.

Fly ash, which is collected from the boiler and economizer hoppers and the two baghouses, represents about 3 percent by weight of the waste feedstock. In the air emission control system, the first baghouse is followed by a two-stage wet scrubber.

The flue gases first enter the hydrochloric acid (HCl) wet scrubber, which uses water to remove highly soluble, HCl from the flue gas stream. A 10 to 12 percent HCl solution is formed in the recirculating stream. The HCl scrubber blowdown is further treated in the HCl rectification system, which cleans and concentrates the HCl to a 30 percent solution for sale in the water treatment industry. The HCl recovery rate is typically 1.3 percent by weight of the waste feedstock.

The flue gases then enter the sulfur dioxide (SO_2) scrubber, which uses lime to react with and remove SO_2 from the flue gas. The reaction of lime and SO_2 with the oxygen in the process forms calcium sulfate, or gypsum. The gypsum is washed and dewatered in a centrifuge to meet a specified solids content (<10 percent) for sale to the cement and wallboard industries. The gypsum recovery rate is typically 0.3 percent by weight of the waste feedstock.

These treatment processes result in materials that are recoverable as a marketable byproduct: stabilized bottom ash, HCl, and gypsum. While these processes occur after combustion of the waste, they are often considered another form of recycling and will decrease the amount of waste or ash requiring disposal in a landfill.

Compatibility of Conversion Technologies and Recycling

In 2002 the Integrated Waste Services Association (IWSA), a waste-to-energy industry trade association, conducted a nationwide survey to re-examine whether recycling and WTE were compatible. An initial study by IWSA in 1992 had demonstrated that recycling and WTE support one another in many ways. The findings of the 2002 survey findings include:[2]

- 100 percent of WTE plants are linked to off-site recycling programs;
- 82 percent of WTE facilities have on-site recycling (e.g., metals, ash reuse, other);
- 57 percent of WTE communities have higher recycling rates than the national rate (at the time of the study) of 28%. The average recycling rate for WTE communities across the United States was 33%; and
- 100 percent of respondents surveyed provided evidence supporting WTE and recycling compatibility.

It should be noted that as a trade association of conversion technology vendors, IWSA may be motivated to demonstrate the compatibility of recycling and conversion technologies.

[2] Jonathan V.L. Kiser, "Recycling and Waste-to-Energy: The Ongoing Compatibility Success Story," *MSW Management,* May/June 2003.

Impact of Recycling on Conversion Facilities

Our review indicates that the County's stated intention to increase the level of recycling from 44 to 60 percent would influence a Conversion Facility in one of three ways:

1. **Size.** How much disposal capacity should the Conversion Facility(ies) be designed to accommodate?
2. **Timing.** When should the County plan to have additional processing units of a Conversion Facility constructed to meet future increases in the quantity of solid waste generated?
3. **Energy Generation.** Depending upon the types of recyclable materials the County focuses on, the impact on a Conversion Facility's ability to generate power could be positive, negative, or neutral.

Presented below is a discussion of the interrelationship between changes in the County's recycling program and the development of a Conversion Facility.

Required Disposal Capacity

As discussed in Section 6, one of the most important considerations if the County were to proceed with a Conversion Facility would be how large the Conversion Facility should be and how many Conversion Facilities should be constructed. The capacity and number of the Conversion Facilities will be directly impacted by the assumed level of recycling in the future.

To illustrate the beneficial impact of recycling, if each year the County continued to recycle only 44.6 percent of the solid waste generated in the County, we estimate that in 2016 it would need a Conversion Facility sized at approximately 3,700 TPD to dispose of the 1,224,000 tons of waste requiring disposal (from Table 7-1, 2,209,300 tons multiplied by 55.4%) instead of the 3,200 TPD facility assumed under the Base Case recycling scenario, which assumes the level of recycling has increased from 44.6 percent in 2007 to 47.3 percent in 2016.

Similarly, by 2036, with no increase in the current level of recycling of 44.6 percent, we estimate the County would require Conversion Facility disposal capacity sized at approximately 5,600 TPD, assuming 90 percent annual availability. Under the Base Case scenario, we estimate that in 2036, the County will require approximately 4,700 TPD of disposal capacity, a difference of 900 TPD of disposal capacity that would have been required if the current recycling level of 44.6 percent was not increased to 53.3 percent.

If one were to assume that the capital cost of a Conversion Facility was approximately $175,000 per ton in 2007 dollars, reducing the amount of required disposal capacity by 900 TPD would save the County approximately $158,000,000 in capital costs, expressed in 2007 dollars.

If in the future the County determines to proceed with the development of a Conversion Facility, it will be critical for the County to identify what represents an attainable recycling level by 2016.

Need for Additional Disposal Capacity

As the amount of waste generated in the County increases in the future, and if the County were to proceed with a Conversion Facility, it is likely that the County will require the installation of additional disposal capacity after 2016. How much additional disposal capacity will be required will be influenced by the amount of waste the County is able to recycle. The initial design of a Conversion Facility should include consideration of the construction of additional processing lines in the future and should also consider the likelihood of attaining increased levels of recycling. This will require careful consideration by the County in terms of having the necessary disposal capacity on a timely basis but not installing it so early that the County has tens of millions of dollars invested in equipment that is being operated at a low, inefficient rate. The County could expect to realize economies of scale by adding additional processing lines that are similar in size to the existing lines.

Impact on Ability to Generate Energy

Just as the size of a Conversion Facility will be impacted by the level of recycling achieved in the County, so will the amount of energy a Conversion Facility can generate. The impact may be positive, negative, or neutral. For illustrative purposes, presented below is a discussion of different ways that energy production could be impacted under various approaches to recycling that differ from the Base Case discussed previously.

A review of the data in Table A-1 in Appendix A indicates that a significant portion of the material reported to have been recycled in the County would not be good sources of feedstock for the recommended Conversion Technologies. Table 7-10 presents a summary of those materials, in 2004 tons, that are not ideal types of feedstock at a Conversion Facility.

Table 7-10
Recycled Material Which are Not a Good Source of Feedstock for the Recommended Conversion Technologies

Material	Tons (2004)	% of Total for 2004
Aluminum cans	3,534	0.52
Tin cans	2,857	0.42
Container glass	24,503	3.59
Food waste	32,900	4.83
Yard waste	222,701	32.67
Ferrous metals	53,979	7.92
Non-ferrous metals	16,733	2.45
Mixed tin, alum., plastic, glass from County transfer station drop-off sites	1,325	0.19
Total	358,532	52.59%

Note: Values from Appendix A, Table A-1.

The information in Table 7-10 indicates that approximately 53 percent of the material that the County recycled in 2004 would not be a good feedstock for the recommended Conversion Technologies.

We have developed estimates of the quantities of the same recyclable material shown in Table 7-10 through 2036 at 60 and 70 percent recycling rates. The results of this analysis are provided in Table 7-11.

Table 7-11
Recycled Material Which are Not a Good Source of Feedstock for the Recommended Conversion Technologies

Material	Tons at 60% (2036)	% of Total at 60%	Tons at 70% (2036)	% of Total at 70%
Aluminum cans	15,113	0.76%	15,952	0.68%
Tin cans	17,521	0.88%	18,494	0.79%
Container glass	91,655	4.59%	96,747	4.14%
Food waste	294,899	14.77%	409,590	17.54%
Yard waste	435,101	21.79%	459,273	19.67%
Ferrous metals	121,126	6.07%	121,126	5.19%
Non-ferrous metals	23,412	1.17%	23,412	1.00%
Total	998,827	50.02%	1,144,594	49.03%

Note: Values from Tables 7-5 and 7-8.

To the extent that the County could increase the amount and types of recycled material, as shown in Table 7-11, the energy conversion capability of the Conversion Technologies could actually be improved.

If the County were to implement the Base Case recycling level by 2036, there are three potential impacts on the ability of the Conversion Facility to produce energy. The potential impact will depend on the types and quantities of recyclable materials the County determines it wants to increase. The potential impacts are as follows:

1. **Improved energy generation capability**. The energy generation capability of the Conversion Facility could improve if the County were to focus its increased recycling efforts on the following types of materials that were disposed of at the Cedar Hills landfill in 2003:

Material	Quantity Disposed of at Cedar Hills Landfill in 2003 (thousands of tons)
Food waste	187
Yard waste	47
Construction and demolition	39
Metals	65
Glass	28
Total	366

   Most of these materials have limited thermal energy (glass, metals, food waste), can represent potential air emissions challenges (yard waste), or can be difficult to handle (construction and demolition debris). The removal of those materials from the waste stream would likely have a beneficial impact on the thermal production capability of a Conversion Facility.

2. **Decreased energy generation capability**. The energy generation capability of the Conversion Facility could decrease if the County were to focus its increased recycling efforts on the following types of materials that were disposed of at the Cedar Hills landfill in 2003:

Material	Quantity Disposed of at Cedar Hills Landfill in 2003 (Thousands of Tons)
Low grade recyclable paper	58
Compostable paper	52
Plastics	101
Newspaper	25
OCC	43
Total	279

These materials have significant energy content and their removal from the waste stream could decrease the amount of energy a Conversion Facility could generate.

3. **No net effect**. There could be no net effect on the generating capability of a Conversion Facility if the County were to focus its increased recycling efforts on an even distribution of the recyclable materials along the line of what was presented in the previous two tables. For example, if the County removed some combination of glass, metals, yard waste, food waste, lumber and OCC, there may be a trade-off between the loss of heat content in OCC and the removal of glass and metal that have little heating value.

Summary

It is clear that future changes in the level of recycling in the County could have a significant impact on the development of a Conversion Facility. This is particularly true in determining the amount of disposal capacity to be installed and the frequency with which new disposal lines should be added.

Our review of the estimated quantity and composition of the solid waste assumed to be delivered to a Conversion Facility under the Base Case scenario indicates that this assumed level of recycling should not have a significant impact on the energy generating capability of a Conversion Facility and there should be a more than sufficient quantity of waste. It should be anticipated that the net energy generation of the facility (expressed as KWh/ton of waste processed) will decrease as the level of recycling increases to 70 percent.

The data we developed for a 60 percent recycling level indicates that throughout the 20-year study period there will still be a more than sufficient supply of solid waste but that there may be a small decrease in the amount of energy generated per ton of waste processed.

At a 70 percent recycling level, the data indicates that by 2036, a small shortfall of solid waste is forecast and the heating value of the solid waste will somewhat reduce the net energy generation.

The level of future recycling is a critical policy decision that the County must address as it proceeds to evaluate its waste disposal options. By achieving the Base Case recycling goal, the County could potentially save hundreds of millions of dollars in construction costs by constructing a smaller Conversion Facility. However, if the County proceeds with the construction of a smaller Conversion Facility and fails to achieve its recycling goals, it could be faced with a significant shortfall in disposal capacity.

The County must set recycling goals it realistically believes it can achieve and must dedicate the time, effort and money required to meet these goals.

Section 8
BACKUP DISPOSAL CAPACITY FOR CONVERSION FACILITIES

Section 8
BACKUP DISPOSAL CAPACITY FOR CONVERSION FACILITIES

For the purposes of this section of the report, the term "Backup Disposal Capacity" refers to the method(s) the County must have in place to meet its total disposal needs in the event that the primary disposal method(s) are not available either in total or in part. Backup Disposal Capacity is a key consideration regardless of which method of disposal the County selects. However, the employment of the Conversion Technology Disposal Option would require the County to consider certain aspects that would not be associated with the Waste Export Option and are beyond those outlined in the County's Waste Export Plan.

Need for Backup Disposal Capacity

The County may require Backup Disposal Capacity for several reasons, including:

- The required disposal of non-processible and unacceptable wastes;
- Scheduled and unscheduled maintenance of Conversion Facility(ies);
- A natural disaster or a force majeure event that affects either the primary disposal method or ancillary systems such as the long-haul system;
- Lack of market or use for residual waste;
- Unexpected increase in waste generation or change in composition; or
- Increase in waste generation before additional processing lines have been added to the Conversion Facility.

To a certain extent, the need for Backup Disposal Capacity may be able to be reduced through appropriate and considered design and operation of the transfer stations in conjunction with the Conversion Facility as well as the potential use and recovery of non-processible waste and beneficial use of residuals. Even if these efforts are successful, they will not eliminate the need for a plan for Backup Disposal Capacity in the event currently unexpected problems are encountered.

Backup Disposal Capacity Options

Presented below is a discussion of options that may be available to the County as ways to approach the need for Backup Disposal Capacity.

Conversion Technology Redundancy

If the County were to build redundancy into its Conversion Technology system, the amount of Backup Disposal Capacity required could be reduced. This redundancy could come in two ways, each of which provides different benefits related to backup disposal requirements. First, the County could choose to build multiple processing trains at the Conversion Facility. As discussed in Section 6, this would provide some flexibility during scheduled and unscheduled outages. This method could lose some economies of scale as a result of using smaller processing trains, but if the size of the trains stays above a specific threshold, the impact of this increased cost can be reduced. The second method the County could use to build in redundancy would be to locate these multiple processing trains on multiple sites, effectively building two or more different Conversion Facilities. This option takes advantage of the flexibility of multiple processing trains and also insulates the County from risks that could impact one Conversion Facility while leaving the other Conversion Facilities unaffected. While these two options address the County's need for backup due to scheduled and unscheduled outages as well as logistical problems, they may not sufficiently address backup needs as a result of unforeseen waste generation increases or less-than-expected recycling and reuse quantities.

To address these issues, the County could incorporate excess capacity into the Conversion Facilities. Excess design capacity could be provided from the outset either as larger-sized processing trains, or as additional processing trains beyond the number initially required to handle the expected waste quantities. While this method of sizing can accommodate, among other things, an unexpected growth in the waste stream, increased waste tonnages resulting from a catastrophic event, or less than planned recycling or reuse, it is often not a cost effective way of providing Backup Disposal Capacity based on the high capital cost of Conversion Facilities.

In-County Disposal

Currently, the County expects the Cedar Hills Regional Landfill to have permitted capacity for County waste at least until 2016. With the implementation of more aggressive recycling programs and the construction of Conversion Facilities that could be operational prior to 2016, the amount of waste requiring landfilling would decrease significantly, potentially extending the life of Cedar Hills even further. The County could also elect to develop one or more additional cells at Cedar Hills, thereby increasing the available volume for future backup disposal needs. Finally, if the County were to employ early waste export as outlined in the current Waste Export Plan, the life of the Cedar Hills landfill could be further extended. By using these methods to preserve the airspace at Cedar Hills, the landfill could provide the County with backup disposal that could be utilized for any scenario where backup disposal may be necessary. By keeping an in-county backup disposal facility, the County would be able to maintain stronger control of its waste management responsibilities as well as avoid the cost and energy required of long-hauling waste. Since the amount of waste requiring disposal, either as normal bypass waste or as unprocessed waste when the Conversion Facilities are not in service, would be significantly less than is currently disposed of at Cedar Hills, the operation requirements at Cedar Hills would also be significantly reduced. This would likely save the County landfill operation costs but would also sacrifice some economies of scale it currently realizes at the Cedar Hills landfill.

Long-Haul to Regional Landfill

A third backup disposal option available to the County is long-haul to a regional landfill. The three typical methods of long-haul are rail, truck, and barge, with rail being the current method of choice in the northwestern United States. Long-haul and disposal would likely be contracted services. Ownership and operation of an intermodal facility (truck-to-rail or possibly truck-to-barge) would likely depend on the quantity of waste material handled. In our opinion, given the likely amount of normal bypass waste and backup disposal waste, the County should give serious consideration to contracting out intermodal service. In addition, the County would need to make arrangements for the use or disposal of residue ash from the Conversion Facility, as discussed in Section 9. In the event the County is not able to get permission from regulators to utilize a more beneficial use for such residue ash and it must be landfilled, the County may find it helpful to combine the arrangements for the long-haul and disposal of both residue ash and any solid waste which cannot be processed by the Conversion Facility. The advantage of long-hauling waste to a regional landfill is that the County would no longer have to operate the Cedar Hills landfill to handle a much smaller amount of waste. Also, much, but probably not all, of the permitting and environmental risks of disposing of the waste would be delegated to the operator of the regional facility. It is not clear whether this option would cost more or less than the in-county backup disposal option, as the actual final costs would depend on the amount of waste that requires disposal, the terms of the contract, and the type of material being disposed of.

For comparison, the Spokane Regional Waste-to-Energy Facility utilizes long-hauling via rail to a regional landfill in central Washington for both the disposal of its bypassed waste and the disposal of its residue ash. The Spokane System[1] pays tipping fees of $45.49 per ton for its ash residue ($22.26 of this cost is due to transportation). It also pays $47.83 per ton for disposal of up to 10,000 tons of bypassed waste and $45.44 per ton above 10,000 tons.

Backup Disposal at Other Conversion Facilities

In order to help inform the County's consideration of backup disposal options, Table 8-1 provides the backup disposal methods selected by other owners of Conversion Facilities.

[1] As discussed in Section 6, the Spokane Regional Solid Waste System ("Spokane System") includes Spokane County, the City of Spokane, 12 other cities and towns, and Fairchild Air Force Base.

Table 8-1
Methods of Backup Disposal at Existing Conversion Facilities

		Material Requiring Backup Disposal	
Facility	Conversion Technology	MSW Stream(1)	Residue Ash(2)
Marion County, OR	Mass Burn	Trucked to Private Landfill	Trucked to County Monofill
Spokane, WA	Mass Burn	Rail to Private Landfill	Rail to Private Landfill (Monofill)
Stanislaus, CA	Mass Burn	Trucked to Landfill	Trucked to Landfill (Monofill)
Kent County, MI	Mass Burn	Trucked to County Landfill	Trucked to County Landfill (Monofill)
Lancaster County, PA	Mass Burn	Trucked to Landfill	Trucked to Landfill (Daily Cover)
Baltimore, MD	Mass Burn	Trucked to Landfill	Trucked to Landfill (Monofill)
Detroit, MI	RDF	Trucked to Landfill	Trucked to Landfill (Monofill)
Hartford, CT	RDF	Trucked to Landfill	Trucked to Landfill (Monofill)
Norfolk, VA	RDF	Trucked to Landfill	Trucked to Landfill (Daily Cover)
SEMASS, MA	RDF	Trucked to Landfill	Trucked to Landfill (Monofill)
Hamburg, Germany (MVR)	Advanced Thermal Recycling	Diverted to other Conversion Facilities	Used as Base for Adjacent Port
Hamburg, Germany (MVB)	Advanced Thermal Recycling	Diverted to other Conversion Facilities	Used as Base for Adjacent Port

(1) When the Conversion Facility is not available.
(2) When residue disposal or recovery system is not available.

Conclusions

Backup Disposal Capacity would be necessary if the primary disposal method for County waste were a Conversion Facility. There are three principal backup disposal options for Conversion Facilities in this region: waste export to a regional landfill; in-county landfilling at the County's Cedar Hills landfill where options exist to extend the capacity and life of the landfill; and, to a lesser degree, construction of excess capacity at the Conversion Facility(ies).

As discussed in Section 6, R. W. Beck believes that if the County decides to proceed with a Conversion Facility, the County should employ multiple processing trains to take advantage of operating and scheduling flexibilities. Nevertheless, the siting of oversized or multiple facilities, even when considering the backup disposal advantages, may not be the County's most cost effective alternative. Furthermore, based on the information presented in this section and in other sections of this report, in our opinion the County should consider the advantages of preserving airspace at the Cedar Hills landfill as one way of providing Backup Disposal Capacity. If the County decides at some point to develop the Conversion Technology Disposal Option, it is likely that the choice for backup disposal will be between long-hauling to a regional landfill, continued landfilling at the Cedar Hills landfill, or a combination of the two.

Section 9
RESIDUE ASH MANAGEMENT

Section 9
RESIDUE ASH MANAGEMENT

It is important to understand that the three Conversion Technologies under review will generate residue ash that, under current State of Washington regulations, must be landfilled. The Conversion Technologies should be capable of reducing the *volume* of the incoming solid waste by up to 90 percent as outlined in Table 3-1. However, the *weight* of the residue ash can be expected to be approximately 20 to 25 percent of the incoming waste. The Conversion Technologies can save airspace in landfills, but they do not eliminate the need for proper disposal and/or beneficial use of the residue.

The composition and classification of residue ash from Conversion Facilities is important to the County because these aspects impact the manner in which it must be disposed of, which in turn will impact the County's overall cost of solid waste management and its flexibility in disposal of residue ash.

As part of the review of the potential for the beneficial uses and/or disposal of residue ash at Conversion Facilities in King County, R. W. Beck relied both upon our experience in the industry and on information provided by the Washington State Department of Ecology (DOE). We discussed the residue ash disposal matter with DOE as well as the operators of existing Conversion Facilities. The purpose of these discussions was to gain an understanding of the issues that are most important to state regulators regarding the composition, recovery and disposal of residue ash generated by Conversion Facilities. We also reviewed available reports and studies from other Conversion Facilities.

This section of the report presents a discussion of the following key issues regarding residue ash from Conversion Facilities, specifically:

- The existing regulatory framework for residue ash in Washington State;
- Factors that impact residue ash management;
- Potential uses for residue ash;
- Potential markets for residue ash;
- Disposal of residue ash; and
- Likelihood that residue ash from a Conversion Facility could receive a beneficial use designation.

Existing Regulatory Framework for Residue Ash in Washington

The state's regulations address residue ash from Conversion Facilities as "Special Incinerator Ash." Under chapter 70.138.020 Revised Code of Washington (RCW), "Special Incinerator Ash" means residues resulting from the operation of incinerators or energy recovery facilities managing municipal solid waste, including solid waste from residential, commercial, and industrial establishments, if the residues (a) would otherwise be regulated as hazardous wastes under chapter 70.105 RCW; and (b) are not regulated as a hazardous waste under the federal Resource Conservation and Recovery Act, 42 U.S.C. Sec. 6901 et seq. The procedures for determining whether a residue ash is a hazardous waste, as defined in chapter 70.105 RCW, are contained in Washington Administrative Code (WAC) 173-303.

Applicable Designation Tests

The specific procedures required in the state of Washington to determine whether a residue ash or a solid waste is a dangerous waste are contained in paragraph (3) of WAC 173-303-070. These procedures, briefly described in the following paragraphs, would be applied to the residue ash expected to result from a Conversion Facility in King County.

First, the residue ash is not a discarded chemical product according to the criteria outlined in WAC 173-303-081.

Second, since the Conversion Facility is not a listed dangerous waste source and would not knowingly accept any hazardous waste, the residue ash is not from a listed dangerous waste source as described in WAC 173-303-082.

Third, the residue ash would be evaluated to see if it exhibited any of the dangerous waste characteristics identified under WAC 173-303-090. These characteristics include ignitability, corrosivity, reactivity, and toxicity. Residue ash is neither ignitable nor reactive. For purposes of determining corrosivity and toxicity, quarterly tests results would be performed on the residue ash from the Conversion Facility for several years. The analytical data are obtained using the Toxicity Characteristic Leaching Procedure (TCLP) and the pH of a solid method.

Finally, to determine if the residue ash would meet any dangerous waste criteria, either static acute fish toxicity tests or acute oral rat toxicity tests would be performed pursuant to WAC 173-303-110, using representative samples of the residue ash from the Conversion Facility. Fish toxicity test are typically applied, since they are shorter in duration, less costly, and more representative of the species most likely to be affected. The test is intended to determine whether any of the samples would be designated as either dangerous waste or extremely hazardous waste.

Also, to determine if the residue ash is a persistent dangerous waste pursuant to WAC 173-303-100, the polycyclic aromatic hydrocarbons (PAH) content of the residue ash would be determined by testing a single composite sample representing multiple quarterly samples of residue, in accordance with WAC 173-303-110.

Changes in Applicable Designation Tests

We discussed with representatives of DOE whether there are any anticipated changes in its current applicable designation tests. We were informed that DOE does not currently have any plans to modify any of the aforementioned testing requirements because DOE believes the existing tests are suitable for determining whether residue ash from Conversion Facilities represents a potential hazard to the environment.

Factors that Impact Residue Ash Management

Composition of Incoming Waste

The actual composition of residue ash is determined not so much by the manner in which it is processed by any technology, but rather by what is disposed of by the residents and businesses generating the solid waste that is received by solid waste disposal facilities. If it were possible to prevent such items as mercury-based thermometers, household cleaners, lead automobile batteries, and fluorescent light bulbs from being thrown out with other solid waste, the composition of residue ash would not be as problematic as it is. Unfortunately it is extremely unlikely that such items, as well as many others, will disappear from the waste stream. For planning purposes, it should be anticipated that the household hazardous waste item that is currently being disposed of in the wastebasket in someone’s kitchen may continue to find its way into the residue ash of a Conversion Facility.

Heavy metals such as mercury and lead are examples of contaminants that can have a significant impact on the composition of residue ash. In addition to being present in residual waste, heavy metals could also be introduced into the waste stream by various commercial and industrial enterprises. While the volume of the incoming waste is typically reduced by 90 percent by the Conversion Facility, the amount of heavy metals is not similarly reduced and contaminant levels in residue ash can become more concentrated. As discussed in the previous section, the actual level of such material in the residue ash will determine if the residue ash will be classified as a hazardous material by a regulatory agency. Significant progress has been made in recent years in: 1) reducing the amount of hazardous material used in the manufacture of goods; 2) educating the public about the problems with these items; 3) removing the materials from the waste stream by implementing household hazardous waste collection programs; and 4) treating residue ash prior to placement in a landfill to convert heavy metals to non-soluble forms. In spite of these improvements, it will be critical to continue monitoring the composition of residue ash.

Mercury is an example of a contaminant that remains a challenge. Our discussions with DOE representatives indicated that mercury is still a significant issue for the Spokane Conversion Facility, since mercury continues to be used in the manufacture of certain common items including batteries, switches, fluorescent lights, and toys.

While the state of Washington has recently passed legislation (Engrossed Substitute House Bill 1002) banning mercury from selected consumer products, including mercury-added novelty items, manometers, and thermometers, the ban's effect remains to be seen. If this ban and other management activities, especially recycling of fluorescent lamps and thermostats, are effectively implemented and enforced by the time a Conversion Facility would be operating in King County, the amount of mercury in the incoming waste stream could be reduced. This would result in decreases in the amount of mercury in the residue ash.

In addition to heavy metals, certain chemicals such as sulfur, chlorine, iodine, and bromine can also affect the composition of the residue ash and air emissions compositions if such chemicals are a part of the incoming waste stream. In addition to being present in certain household items, these chemicals can also be introduced into the waste stream as a part of construction waste and industrial chemicals (drywall, pool cleaning, etc.).

One approach for reducing the amount of certain contaminants that cannot be eliminated from consumer products, like mercury and sulfur, from entering the waste stream is through continuing education and diversion programs. The focus of such programs is to inform the public that these types of materials should never reach either the Conversion Facility or a landfill and residents should remove them from the waste stream as part of a household hazardous waste program. Education on topics such as the proper disposal of household hazardous waste and construction and demolition waste is important and is less expensive than the significant pre-processing or screening steps used to try to minimize and divert these contaminants once they have been introduced into the waste stream.

The County has already taken important steps to reduce the introduction of contaminants into the solid waste stream that would likely be processed by a Conversion Facility. Materials such as construction and demolition, hazardous, and green wastes are currently being diverted by the County, so that they are not supposed to be delivered to Cedar Hills Landfill. The results of the Waste Characterization Study discussed in Section 2 of this report indicate that the County has been relatively successful in its diversion efforts.

To the extent that the County can continue to expand its program to either eliminate the generation of, or divert, contaminants from the waste stream, the residue ash from a Conversion Facility would be positively impacted. Nevertheless, it should be anticipated that the composition of the residue ash from a Conversion Facility will have to be continually monitored, analyzed and evaluated throughout the Conversion Facility's operating life.

Type of Conversion Technology Employed

Each Conversion Technology uses very similar methods for combustion of the waste. The differences between the technologies are associated with the way that they process waste prior to the combustion, and the methods used to treat the resulting materials after combustion. For example, RDF facilities are characterized by their shredding and sizing of materials into a more homogenous material (RDF) as compared to mass burn facilities which do very little of this pre-processing. Likewise, advanced thermal recycling facilities include treatment of bottom and fly ashes that is more extensive than existing mass burn or RDF facilities in the United States. Presented below is a discussion of how the differences in technology can impact the composition and characteristics of the residue ash.

Residue Treatment and Air Pollution Control

Most of the mass burn, RDF, and advanced thermal recycling facilities currently employ relatively similar residue treatment and air pollution control processes, although typically to a greater extent and redundancy in advanced thermal recycling. These processes have improved significantly in the last 10 years as the requirements imposed by regulatory agencies have increased and the technologies have improved. Keep in mind that all three of the Conversion Technologies generally operate well within specified permit requirements, including the characteristics of the residue ash.

Control of the combustion process in the boiler is crucial for ensuring that the materials are combusted completely, that the process occurs efficiently, and that emissions associated with incomplete or poor combustion, such as dioxins and furans, are kept to a minimum. Maintaining proper temperature to assure combustion of certain pollutants is critical. Operators effectively manage the combustion process by controlling the temperature, the supply of air and the movement of the waste through the boiler.

The flue gases that result from the combustion process are subjected to certain processes to remove contaminants prior to the flue gas exiting the stack. Particulate matter that is recovered from the flue gas is referred to as “fly ash” and is one of the components of the residue ash that must be disposed of. Treatment of the flue gas often begins with the addition of ammonia at the proper temperature in a process called “selective non-catalytic reduction (SNCR) for nitrogen oxides (NOx)” which is designed to result in the removal of NOx gases. Carbon, in the form of charcoal, is also injected into the exhaust gas to remove mercury as well as certain other organics such as dioxins and furans. Exhaust gases are often treated in scrubbers (dry and wet) to neutralize contaminants like sulfuric and hydrochloric acids. Dry scrubbers involve spraying a mist of lime slurry into the flue gases, while wet scrubbers involve pulling the air through a liquid slurry of lime. Baghouses are used by Conversion Facilities to remove particulate matter and metals. Baghouses are basically made up of hundreds of fabric bags that filter the exhaust gas as it is drawn through them. The particulate material captured by the baghouses is the fly ash.

Another process developed by Wheelabrator and employed at many facilities in the United States and throughout the world is called Wes-PHix. Wes-PHix is a process that chemically transforms lead and other heavy metals in the fly ash into mineral compounds that substantially reduce solubility. It is used as a method to minimize leaching of heavy metals and improve TCLP test results.

The second component of the residue ash is the “bottom ash,” which represents the material removed from the boilers after combustion is complete. The efficiency of the combustion process is often measured by determining the amount of unburned carbon remaining in the bottom ash. The goal of a Conversion Facility is to reduce, to the greatest extent possible, the amount of unburned carbon in the bottom ash.

Following the combustion process, phosphoric acid is added to both the bottom and fly ashes at most facilities. The addition of phosphoric acid changes the pH of the ash material to make it more neutral. The acid also bonds with lead and cadmium particles to create complex phosphates that are intended to not leach when subjected to other acids. This step is crucial to ensure passage of the required TCLP test that is conducted periodically on residue ash.

The final design of any Conversion Facility would be carefully reviewed by DOE as a part of granting various operating permits. DOE will want to evaluate the ability of the proposed design to meet established permit requirements for both air emissions and residue ash. It should be anticipated that the design of a Conversion Facility would require design and installation of equipment capable of meeting the maximum available control technology (MACT) standards. This will include consideration of how the residue ash will have to be handled, treated, and disposed of.

Co-Mingling of Bottom and Fly Ash

The composition of residue ash is impacted by whether the fly ash and bottom ash, which are generally collected separately, are co-mingled prior to disposal. Fly ash will often represent approximately 20 percent of the total residue ash with bottom ash representing approximately 80 percent. Certain heavy metals, such as mercury and lead, are volatized at high temperatures during the combustion process and become part of the flue gas. These materials are recovered by the scrubbers as part of the fly ash.

The question revolving around co-mingling of the ash streams is whether it is better to separate the fly ash and its heavy metals from the bottom ash. This could become important if a market for the bottom ash could ever be developed.

The answer to this question is not currently clear. Most Conversion Facilities currently mix the two ash streams. This is done because there are certain materials in the bottom ash that can stabilize certain metals in the fly ash, reducing their ability to leach out. Certain operators of Conversion Facilities add dolomite to the fly ash to help stabilize other metals. As previously discussed, other operators apply the WES-PHix process to the fly ash for the same reason. The potential problem of not mixing the two ash streams is that there is a possibility that, in certain circumstances, the fly ash may no longer be considered non-hazardous.

The determination by the County regarding whether to co-mingle bottom and fly ashes at a Conversion Facility would need to be made very carefully and must be made in consultation with DOE and the local health department. Since the history of the uses or disposal of these types of ash has required either monofilling or use as daily cover and road bases in landfills, many facilities currently mix the bottom and fly ashes from their facility to treat (neutralize) the hazardous constituents in both materials. However, as their specific characteristics have become better defined, and as regulatory agencies have become more willing to consider their potential for beneficial use, the possible need to reconsider co-mingling has increased. Whether or not the current practice of co-mingling will change will depend on whether a positive economic benefit for the beneficial use of residue ash can be developed.

As discussed below, there are several potential uses for residue ash from Conversion Facilities and each use requires specific characteristics. Uses such as base courses for roads may require only the bottom ash, while segregated fly ash can be used as a binder in concrete. Ultimately, a Conversion Facility would need to be designed to meet the requirements specified by the state of Washington.

Potential Uses for Residue Ash

Currently the most common method of disposal of residue ash, and the only acceptable method in Washington, is in landfills. This disposal often occurs in a monofill, which is a single cell separate from where other waste is placed. This is done because, due to its density, the same weight of residue ash takes up much less air space (volume) than MSW. Also, unlike MSW, regulations often allow the residue ash to be placed without being covered each day. Where the use of residue ash as a cover material is permitted by the state regulatory agency, landfill operators may also take advantage of these aspects by employing residue ash as daily cover over the MSW as well, instead of using soil. In addition, residue ash may also be used for the construction of access roads on the landfill (i.e., within the limits of the landfill liner system). If the residue ash can be used for such purposes, Conversion Facility operators may be able to obtain better disposal rates on their residue ash.

Attempts have been made for many years to find a beneficial use for residue ash outside of landfills. Since residue ash, especially bottom ash, often contains relatively few active contaminants and produces acceptable TCLP test results, reuse of the material has been considered and, if ever developed, would further increase the amount of waste diverted from landfills as a result of Conversion Facilities. Residue ash is being tested and used as a construction material, particularly in Europe. For example, several projects have used residue ash as structural fill, as aggregate in cement blocks, and as an additive in asphalt or concrete. Residue ash also has applicability in environmental remediation at brownfields or mines and in several agricultural applications. Ultimately, the beneficial reuse of the residue ash will be limited to the allowed uses as defined by the regulatory agencies.

Potential uses for residue ash are driven first by state regulatory requirements and second by demand for the material to fill a need. In Florida, for example, strides have been made in the use of bottom ash in road construction and the manufacture of concrete. This is partly because the demand for coarse aggregates in Florida far exceeds the supply. Since the soils in Florida are predominantly sandy, much of the needed coarse material must be trucked or shipped to the state, resulting in much higher unit prices. This environment has facilitated the process to make bottom ash an acceptable material for construction in Florida.

Regardless of the suitability of the residue ash for the application, or the regulatory acceptance of these uses, in order for the activity to be sustainable, a strong market must exist for the resulting products. Since Washington does not have the same geologic constraints as Florida (good aggregates are generally abundant in Washington) the same market conditions will not apply. In order to be competitive and profitable, the County must either find a need in the market that ash residue can fill, or fill a need less expensively than it is currently being filled.

Likelihood that Conversion Technology Residue Could Receive a Beneficial Use Designation

As discussed previously, in the state of Washington residue ash is designated as "Special Incinerator Ash" and is required to be disposed of separate from other solid wastes. To overcome the first barrier to offering new options for disposal and recycling of the residue ash the County would have to show through test results that its residue ash is not a dangerous waste and should therefore be designated a "Solid Waste." This change will allow uses for the residue ash to include daily cover material in landfills and base material for access roads on a landfill. A classification of residue ash as Solid Waste would also allow the County to seek other methods of recovery and potentially find a use entirely separate from landfills.

The Spokane Regional Waste-to-Energy Facility, owned by the Spokane System,[1] completed this process and was able to change its residue ash designation from "Special Incinerator Ash" to "Solid Waste." This designation will allow the material to be disposed of with other solid wastes and opens up opportunities for the Spokane System to pursue reuse opportunities. It is our expectation that, since Spokane has already completed this step and DOE has approved this change, a re-designation of the County's residue ash could be made easier. After startup of the Conversion Facility in King County, DOE's concurrence of the residue ash as a Solid Waste would require several years of facility operation, residue sampling and testing. For illustrative purposes, we have included a more detailed discussion of Spokane's residue ash management in Appendix B.

Conclusions

The disposal of residue ash in the state of Washington is highly and carefully regulated by DOE, which has established a series of applicable designation tests which must be followed. Because the Spokane Conversion Facility has been able to produce a residue ash which meets or exceeds all permit requirements for disposal in a monofill at the Roosevelt Regional Landfill, it is reasonable to expect that the residue ash from a King County-owned Conversion Facility could do so as well.

[1]The Spokane Regional Solid Waste System ("Spokane System") includes Spokane County, the City of Spokane, 12 other cities and towns, and Fairchild Air Force Base..

In March 2007, the Spokane Conversion Facility also received approval from DOE to modify the designation of its residue ash from “Special Incinerator Ash” to “Solid Waste.” This re-designation increases the potential to either find some possible beneficial use for the residue ash or an alternative means of disposal. It is likely that a King County-owned Conversion Facility could receive the same designation.

There are certain measures the County could take to further enhance the possibility of achieving a “Solid Waste” designation for the residue ash from a Conversion Facility. These measures include: 1) continuing to provide alternative means of disposal for problematic materials such as construction and demolition debris and household hazardous wastes; further 2) encouraging household hazardous waste collection programs; and 3) continuing its public education program highlighting the benefits of recycling and the problems associated with introducing hazardous material to the waste stream.

In our opinion, the current regulatory framework in the state of Washington and the efforts of the Spokane System provide several viable options for the County to consider regarding the disposal of residue ash. While some regulatory changes would be required to make other beneficial uses viable, we believe that DOE would be open to the development of these avenues if testing supported their safety.

Section 10
ESTIMATE OF NET EMISSIONS

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This section of the report presents R. W. Beck's estimates of net emissions for the Conversion Technology and Waste Export Disposal Options. For the Conversion Technology Disposal Option, we estimated emissions for each of the three Conversion Technologies evaluated in this report: 1) mass burn, 2) RDF, and 3) advanced thermal recycling. For the Waste Export Disposal Option, we developed estimates for two landfill gas technologies: 1) active gas collection with landfill gas flaring, and 2) active gas collection with energy generation.

This section also presents assumptions, emission calculation methods, and estimates of associated air quality impacts. Emissions estimates were developed based on the technology-specific activities that are described in this section for the disposal of County waste during the study period from 2016 through 2036.

The emission inventories include: 1) criteria pollutants, 2) toxic pollutants of importance in waste management, and 3) greenhouse gases. The criteria pollutants in the emission inventories include oxides of nitrogen (NO_X), carbon monoxide (CO), sulfur dioxide (SO_2), particulate matter with an aerodynamic diameter less than 10 micrometers (PM_{10}), and lead. The toxic pollutants in the emission inventories include hydrochloric acid (HCl), mercury, and total chlorinated dibenzo-p-dioxins/dibenzofurans. The greenhouse gases include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).

With the exception of greenhouse gases, emission calculations for Conversion Technologies combusting waste are generally straightforward. Waste is burned and the emissions from the combustion of that waste are introduced to the air pollution control equipment in each facility. The emission inventories for the three Conversion Technologies include emissions for the study period 2016 to 2036. Estimating emissions from landfills is a bit more complicated. Emissions are constantly generated as the waste decomposes, and the waste deposited in a landfill can potentially take hundreds of years to decompose, although the emissions will be more intense soon after the waste is deposited in the landfill compared to later years. Emission calculations for landfills must therefore be completed for many years into the future, well beyond the study period of this report. In the emission inventories for the Waste Export Disposal Option we have included emissions from 2016 to 2200 in an attempt to include in the estimate all future emissions from waste that would be deposited in a landfill during the study period of 2016 through 2036.

Emission rates were calculated using published emission factors from the U.S. Environmental Protection Agency's (EPA's) AP-42 reference document and from the International Panel on Climate Change's "Guidelines for National Greenhouse Gas

Inventories." Available source-specific emission information was also used to calculate the emission inventories.

Greenhouse gas emissions can be divided into two categories: 1) sustainably harvested biogenic sources ("biogenic") and 2) fossil emissions. Biogenic greenhouse gas emissions are from biomass materials such as food, wood, and paper. Fossil greenhouse gas emissions are from materials with fossil origin (i.e., petroleum, coal, peat) including plastic and some textiles. The emission inventories included in this report are presented as total greenhouse gas emissions so that the technologies can be evaluated against each other.

Four of the technologies being considered in this report involve converting the waste to energy. All three Conversion Technologies use the heat from the combustion of waste to make steam for electricity generation. We have assumed that energy generation at a landfill will use internal combustion engine-driven generators to produce electricity from captured landfill gas. This is the technology employed at Roosevelt Regional Landfill in eastern Washington. The electricity generated from the County's waste will offset some portion of electricity generated by other electrical utilities in Washington State and also avoid the greenhouse gas emissions that would be released by the electrical utilities generating the electricity. We have had discussions with representatives of Puget Sound Energy regarding the potential for the construction of a Conversion Facility. Puget Sound Energy advised that although waste-to-energy is not currently considered a renewable energy in the state of Washington, the utility could use the power produced by a Conversion Facility. Puget Sound Energy anticipates that the energy produced from a Conversion Facility would replace energy that would otherwise be generated by the combustion of natural gas. The Puget Sound Clean Air Agency does not currently have any guidance for calculating greenhouse gas emissions or avoided emissions from energy generation; however, the Energy Information Administration, an office of the U.S. Department of Energy, provides guidance on calculating the avoided greenhouse gas emissions for each state.

The criteria pollutant, toxic pollutant, and greenhouse gas emission inventories for the three Conversion Technologies and the two landfill gas technologies are presented in the following subsections, along with assumptions, calculations, and estimates of air quality impacts.

Methodology

The following subsections present the assumptions, emission factors, and emission calculation methods that were used to estimate emissions of criteria pollutants, toxic pollutants, and greenhouse gases.

Criteria Pollutant and Toxic Pollutant Emission Calculations

We calculated criteria and toxic pollutant emission rates for each of the technologies based on the use of emission factors from the EPA's AP-42 reference document and emission source test data for similar waste disposal methods.

Emission Calculations for the Waste Export Disposal Option

To calculate the emissions for the two landfill gas technologies, we began by calculating the volume of landfill gas assumed to be generated by waste deposited in the landfill. Landfill gas is a product of waste material being decomposed by different bacteria in a landfill. For the purpose of estimating the emissions from solid waste generated by the County, we have assumed that County's waste will be deposited into its own cells at a landfill, so we have only calculated the emissions associated with the County's waste. In reality, a landfill would not be operated in this fashion. In addition, we have assumed that by volume, the landfill gas generated will be composed of 55 percent methane and 45 percent carbon dioxide with small amounts of nonmethane organic compounds (NMOC) and other inorganic compounds.

The volume of landfill gas generated at a landfill is calculated based on a first-order decomposition rate equation used in the EPA's Landfill Gas Emissions Model (LandGEM) Version 3.02. The first-order decomposition rate equation (see Equation 1) calculates the methane emissions based on the amount of waste landfilled each year, the methane generation rate constant, and the potential methane generation capacity of the waste. Most of the private regional landfills available to the County are located in arid locations; LandGEM recommends a methane generation rate of 0.02 $year^{-1}$ and a potential methane generation capacity of 100 cubic meters of methane per megagram of waste should be used for inventorying landfill emissions in arid areas.

Equation 1

$$Q_{CH_4} = \sum_{i=1}^{n} k L_o M_i e^{-kt_i}$$

where

QCH_4 = annual methane generation in the year of the calculation (m^3/year),

i = 1-year time increment,

n = (year of the calculation) – (initial year of waste acceptance),

k = methane generation rate ($year^{-1}$),

L_o = potential methane generation capacity (m^3/Mg),

M_i = mass of waste accepted in the *i*th year (Mg),

t_i = age of the section of waste mass M_i accepted in the *i*th year (years).

Landfill gas generation was calculated out to the year 2200 for the County waste deposited in the landfill during the study period of 2016 to 2036. The waste deposited in the landfill during the study period will continue to degrade and produce small volumes of landfill gas for many years past 2200. For this report, the emission inventories for the two landfill gas technologies are calculated based on the volume of landfill gas generated between 2016 and 2200.

We developed estimates of concentrations of mercury, reduced sulfur, chlorinated compounds, NMOC, and volatile organic compounds (VOC) in the landfill gas using the EPA's AP-42 default compound concentrations for landfill gas (see Table 10-1). We assume 80 percent of the landfill gas generated is captured using landfill gas collection systems at both landfills, and fugitive landfill gas emissions result in 20 percent of the total landfill gas generated at both landfills. The 80-percent capture assumption is typical of actual performance at properly designed and operated landfills. The gas capture percentage at a landfill can reasonably be expected to increase over time as more of the surface area is under final cover. As an example, the estimated gas capture rate for the Roosevelt Regional Landfill in 2005 was 78.9 percent, based on measured gas capture rates and gas production estimates. Because this capture assumption is important in the overall assessment of the landfill gas technologies, we have performed a sensitivity analysis where the gas capture rate was alternatively assumed to be 70 percent and 90 percent.

Table 10-1
Pollutant Concentrations in Landfill Gas

Pollutant	Molecular Weight	Concentration (ppmv) (1)
Mercury	200.61	2.92E-04
Chlorinated Compounds	35.453	42
Reduced Sulfur Compounds	32.064	46.9
NMOC as hexane	86.18	2,420
VOC as hexane	86.18	2,057

ppmv = parts per million by volume

(1) AP-42 Table 2.4-1, Default Concentrations for LFG Constituents

To calculate emissions for the two landfill gas technologies, R. W. Beck obtained data from two private regional landfills: Columbia Ridge Landfill in eastern Oregon and Roosevelt Regional Landfill in eastern Washington. The Columbia Ridge landfill combusts the captured landfill gas in a flare. The Roosevelt landfill has a contract with Klickitat Public Utility District (PUD) to combust captured landfill gas in internal combustion engines and generate electricity. Emission source test data for the Roosevelt landfill flare and emission source test data for the Klickitat PUD internal combustion engines were used to calculate NO_X, CO, and PM_{10} emission rates for the two landfill gas technologies. SO_2, VOC, HCl, and mercury emission rates for the two landfill gas technologies were calculated using a mass balance approach and the assumed composition of the landfill gas with typical pollutant control efficiencies for flares and internal combustion engines. Typical pollutant control efficiencies for combusting landfill gas in flares and internal combustion engines are presented in

Table 10-2. Flare and internal combustion engine secondary emission factors are presented in Table 10-3.

Table 10-2
Typical Control Efficiencies
for Landfill Gas Combustion

	Typical Control Efficiency (%)	
Pollutant	Flare	Internal Combustion Engine
NMOC	99.2	97.2
Halogenated Species	98	93
Non-Halogenated Species	99.7	86.1
Mercury	0	0

Source: AP-42 Table 2.4-3, Control Efficiencies for LFG Constituents

Table 10-3
Secondary Pollutant Emission Factors
for Landfill Gas Combustion

	Emission Factors (lb/106 dscf CH_4)	
Pollutant	Flare (1)	Internal Combustion Engine (2)
NO_X	20.2	130
CO	4.5	374
PM_{10}	25.8	19
CH_4 (3)	--	2.1
N_2O (3)	--	0.2

(1) Derived from Klickitat PUD engine generator system at Roosevelt landfill (June 1999).
(2) Derived from flare source test data at Roosevelt landfill (February 2003).
(3) 2006 International Panel in Climate Change's Guidelines for National Greenhouse Gas Inventories, Volume 2. Energy, Table 2.2, corrected to 500 Btu per scf landfill gas.

Emission Calculations for the Conversion Technology Disposal Option

We developed estimates of emissions for the mass burn and RDF Conversion Technologies using emission factors from AP-42 Chapter 2.1, "Refuse Combustion." Note that AP-42 emission factors are average values from source tests representing a sample of mass burn and RDF facilities located across the United States; each of these facilities has a different waste stream composition. Where AP-42 emission factors do not represent a large sample of different facilities, the EPA gives those emission factors a rating of “Below Average.” Any AP-42 emission factor with a Below Average rating has been noted as such in Table 10-4.

From an air emissions standpoint, an advanced thermal recycling Conversion Facility can be considered to be a commercial mass burn facility with distinctive air pollution control devices compared to typical mass burn facilities currently in operation in the United States, most of which were placed into commercial operation 12 to 20 years ago. Waste Recovery Seattle International provided emission factors for the advanced thermal recycling Conversion Technology based on source test data for an advanced thermal recycling facility located in Hamburg, Germany. A typical advanced thermal recycling Conversion Technology includes a selective non-catalytic reduction (SNCR) system to control NO_X emissions, an active carbon injection system followed by a baghouse to control particulate matter and mercury emissions, a two-stage HCl scrubber to control acid gas emissions, a single-stage scrubber with lime injection to control SO_2 emissions, and a second active carbon injection system followed by a baghouse to further control particulate matter. Table 10-4 presents the mass burn, RDF, and advanced thermal recycling emission factors used in calculating the emission inventories for each Conversion Technology.

Air pollution control equipment at a typical mass burn or RDF facility currently in operation in the United States has not been as extensive as the proposed air pollution control equipment at an advanced thermal recycling facility. A typical mass burn or RDF facility includes an SNCR system, a spray dryer absorber for acid gas control, active carbon injection for mercury control, and a fabric filter baghouse. However, a mass burn or RDF facility could be designed to include the same air pollution control equipment used at an advanced thermal recycling facility which, in effect, would make it an advanced thermal recycling Conversion Facility. During the last 20 years, existing Conversion Facilities have been required to either initially install or undertake a retrofit of air pollution control equipment representative of the “maximum available control technology” (MACT). The MACT standards are set by the EPA based on the demonstrated performance of specific equipment in the United States. We are not aware of any technical reason that the construction of new mass burn and RDF facilities that included the same air pollution control equipment as advanced thermal recycling could not result in similar levels of emissions. For this reason, we would expect a newly constructed mass burn or RDF Conversion Facility to experience better emission factors than those shown in Table 10-4.

Table 10-4
Emission Factors for Mass Burn, RDF, and
Advanced Thermal Recycling Conversion Technologies

	Emission Factors		
Criteria Pollutants	Mass Burn (1) (lb/ton)	RDF (2) (lb/ton)	Advanced Thermal Recycling (3) (lb/ton)
NO_X (4)	1.96E+00	2.76E+00	4.91E-01
CO	4.63E-01	1.92E+00	1.27E-01
SO_2 (5)	5.54E-01	4.41E-01	2.59E-02
PM_{10}	6.20E-02	1.33E-01	6.06E-03
Toxic Air Pollutants			
CDD/CDF (6)	6.61E-08	2.44E-08	2.88E-12
Mercury (5)	2.20E-03	2.92E-04	1.88E-06
Lead (5)	2.61E-04	1.04E-03	4.50E-06
HCl	2.11E-01	5.28E-02	3.90E-03

CDD/CDF = Total chlorinated dibenzo-p-dioxins/dibenzofurans

(1) AP-42 Tables 2.1-2 and 2.1-4, Emission Factors for Mass Burn Waterwall Combustors, Emission factors for spray dryers with fabric filters.
(2) AP-42 Table 2.1-8, Emission Factors for Refuse-Derived Fuel-Fired Combustors, Emission factors for spray dryers with fabric filters
(3) Provided by Waste Recovery Seattle International from 2005 source test data at MVR facility in Hamburg, Germany.
(4) Assume 45% NO_X emission reduction for SNCR system at mass burn and RDF facilities.
(5) RDF emission factors were given a "below average" rating.
(6) Advanced thermal recycling CDD/CDF emission factor is in Toxic Equivalents.

Greenhouse Gas Emission Calculations

We calculated greenhouse gas emission rates for each waste disposal option. Greenhouse gas emissions include provision for the transportation of solid waste and the greenhouse gas emissions generated by landfilling or combusting the waste. Transportation emissions are based on round-trip travel for each transportation mode and include:

- Diesel trucks transporting waste from the King County transfer stations to either the intermodal facility for the Waste Export Disposal Options or the Conversion Technology facility (assume 27 tons of compacted waste per truck round trip);
- Diesel trucks transporting non-processible waste and residual ash from the Conversion Technology facility to an intermodal facility (assume 27 tons per truck round trip); and

- Diesel locomotives transporting the waste from the intermodal facility to a landfill or diesel locomotives transporting the non-processible waste and the residual ash from the intermodal facility to a landfill.

We assumed equal deliveries of the projected County waste between the existing County transfer stations and the intermodal facility. We have also assumed the Conversion Technology facility would be located in South King County. The EPA's Mobile 6 model calculated a diesel truck CO_2 emission factor of 3.13 pounds CO_2 per vehicle mile traveled. Greenhouse gas emission calculations for the locomotives are based on emission calculations shown in the 2006 King County Waste Export System Plan. The locomotives have an assumed fuel efficiency of 1,550 ton-miles per gallon of diesel fuel. A locomotive CO_2 emission factor of 22.23 pounds CO_2 per gallon of diesel fuel is based on the diesel fuel containing 6.12 pounds of carbon per gallon and 99 percent of the carbon being oxidized when the diesel fuel is burned.

Greenhouse gas emission inventories for the combustion and landfilling of waste in the five evaluated technologies are more complicated than the criteria pollutant and toxic pollutant emission inventories because they must consider two additional factors beyond the simple calculation of the CO_2, CH_4, or N_2O emission rates. These factors are:

1. Some of the greenhouse gas emissions evolve from the decomposition of sustainably harvested biogenic materials and these emissions would have evolved over time even if the materials had been allowed to decompose naturally.
2. Landfilling, in particular, stores a certain quantity of biogenic carbon permanently, thus removing it from the natural cycle of decomposition to greenhouse gas and subsequent re-incorporation into biological material.

Accordingly, greenhouse gas emissions were not estimated using the same methods as the criteria and toxic pollutants, but rather were estimated in consideration of the specific waste profile for King County. A calculation spreadsheet was developed specifically for this project that simulates the EPA's Waste Reduction Model (WARM), which allows consideration of the specific details of the King County waste disposal alternatives.

For the landfill gas technology that involves flaring, estimated greenhouse gas emissions include provisions for assumed CO_2 emissions from captured landfill gas combustion in the flare and fugitive CO_2 and CH_4 emissions from landfill gas not collected by the landfill. However since virtually all the CO_2 is of biogenic origin, the CO_2 is not counted in the emission inventory. The CH_4 is counted in the emission inventory, because even though it is of biogenic origin, it would not have evolved from normal aerobic decomposition in a natural environment, since methane is the product of an anaerobic process rather than an aerobic process.

For the landfill gas technology that involves energy generation, estimated greenhouse gas emissions include CO_2, CH_4, and N_2O emissions from captured landfill gas combustion in internal combustion engines and the fugitive CO_2 and CH_4 emissions from landfill gas not collected by the landfill, although the CO_2 is not counted for the same reasons as described above. The internal combustion engines will still produce some CH_4 and N_2O emissions (see Table 10-3).

For the purposes of this report, the greenhouse gas emissions from the three Conversion Technologies were considered together, even though there are differences between the three technologies due to different degrees of recycling. The three Conversion Technologies were combined into a single analysis for two reasons. First, the analysis conducted here was based on the EPA WARM model algorithm, which does not distinguish between different methods of waste combustion to generate energy. We believe the advantages that the WARM model offers, with its ability to adapt to the specific King County waste profile outweigh whatever inflexibility the model has in adapting to the differences in the combustion technologies. Second, since the major differences between the three Conversion Technologies for greenhouse gases will result from different degrees of recycling, we believe the three technologies eventually become very similar through the continued implementation of King County's recycling program. The main purpose of the WARM model is to allow solid waste planners to evaluate the differences between waste-to-energy and landfilling with various recycling and recovery programs. The King County waste profile is used in the WARM model and the model computes greenhouse gas emissions for the Combustion Technologies, taking into consideration that portion of the waste which is biogenic.

The major adaptation to the WARM model used in this analysis is to allow specific information to be provided concerning avoided emissions. The standard version of the WARM model provided by the EPA provides unalterable factors for estimating the quantity of greenhouse gases from other sources of electrical generation that are offset as a result of the generation of electricity at the Conversion Facility. These factors are based on national averages for electrical generation and include a large percentage of coal combustion. Since combustion of coal produces the greatest amount of greenhouse gas per unit of electricity delivered, these factors are unrepresentative of Washington State, where electricity mostly comes from other sources. Based on our discussions with representatives of Puget Sound Energy, we believe that any new sources that might be constructed to meet future Washington State electrical demand would not be based on coal combustion. In this analysis, we considered two avoided emission scenarios. The first assumes the electricity avoided at a power plant as the result of the operation of the Conversion Facility follows the profile of how electricity is actually generated at present in Washington State. The second scenario assumes that 100 percent of the electricity that is offset would come from natural gas combustion in a modern, combined-cycle electrical generation facility.

The greenhouse gas emission factors for each Conversion Technology are presented in Table 10-5.

Table 10-5
Greenhouse Gas Emission Factors for Conversion Technology

	Emission Factors/Assumptions		
Waste Category (1)	Energy Content (Btu/lb)	Efficiency	CO_2 from Combustion Alternatives (MTCE/ton) (2)
Aluminum Cans(3)	-335	17.80%	0
Steel Cans(3)	-210	17.80%	0
Copper Wire(3)	-273	17.80%	0
Glass(3)	-235	17.80%	0
HDPE	18687	17.80%	0.76
LDPE	18687	17.80%	0.76
PETE	9702	17.80%	0.56
Corrugated Cardboard	7043	17.80%	0.01
Magazines/Third-Class Mail	5258	17.80%	0.01
Newspaper	7950	17.80%	0.01
Office Paper	6800	17.80%	0.01
Phonebooks	7950	17.80%	0.01
Textbooks	6800	17.80%	0.01
Dimensional Lumber	8300	17.80%	0.01
Medium-density Fiberboard	8300	17.80%	0.01
Food Scraps	2370	17.80%	0.01
Yard Trimmings	2800	17.80%	0.01
Grass	2800	17.80%	0.01
Leaves	2800	17.80%	0.01
Branches	2800	17.80%	0.01
Mixed Paper (general)	7069	17.80%	0.01
Mixed Paper (primarily residential)	7039	17.80%	0.01
Mixed Paper (primarily from offices)	6499	17.80%	0.01
Mixed Metals(3)	-273	17.80%	0
Mixed Plastics	18687	17.80%	0.76
Mixed Recyclables	5000	17.80%	0.11
Mixed Organics	5000	17.80%	0.11
Mixed MSW	5000	17.80%	0.11
Carpet	13400	17.80%	0.47
Personal Computers	1533	17.80%	0.1
Clay Bricks	0	17.80%	0
Concrete	0	17.80%	0
Fly Ash	0	17.80%	0
Tires	11769	17.80%	2.05

(1) Waste categories from the WARM model. The King County waste profile was given in different categories, which were broken into these categories using engineering judgment.
(2) MTCE (metric tons carbon equivalent) is customarily used for greenhouse gases, where CO_2, CH_4, and N_2O are expressed relative to CO_2 in terms of global warming potential and indexed back to carbon.
(3) Negative values are shown for metals because energy is expended in combustion systems to heat the metals, and no energy is given back.

The WARM model analysis includes an estimate of the avoided greenhouse gas emissions for the amount of electricity generated from landfill gas and from the Conversion Technologies. The landfill gas-flaring technology does not generate electricity and, as a result, no avoided greenhouse gas emissions are calculated for that technology. The Energy Information Administration offers guidance for calculating avoided emissions and provides avoided greenhouse gas emission factors for each state. The Energy Information Administration has calculated, for each state, average CO_2, CH_4, and N_2O emissions per kilowatt-hour of energy produced. Table 10-6 presents the avoided greenhouse gas emission factors for Washington based on the current electrical generation methods used in the state. Table 10-6 also shows emission factors for electrical generation assumed to result solely from natural gas combustion in a modern, combined-cycle electrical generation facility. The avoided greenhouse gas emissions are then subtracted from the total greenhouse gas emissions released by each evaluated technology. Note that the emission factors presented in Table 10-6 are based on actual generation methods used in Washington State, rather than an assumption that all of the avoided electrical generation results from fossil fuel combustion.

Table 10-6
Avoided Greenhouse Gas Emission Factors

Generation Scenario	Emission Factors [(1)] (MTCE/kWh)
Washington Current Electrical Generation[(2)]	30.4
Combined Cycle Natural Gas Plant[(3)]	125

(1) MTCE (metric tons carbon equivalent) is customarily used for greenhouse gases, where CO_2, CH_4, and N_2O are expressed relative to CO_2 in terms of global warming potential and indexed back to carbon.

(2) Washington State actual emissions are based on Department of Ecology factor of 0.123 ton CO_2 per kWh.

(3) Natural gas combustion emissions are based on 0.12 lb/MMscf (EPA – AP-42), 1,012 MMBtu/MMscf from WARM model, and assumption that 40% of input heat is turned into electricity.

Emission Calculations

This comparison analysis focuses on three overall categories of pollutants: criteria pollutants, toxic pollutants, and greenhouse gas pollutants. Each class of pollutant is treated differently depending upon on its type, its health/environmental effects, and its regulation.

Criteria Pollutants

The Clean Air Act and its amendments were passed by Congress to provide a program to improve the quality of the air in the United States. The Clean Air Act of 1970 requires the EPA to set National Ambient Air Quality Standards (NAAQS) for the six so-called criteria pollutants: NO_X, CO, SO_2, particulate matter, ozone, and lead.

Particulate matter includes anything that exists in the atmosphere as particles. This can include dust, dirt, soot, smoke, and liquid droplets, including anything emitted as vapors but that condenses in the atmosphere. Particulate matter is usually divided into different classes based on size, ranging from total suspended particulate (TSP) to PM_{10} (particles less than 10 micrometers in mass-mean diameter) to $PM_{2.5}$ (particles less than 2.5 micrometers). Currently, the EPA has issued NAAQS for PM_{10} and $PM_{2.5}$.

Most ozone is not emitted directly; it is formed through reaction of NO_X and VOC in the atmosphere. As such, ozone emissions are controlled through limitation of the VOC precursor.

These pollutants are called “criteria” air pollutants because they are regulated by developing human health-based and/or environmentally-based criteria (science-based guidelines) for setting permissible levels (i.e., NAAQS). The set of standards based on human health is called primary standards; another set of standards intended to prevent environmental and property damage is called secondary standards.

The NAAQS are an effort by the EPA to place an upper limit on the amount of pollutants in the air that will cause only limited health and environmental/property damage impacts. Currently, many ambient monitors are located throughout the United States that measure concentrations of the various criteria pollutants. These data are then compared with the NAAQS to determine the status of the ambient air in each defined area. In an area where the pollutant concentration is below the NAAQS threshold, it is called an attainment area (i.e., it has attained the threshold). Those areas that do not meet the NAAQS are called nonattainment areas. Washington State has had some nonattainment counties in the past, generally for PM_{10}, ozone, and CO; currently, however, all of Washington State is in attainment.

To prevent regions where the air is in attainment from getting worse, the EPA published the Prevention of Significant Deterioration (PSD) program for projects at facilities located in attainment areas. This program focuses not only on the NAAQS but also limits the incremental changes in air quality. The applicability of this permitting program will have to be evaluated by the appropriate permitting agency if a new facility is proposed or a modification to an existing facility is necessary.

Table 10-7 summarizes the criteria pollutant emissions for each evaluated technology. These values include both direct, process-related emissions (e.g., combustion exhaust), fugitive emissions (i.e., emissions that are not captured), and transportation emissions from transport of waste to the disposal location.

Table 10-7
Estimated Criteria Pollutant Emissions for Each Disposal Technology
(in tons for waste disposed of in 20-year period 2016–2036)

	Conversion Technology Disposal Option (1)			Waste Export Disposal Option (2)	
	Mass Burn	Refuse-Derived Fuel	Advanced Thermal Recycling	Active Gas Collection with Flaring	Active Gas Collection with Energy Generation
NO_X	26,693	35,981	6,759	2,362	6,166
CO	6,324	24,831	1,756	590	13,441
SO_2	7,445	5,677	335	496	496
PM_{10}	843	1,723	89	947	712
VOC	29	33	33	7,618	8,201
Total Hydrocarbons	179	--	--	--	--
Lead	3.51	13.39	0.06	--	--

Note: These estimates include emissions from both processing (operation-related and fugitive) and transportation

(1) Based on 20 years of waste processing (from 2016 to 2036)
(2) Based on gas generated from 20 years of waste disposal over 184 years (from 2016 to 2200)

For most of the criteria pollutants, the landfill gas technologies are calculated to have less emissions than the Conversion Technologies. However, for VOC, the Conversion Technologies have very little emissions compared with the landfill gas technologies.

For the Conversion Technologies, advanced thermal recycling has nearly an order of magnitude less criteria pollutant emissions than mass burn and RDF. This can be attributed to the air quality control devices used with advanced thermal recycling. As discussed previously in this section, we are not aware of any reason a mass burn or RDF facility could not achieve levels similar to advanced thermal recycling if the facility was designed to include similar air pollution control technology.

It should be noted that the values in Table 10-7 do not include any avoided emissions for the electricity that is provided by the four technologies that do generate electricity. No formal analysis has been performed here of these offset emissions, but we expect that any such avoided emissions would be low. Even if 100 percent of the electricity was to be provided by a natural gas-fired power plant, combustion of natural gas generates very little SO_2, PM_{10}, VOC, or lead. The primary avoided emissions would be NO_X, and even the NO_X emissions from a modern natural gas electrical generation facility of 75 MW would be 50 tons per year or less.

Toxic Pollutants

The 1990 amendments significantly modified the Clean Air Act. These amendments contained major new provisions for control of toxic air contaminants. The revised Clean Air Act requires regulation of 189 toxic chemicals, the so-called hazardous air pollutant (HAP) list. Generally, HAP chemicals are those that are not explicitly considered criteria pollutants. However, because most hazardous air pollutants are organic, they are included within the VOC category, as a precursor to ozone. The EPA may add chemicals to or delete chemicals from this list of 189. With the delisting of caprolactam and methyl ethyl ketone (MEK), there are currently 187 chemicals on the HAP list.

The 1990 Clean Air Act Amendments also mandated that the EPA set standards for all major sources of air toxics. These standards require major sources of toxic air pollution to use “maximum achievable control technology.” This is intended to ensure that both new and existing major sources of toxic air pollution will use the kind of technology which provides maximum control of toxics on an ongoing basis. An initial list of toxic source categories (i.e., industry types) was published in 1992 and includes municipal solid waste landfills.

State agencies can have the latitude to create their own programs to regulate toxic pollutants. At a minimum, all toxics on the federal HAP list must be included, but the state agencies can include any additional toxics they feel it necessary to regulate. Examples of toxic air pollutants include benzene, which is found in gasoline; perchloroethylene, which is emitted from some dry cleaning facilities; and methylene chloride, which is used as a solvent and paint stripper by a number of industries.

Due to the large list of toxics, evaluating emissions of each toxic can be a major task. As such, the toxics considered in this analysis are those that are considered representative of the range of toxics or that are of specific interest emitted by that source type. Please note that this review was limited to a few key pollutants. It is possible that others could be important at some future date. Table 10-8 summarizes the toxic pollutant emissions for each of the evaluated technologies.

Table 10-8
Estimated Toxic Pollutant Emissions for Each Disposal Technology
(in tons for waste disposed of in 20-year period 2016–2036)

	Conversion Technology Options (1)			Waste Export Disposal Option (2)	
	Mass Burn	Refuse-Derived Fuel	Advanced Thermal Recycling	Active Gas Collection with Flaring	Active Gas Collection with Energy Generation
HCl	2,835	680	50	5	18
CDD/CDF (3)	0.0009	0.0003	--	--	--
PCDD/PCDF TEF (4)	5.24E-06	--	3.71E-08	--	--
Mercury, total	29.6	3.8	0.02	0.012	0.012

Note: This analysis shows but a few representative toxics out of the 187 toxics on the EPA's HAP list.

(1) Based on 20 years of waste processing (from 2016 to 2036)
(2) Based on gas generated over 184 years as a result of 20 years of waste disposal (from 2016 to 2200)
(3) CDD/CDF = total tetra- through octa- chlorinated dibenzo-p-dioxin/chlorinated dibenzofurans, 2,3,7,8-tetrachlorodibenzo-p-dioxin, and dibenzofurans. All are listed as HAPs in 1990 Clean Air Act.
(4) Polychlorinated dibenzo-p-dioxin (PCDD) and polychlorinated dibenzofuran (PCDF) in Toxic Equivalency Factor (TEF)

The information in Table 10-8 indicates that the Conversion Technologies appear to have the potential for significantly greater HAP emissions than the landfill gas technologies. As discussed previously in this section, we believe that with the installation of similar air pollution control technology, the estimates for mass burn and RDF technologies could be similar to those of advanced thermal recycling. Note that in Table 10-7, the Conversion Technologies are shown to have very little VOC emissions compared to the landfill gas technologies. Because most toxics are organic, a high VOC emission rate is a potential indicator of high toxics. This is known to be the case for landfills, though this is not evident in the limited number of toxics shown in Table 10-8.

Greenhouse Gas Pollutants

Gases that trap heat in the atmosphere are called greenhouse gases. Some greenhouse gases, such as carbon dioxide, occur naturally and are emitted to the atmosphere through natural processes and human activities. Other greenhouse gases, such as fluorinated gases, are created and emitted solely through human activities. The principal greenhouse gases that enter the atmosphere because of human activities are:

- CO_2: primarily emitted from fossil fuel combustion, solid waste, trees, and wood products.

- CH_4: emitted during the production and transport of coal, natural gas, and oil. Methane emissions also result from livestock and other agricultural practices and from the decay of organic waste in municipal solid waste landfills.
- N_2O: emitted during agricultural and industrial activities, as well as during combustion of fossil fuels and solid waste.
- Fluorinated Gases: hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride are synthetic, powerful greenhouse gases that are emitted from a variety of industrial processes.

In the case of municipal solid waste landfills and conversion of municipal solid waste, the primary greenhouse gases of concern are carbon dioxide, methane, and, to a lesser extent, nitrous oxide.

Each of these gases has a different capacity to trap heat (i.e., global warming potential), so comparing them directly is not sufficient. Factors have been developed based on the global warming potential of each greenhouse gas in order to allow direct comparisons between the greenhouse gases in terms of CO_2 equivalents. Carbon dioxide has the least capacity, on a mass basis, of all the greenhouse gases to trap heat; it is assigned a global warming potential of 1. Methane has a higher global warming potential of 21 and nitrous oxide has a global warming potential of 310.[1] CO_2 equivalents are frequently converted to carbon equivalents, where only the weight of the carbon is counted.

For instance, for a project that is estimated to emit 150 tons of CO_2, 90 tons of methane, and 8 tons of nitrous oxide, the global warming potential would be 4,520 tons CO_2 equivalent (= 150 ton CO_2 × 1 ton CO_2 equiv/ton CO_2 + 90 ton CH_4 × 21 ton CO_2 equiv/ton CH_4 + 8 ton N_2O × 310 CO_2 equiv/ton N_2O). This same quantity could be further reduced to carbon equivalents by multiplying by the ratio of the weights of carbon to CO_2. So, in the above example, the global warming potential would be 1,233 (= 4,520 × 12/44) tons of carbon equivalents, or more commonly expressed in metric units as 1,118 metric tons of carbon equivalent (MTCE).

Criteria and toxic pollutants generally have relatively local impacts to human health and environmental and property damage. Greenhouse gases, on the other hand, act to trap heat in the atmosphere; hence, they have larger-scale environmental impacts.

Table 10-9 summarizes the greenhouse gas pollutant emissions for the evaluated technologies. As mentioned previously, the three Conversion Technologies have been combined because the EPA's WARM model does not distinguish between different combustion alternatives. These values include both direct process-related emissions (e.g., combustion exhaust, landfill emissions) and fugitive emissions (i.e., emissions that are not captured), but do not include transportation emissions from transport of waste to the disposal location. These values also include the emissions that are avoided by replacing electricity produced in another fashion. These avoided emissions are subtracted from the emissions produced by the technologies to calculate the total net emissions associated with each technology.

[1] Intergovernmental Panel on Climate Change, *Climate Change 1995: The Science of Climate Change* (Cambridge, UK: Cambridge University Press, 1996)

Table 10-9
Estimated Greenhouse Gas Emissions for Disposal Options

	Conversion Technology Disposal Option			Waste Export Disposal Option				
WARM Model Categories	**Electric Utility Avoided CO_2 (MTCE/t) (2)**	**Net (MTCE/t)**	**(MTCE)**	**Electric Utility Avoided CO_2 (MTCE/t) (2)**	**Landfill Net Carbon Storage (MTCE/t)**	**Net (MTCE/t)**	**Active Gas Collection with Flaring (MTCE)**	**Active Gas Collection with Energy Recovery (MTCE)**
Aluminum Cans	-0.0044	0.0044	727.30	0	0	0	-	-
Steel Cans	-0.0027	-0.4273	(89,656.35)	0	0	0	-	-
Copper Wire	-0.0036	0.0036	-	0	0	0	-	-
Glass	-0.0031	0.0031	2,612.74	0	0	0	-	-
HDPE	0.2439	0.5161	73,599.13	0	0	0	-	-
LDPE	0.2439	0.5161	-	0	0	0	-	-
PET	0.1266	0.4334	77,999.64	0	0	0	-	-
Corrugated Cardboard	0.0919	-0.0819	(106,854.94)	0.0396	0.2200	-0.1357	(177,014.60)	(125,410.42)
Magazines/ Third-Class Mail	0.0686	-0.0586	(5,259.84)	0.0160	0.2200	-0.1859	(16,681.09)	(15,246.81)
Newspaper	0.1038	-0.0938	(71,568.91)	0.0140	0.3600	-0.3301	(251,951.11)	(241,240.83)
Office Paper	0.0888	-0.0788	-	0.0689	0.0400	0.1067	-	-
Phonebooks	0.1038	-0.0938	-	0.0140	0.3600	-0.3301	-	-
Textbooks	0.0888	-0.0788	-	0.0689	0.0400	0.1067	-	-
Dimensional Lumber	0.1083	-0.0983	(105,771.14)	0.0204	0.3100	-0.2665	(286,656.26)	(264,696.75)
Medium-Density Fiberboard	0.1083	-0.0983	-	0.0204	0.3100	-0.2665	-	-
Food Scraps	0.0309	-0.0209	(118,366.22)	0.0256	0.0200	0.0345	195,097.50	339,794.29
Yard Trimmings	0.0365	-0.0265	(1,375.76)	0.0152	0.1900	-0.1575	(8,163.87)	(7,374.09)
Grass	0.0365	-0.0265	(18,825.61)	0.0086	0.0800	-0.0616	(43,699.81)	(37,582.53)
Leaves	0.0365	-0.0265	(18,825.61)	0.0162	0.1900	-0.1556	(110,323.03)	(98,863.32)
Branches	0.0365	-0.0265	(1,475.63)	0.0204	0.3100	-0.2665	(14,813.63)	(13,678.83)
Mixed Paper (general)	0.0923	-0.0823	(363,380.16)	0.0374	0.2200	-0.1403	(619,505.31)	(454,138.32)
Mixed Paper (primarily residential)	0.0919	-0.0819	-	0.0354	0.2300	-0.1545	-	-
Mixed Paper (primarily from offices)	0.0848	-0.0748	-	0.0369	0.1800	-0.1015	-	-
Mixed Metals	-0.0036	0.0036	5,652.08	0	0	0	-	-
Mixed Plastics	0.2439	0.5161	1,409,316.91	0	0	0	-	-
Mixed Recyclables	0.0653	-0.0653	-	0	0	0	-	-
Mixed Organics	0.0653	0.0447	154,994.76	0.0334	0.0200	0.0510	176,850.96	292,423.70
Mixed MSW	0.0653	0.0347	56,006.65	0.0334	0.1700	-0.0990	(159,558.13)	(105,773.49)
Carpet	0.1749	0.2951	223,710.78	0	0	0	-	-
Personal Computers	0.0200	-0.0400	(14,605.03)	0	0	0	-	-
Clay Bricks	0.0000	0.0000	-	0	0	0	-	-
Concrete	0.0000	0.0000	-	0	0	0	-	-
Fly Ash	0.0000	0.0000	-	0	0	0	-	-
Tires	0.1536	1.8664	333,174.15	0	0	0	-	-
Totals			**1,421,828.96**				**(1,316,418.38)**	**(731,787.39)**

Note: Includes emissions from processing (operations-related and fugitive) but does not include transportation emissions. Also, emission inventories for both disposal options are based on 20 years of waste disposal (2016 to 2036).

(1) Avoided emissions based on natural gas combustion in a combined-cycle plant with 40% efficiency. Lower values would be shown in both these columns if actual Washington State electrical generation had been used.
(2) Landfill emissions in this table are based on 80% capture of generated landfill gas.

These greenhouse gas emissions totals illustrate the estimate of Total Net Emissions associated with the different technologies. The Waste Export Disposal Option places the waste in the ground where a certain amount will degrade into methane. Most of the methane is captured and burned to create CO_2. The rest of the waste carbon is sequestered in the ground (carbon storage). In the case of the Conversion Technologies, all of the carbon from the waste is converted into CO_2. As such, the Conversion Technologies generate significantly more CO_2, and hence more carbon equivalents, than landfilling.

Greenhouse gases from transportation for each option have been treated separately because the WARM model does not allow the flexibility to treat multiple modes of transport. All of the options investigated here would include some combination of truck and rail movement to transport waste. However, transportation emissions add only approximately 28,000 MTCE for the Conversion Technology Disposal Option, and approximately 56,000 MTCE for the Waste Export Disposal Option. Thus, the impact of transportation emissions is minor and has no effect on the conclusions.

Because of the importance of greenhouse gas emissions, an additional sensitivity analysis was conducted to estimate the effects on the emission calculations if different assumptions had been made. One of the critical assumptions is the gas capture percentage for active gas collection at a landfill. The values in Table 10-9 reflect the assumption that 80 percent of the landfill gas will be captured and routed to some form of combustion. If the percentage assumed had instead been 90 percent, the greenhouse gas emissions for the Waste Export Disposal Option would be reduced significantly to around (2,304,400) MTCE for a landfill with energy recovery and (1,646,700) MTCE for a landfill without energy recovery (note that negative numbers are shown here in parenthesis). Conversely, if the gas capture percentage were to be reduced to 70 percent, greenhouse gas emissions for the Waste Export Disposal Option would be increased to (328,500) MTCE for a landfill with energy recovery and 183,100 MTCE for a landfill without energy recovery. While the effect of this assumption is very significant, it would not change the relative emissions of the Waste Export Disposal Option.

Air Quality Impacts

Air quality emissions can cause a variety of different types of impacts. For the purpose of this report, the discussion of air quality impacts has been divided into of four categories: human health impacts, human welfare impacts, ecological damage, and global warming. Although there are areas of overlap, a separate discussion is presented below for each of these classes of air quality impacts.

Any specific proposal for a new facility, such as any of the Conversion Facilities considered here, would be subject to requirements to obtain one or more air quality permits. Air quality rules and regulations are in a constant state of change and it is likely that in 5 to 10 years, there will be new and/or different requirements for the Conversion Facilities. As part of these permit processes, a much more comprehensive and specific analysis of air quality impacts will be conducted. The science of impact analysis also changes over time, so there may be different ways of evaluating these impacts in the future.

For all of these reasons, the current impact analysis is unavoidably general in nature. The disposal options being considered in this report are several years in the future, and no specific designs are available. The discussion presented in the following paragraphs is mainly qualitative and is based on the general characteristics of the disposal options being considered. We have emphasized areas where there are significant differences between the disposal options being considered.

Human Health Impacts

As discussed previously in this section, many of the air pollutants have the potential, if present in high enough concentrations, to impact human health. For the criteria pollutants, in particular, the EPA and others have conducted major human health investigations that allowed the establishment of NAAQS. These standards are effectively evaluation criteria for determining the acceptability or unacceptability of pollutant levels in the air we breathe. Table 10-10 is a list of existing NAAQS. Note that we have included Washington State standards as well as local standards administered by the Puget Sound Clean Air Agency, which in the current analysis would apply only to the Conversion Facilities. For the Waste Export Disposal Option, some of the landfills that the County may use are located in other states; although the Washington State regulations would not apply in those states, all states have similar standards.

All of the Conversion Technologies and landfill gas technologies being considered in this report emit every one of the pollutants listed in Table 10-10 with the exception of ozone. Ozone is not emitted directly by any of the facilities, but instead is formed in the atmosphere from VOCs and NO_X, which are emitted by all the technologies. However, not all of the pollutants have the same potential air quality impacts. CO, for example, is primarily an urban pollutant caused by motor vehicles and residential heating system (oil and natural gas) combustion. Since none of the technologies emit CO in significant quantities, we would not expect there to be any CO issues arising from any of the technologies. Therefore, no further discussion is provided for this pollutant. Ozone is also a pollutant of primary concern in relation to the large-scale emissions from urban areas. Although ozone impacts have not been addressed directly in this report, the ozone precursor, VOCs, have been discussed here, mainly due to the VOC relationship with air toxic emissions.

Table 10-10
Ambient Air Quality Standards for Criteria Pollutants

Pollutant	National (EPA) Primary	National (EPA) Secondary	State Department of Ecology	Local PSCAA
Total Suspended Particulate Matter (TSP)				
Annual Geometric Mean (µg/m^3)			60	
24-Hour Average (µg/m^3)			150 (1)	
Inhalable Coarse Particulate Matter (PM_{10})				
Annual Average (µg/m^3)	(b)		50	54 (3)
24-Hour Average (µg/m^3)	150 (1)		150 (1)	154 (4)
Fine Particulate Matter ($PM_{2.5}$)				
Annual Average (µg/m^3)	15 (5)	15 (5)		15 (3)
24-Hour Average (µg/m^3)	35 (6)			35 (7)
Sulfur Dioxide (SO_2)				
Annual Average (ppm)	0.03	--	0.02	0.02
24-Hour Average (ppm)	0.14 (1)	--	0.10 (1)	0.10
3-Hour Average (ppm)	--	0.50 (1)	--	--
1-Hour Average (ppm)	--	--	0.25 (8)	0.25 (8)
1-Hour Average (ppm)	--	--	0.40 (1)	0.40
Carbon Monoxide (CO)				
8-Hour Average (ppm) (1)	9		9	9.4
1-Hour Average (ppm) (1)	35		35	35
Ozone (O_3)				
8-Hour Average (ppm) (9)	0.08	0.08		0.08
1-Hour Average (ppm)	(10)	(10)	0.12	(10)
Nitrogen Dioxide (NO_2)				
Annual Average (ppm)	0.053	0.053	0.05	0.053
Lead				
Quarterly Average (µg/m^3)	1.5	1.5		1.5

µg/m^3 = micrograms per cubic meter; ppm = parts per million; blank cells indicate no standard
Note: All values not to be exceeded except as noted; all averages arithmetic except TSP annual geometric mean.

(1) Not to be exceeded more than once per year
(2) Particles <10 micrometers in size; Federal annual PM10 standard revoked as of Sept. 21, 2006
(3) The 3-year annual average of the daily concentrations must not exceed level
(4) The 3-year average of the 99th percentile (based on the number of samples taken) of the daily concentrations must not exceed level
(5) Attainment based on the 3-year average of the weighted annual mean PM2.5 concentrations from single or multiple community-oriented monitors not exceeding level
(6) Attainment based on the 3-year average of the 98th percentile of 24-hour concentrations at each population-oriented monitor within an area not exceeding level
(7) The federal 24-hour standard for $PM_{2.5}$ was revised as of Sept. 21, 2006. The current PSCAA standard of 65 ppm is based on the previous federal standard but has been superseded by the new federal limits. Although PSCAA has not yet adopted the new federal standard, it must do so soon. So as to avoid confusion, only the prevailing federal standard is reported to represent the maximum level that PSCAA can adopt.
(8) Not to be exceeded more than twice in seven consecutive days
(9) Attainment based on 3-year average of the 4th highest daily maximum 8-hour ozone concentration at each monitoring location
(10) Federal 1-hour ozone standard was revoked in all areas except 14 remaining nonattainment areas. The federal and the PSCAA 1-hour standard lapsed on June 15, 2005.

Source: Geomatrix Consultants, Inc. based on most recent local, state, and federal rules.

The criteria pollutants typically of concern for the disposal options are SO_2, NO_X, lead, and various forms of particulate matter. These pollutants can have significant but localized impacts on human health. However, by virtue of the air permit requirement, it is unlikely that any of the disposal options considered here would have any significant impact on human health from criteria pollutants. There are differences between the technologies that are worth discussing even if all of the technologies have low overall impacts. In terms of NO_X emissions in particular, the Conversion Technology option is calculated to have greater emissions than the Waste Export options. However, NO_X emissions from advanced thermal recycling are only slightly greater than from energy generation from landfill gas. The mass burn and RDF technologies have much higher NO_X emissions, owing mostly to the lower control efficiency assumed for the NO_X removal systems on these units. The difference between the mass burn/RDF technologies and advanced thermal recycling reflects how currently operating facilities have been constructed, not any theoretical limit of the technology. We believe that mass burn and RDF facilities could achieve levels similar to those of advanced thermal recycling if those facilities were equipped with similar air pollution control equipment.

Estimated NO_X emissions for the landfill gas technologies are lower simply because there is less combustion involved. The difference in NO_X emissions between the two landfill gas technologies reflect the higher NO_X emissions for engine generators versus the flare technology. In terms of air quality impacts, higher NO_X emissions can result in higher ambient NO_2 concentrations, but since Washington State has relatively low NO_2 concentrations, this would not be expected to result in any significant human health impacts from direct NO_2 exposure. Higher NO_X can also result in greater ozone concentrations, more nitrate particles in the atmosphere, and increased acid rain. NO_2 can irritate the lungs and lower resistance to respiratory infections such as influenza. The effects of short-term exposure are still unclear, but continued or frequent exposure to concentrations that are typically much higher than those normally found in the ambient air may cause increased incidence of acute respiratory illness in children.

SO_2 emissions are a direct result of the sulfur found in the fuel. As with the NO_X emissions, the Conversion Technologies are calculated to generate more SO_2 simply because there is more combustion and a greater portion of the sulfur contained in the waste is transformed into sulfur dioxide. The differences between the three Conversion Technologies reflect the air pollution control systems assumed to be installed on the units. As with the NO_X, these do not reflect an inherent limitation of the technology, but rather a typical difference in systems as previously constructed. Advanced thermal recycling is seen to have very low SO_2 emissions due to the high level of acid gas scrubbing used in the design of these systems. Impacts from SO_2 include direct inhalation impacts from both short-term and long-term exposures. The major health concerns associated with exposure to high concentrations of SO_2 include effects on breathing, respiratory illness, alterations in pulmonary defenses, and aggravation of existing cardiovascular disease. Major subgroups of the population that are most sensitive to SO_2 include asthmatics and individuals with cardiovascular disease or chronic lung disease (such as bronchitis or emphysema) as well as children and the elderly.

Lead emissions occur only with the Conversion Technologies. However, because the vast majority of the lead is captured in particulate control systems that are an essential part of all solid waste conversion systems, lead emissions are calculated to be very small. Despite the presence of some lead in the three Conversion Technologies, lead emissions are sufficiently low that none of the Conversion Technologies has the potential for significant lead impacts to human health.

Regulations exist that address particulate matter as a whole, irrespective of the chemical constituency of the particles. Older regulations addressed a poorly defined pollutant known as TSP. Those regulations have mostly been replaced by regulations for particles with specific size specification, such as $PM_{2.5}$ for particles smaller than 2.5 micrometers in mass-mean diameter. In the current discussion, we address particulate matter in general, but also provide qualitative discussion of the different particle sizes emitted by the solid waste options.

Particulate matter is formed in all combustion processes, especially with solid fuels. For the Conversion Technologies, there are extensive control systems installed to reduce particulate emissions. The particulate emissions quoted here reflect typical systems, but it is possible to reduce the emissions for all Conversion Technologies by increasing the capture efficiency of the control device. Advanced thermal recycling shows very low particulate emissions due to the two stages of particulate control used. The landfill gas technologies have significant particulate emissions, but it should be noted that much of the particulate at the landfill results not from the gas combustion systems, but rather as fugitive dust from the handling and movement of the solid waste. Typically the particle sizes for fugitive dust are larger, and hence have lower health impacts than the smaller particles from combustion. Major concerns for human health from exposure to particulate matter are: effects on breathing and respiratory systems, damage to lung tissue, cancer, and premature death. The elderly, children, and people with chronic lung disease, influenza, or asthma tend to be especially sensitive to the effects of particulate matter.

In addition to the criteria pollutants discussed above, there are a host of other air pollutants for which no ambient criteria exist. Those that have human health impacts are frequently called “air toxics” or “HAPs.” We have not attempted to quantify all these contaminants here, but rather focused on a few that are of particular interest in the solid waste industry. The general pollutant called VOCs includes a large number of these air toxics. Many, though not all, of the air toxic issues can be evaluated using VOC emission rates. In fact, as discussed previously, the issue of VOCs is one of the significant differences between the Conversion Technologies and the Waste Export Disposal Option. VOCs are essentially unburned gases and since the Conversion Technologies burn virtually all of the hydrocarbons in the solid waste, they have little to no VOC emissions. Landfills, on the other hand, create landfill gas and a certain percentage of this gas escapes as a fugitive emission. These fugitive emissions can contain a variety of chemical species, such as benzene or vinyl chloride, that are known carcinogens. Both landfill gas alternatives have significant emissions of VOCs compared with the Conversion Technologies. The private regional landfills considered in this report have significant buffer areas between the waste disposal areas and any off-site property, so concentrations of these gases in the ambient air are greatly diluted before reaching off-site areas.

The combustion of solid waste does, however, produce some air toxics that landfills do not produce in significant quantities. The burning of plastic material that contains chlorine, such as polyvinylchloride (PVC), produces higher HCl emissions than occur in a landfill. The advanced thermal recycling Conversion Technology has a specific scrubber designed to control these particular emissions. The other two Conversion Technologies have significant emissions of HCl compared with landfills, although both technologies could add similar scrubbers. HCl is an acid-forming gas that can impact human respiratory systems.

The family of compounds known as dioxins and furans are also produced in solid waste combustion. These highly carcinogenic compounds are always an important issue for any system that combusts solid waste. Modern solid waste combustion systems have been designed to minimize dioxin and furan emissions by maintaining high enough temperatures to destroy them in the combustion process. Especially with the advanced thermal recycling option, the reported emissions of these compounds are sufficiently low to not cause human health concerns.

Finally, mercury is an increasingly important pollutant in the solid waste industry. Landfill flares emit small amounts of mercury, but higher levels are found in direct solid waste combustion systems. Mercury emissions from the Conversion Technologies can be reduced with the use of carbon injection systems as part of the air pollution control equipment.

In summary, all five of the technologies considered in this section will be required to operate under the terms of an air quality permit, which will limit the potential for these facilities to impact human health. There are, however, differences between the technologies in terms of the residual impacts that are left after the imposition of controls required by the permits. Both landfill gas technologies emit significant quantities of VOCs that are not emitted by any of the Conversion Technologies. Conversely, the Conversion Technologies, as typically implemented in the United States in the past, have had higher emissions of combustion products such as NO_X and SO_2. The advanced thermal recycling Conversion Technology, due to its advanced air pollution control system, is reported to emit low levels of these criteria pollutants. We believe the same type of equipment could be added to mass burn or RDF facilities to obtain similar results.

Human Welfare Issues

In addition to human health, air pollutants pose a number of potential human welfare issues. These include nuisance impacts, typically dust and odor, as well as visibility degradation. Air quality permits are designed to protect human welfare in addition to human health, and since all five of the technologies considered in this section would be subject to air quality permit requirements, the human welfare impacts of these options would be limited. Presented below is a general discussion that allows the disposal options to be compared in terms of the potential to impact human welfare, without actually quantifying the level of impact.

The term "dust" refers to particulate matter released from the movement or handling of personnel and materials using heavy equipment. The smaller dust particles pose some human health impacts and have been discussed above, but larger particles are incapable of penetrating the human lung and generally pose few human health issues. Dust consists of particles of all sizes, but since the human health impacts of the small particles contained in dust were addressed above, the current discussion concerns the larger particles. The impacts of dust are usually close to the source of emission because the larger particles do not travel well in the atmosphere. The usual impact from dust emission is soiling, where a layer of particle matter can settle on surrounding property.

The handling of solid waste always poses some dust issues, but at Conversion Facilities, it is easier to control dust by enclosure or capture. Landfills operate in the open air, exposed to wind, and dust can be a significant issue. Sources of dust emission at an operating landfill include the dumping of waste, the subsequent movement and placement of the waste in the active face, the compacting of the waste, the handling of cover materials as well as cell construction materials, and the travel of trucks and other heavy equipment on unpaved surfaces. Dust impacts on surrounding neighbors can be significant if the neighbors are in close proximity. In the case of the private regional landfills considered for this report, we assume there are no close neighbors and dust emissions are not typically an issue.

Odor is always an issue with any facility that handles solid waste. Similar to dust, the odor is easier to control at Conversion Facilities, since the places where solid waste is exposed can be enclosed and the air can be captured and routed to combustion or control systems. Also, solid waste at Conversion Facilities is not normally kept on-site for sufficient time to allow significant biological gas production to occur. Landfills, on the other hand, deal with solid waste in the open air and more importantly, promote anaerobic decomposition which produces hydrogen sulfide and other odorous gases. Landfill gas has an extremely strong and offensive odor. The two landfill gas technologies considered in this report employ active gas control systems that are intended to capture the majority of the landfill gas and route it to some form of combustion system. However, a certain percentage of the gas escapes to the atmosphere and poses the potential for odor impacts. In the case of the private regional landfills considered here, there are no close neighbors and odor is not currently a significant matter.

Visibility degradation is an increasingly important issue for combustion facilities. National parks and wilderness areas, as well as some other special lands, have been designated as Class I areas under the Clean Air Act and afforded special protection from visibility degradation. Evaluation of visibility degradation is required, even for facilities located hundreds of miles from a Class I area. Special long-range transport air quality models are used to evaluate these impacts. Of particular concern are emissions of sulfur and nitrogen oxides, since these pollutants can form sulfate and nitrate particles in the atmosphere. These small aerosols, as they are called, are major contributors to visibility degradation. The landfill gas technologies have fewer issues with visibility degradation for several reasons. The trend for the siting of new large landfills in both Washington and Oregon has been east of and far from the Class I areas in the Cascade Mountains, thus landfills that might be considered by King County for future disposal are less likely to impact these Class I areas. Also, the relatively lower emissions of SO_2 and NO_X associated with the landfill gas technologies, when compared with the Conversion Technologies (except advanced thermal recycling), lead to lower potential visibility impacts. For the Conversion Technologies, visibility degradation, unless addressed in the design of the air pollution control equipment, could become a major issue since National Parks Service and USDA Forest Service criteria for visibility degradation are very stringent and any significant source of SO_2 and NO_X in Western Washington would be rigorously evaluated.

In summary, as with human health issues, the human welfare issues are also limited by the air permit process and all of the technologies in this review here should be capable of being operated in such a way that there will be little to no impact to human welfare. The residual impacts after all of the permit controls are implemented will likely show that landfills have greater potential dust and odor impacts, while the Conversion Technologies may have greater potential to impact visibility unless properly addressed.

Ecological Damage

Emissions of air pollutants from solid waste facilities can impact the natural environment in several ways. The most important of these is the potential for acidification of water systems as a result of sulfur and/or nitrogen oxide emissions. The process, referred to as "acid deposition" can impact streams, wetlands, and sensitive plant habitats. As with the above impacts, the air quality permits will impose requirements on the acid-forming pollutant emissions from all the technologies reviewed in this section. In general, technologies with higher SO_2, NO_X, or HCl emissions will have the greater potential for acid deposition and its associated impacts. Thus, the Conversion Technologies, with the exception of advanced thermal recycling, have greater potential for acidification impacts than the landfill gas technologies, unless the mass burn and RDF technologies address this matter by adding scrubbing capability.

Specific toxicity is another form of ecological damage, where a particular pollutant may cause impacts to a plant or animal species. The level of detail of this study precludes the evaluation of specific toxicity issues for any of the disposal options. Typically, specific ecological toxicity is not a significant issue for solid waste facilities.

Eutrophication refers to a shift in the nutrient balance for plants and microorganisms in the ecosystem. There is no evidence to suggest that any of the technologies reviewed here have the potential for this type of impact through airborne release and deposition.

In summary, none of the solid waste disposal technologies poses a specific threat for ecological damage. The potential exists for some of the Conversion Technologies, unless designed to reduce acid-forming pollutant emissions, to cause some acidification if sensitive environments are located close to the facility. But it is unlikely these impacts would be significant enough to make a distinction between the disposal options.

Global Warming

The subject of global warming refers to the potential for climate modification caused by emissions of carbon and nitrogen species from man-made sources. After some years of scientific uncertainty and controversy, it is becoming increasing clear that man-made emissions of these chemical species have resulted in increased airborne concentrations worldwide and are almost certainly modifying the earth's climate. The major contributors are CO_2, CH_4, and to a lesser extent, N_2O. Collectively, these chemical species are referred to as "greenhouse gases." These chemical species have previously not been addressed in air pollution regulations and in fact, until recently, have not been considered pollutants in the atmosphere. However, recent concern about the climate modification effects of greenhouse gases requires that global warming potential be evaluated for the solid waste disposal options considered here.

It is important to understand that the subject of global warming and the effects of greenhouse gas emissions have only recently emerged as an air quality issue. For example, as recently as April 2, 2007, the EPA was instructed by the U.S. Supreme Court that it did have the regulatory authority to regulate greenhouse gas from mobile sources, after the EPA had argued before the Court that it had no such authority. As part of the preparation of this report, we contacted the Puget Sound Clean Air Agency and asked for guidance. The response from the Puget Sound Clean Air Agency was that they had no guidance in these areas, although they anticipate developing such guidance at some time in the future. Although there is a great deal of literature on the topic, there is little formal guidance on how to evaluate the global warming potential of projects such as the solid waste disposal options being considered by the County.

There are, however, a number of conclusions that can be drawn. The topic is complicated by the fact that the different greenhouse gases have different global warming potentials. A compounding complexity is that the greenhouse gases have different residence times in the atmosphere. For example, the two most important greenhouse gases, CO_2 and CH_4, illustrate this point. On an instantaneous basis the global warming potential for CH_4 is more than 50 times greater than CO_2, but because CO_2 has a much longer residence time in the atmosphere (100 years or more) compared with CH_4 (typically 13 years) the actual relative impacts on global warming of these two greenhouse gases differ, depending on how far out in the future one calculates the impacts. Although nothing has been standardized in this rapidly evolving science, it has become somewhat standard practice, for example in the Kyoto Protocol, to use 100 years as the time period and a factor of 21 to relate the global warming potential of these two greenhouse gases. Accordingly, in the current analysis we have computed an artificial pollutant, called CO_2 equivalents, which adds CO_2 emissions to 21 times methane emissions. Similarly, for a 100-year horizon, N_2O emissions are 310 times more potent as a greenhouse gas than CO_2, so CO_2 equivalents are also computed by adding 310 times the N_2O emissions. These are then further reduced to "carbon equivalents" by multiplying the CO_2 equivalents by the ratio of molecular weights, 12/44. Carbon equivalents are customarily reported as metric tons carbon equivalent, or MTCE.

When the greenhouse gas emissions of the five technologies are considered, we estimate that the three Conversion Technologies have larger greenhouse gas emissions than the two landfill gas technologies. In making these estimates, we have made several assumptions, including:

1. 20 percent of the landfill gas escapes combustion and is emitted to the atmosphere as a mixture of approximately 55 percent methane and 45 percent CO_2.
2. Landfill gas emissions occur over time while Conversion Technology emissions occur as the waste is combusted, so in making these comparisons, the landfill gas emissions resulting from 20 years of disposal were computed for many years in the future after disposal is assumed to have ceased.

One important assumption we made in the calculation of greenhouse gas emission rates for these solid waste disposal options concerns the issue of avoided emissions. By combusting solid waste and generating electricity, Conversion Technologies avoid other means of electrical generation and the greenhouse gas emissions associated with those generation methods. The current analysis was performed using two methods. Values shown in Table 10-9 are based on an assumption that the avoided electricity would be from natural gas combustion in a modern combined-cycle plant, capable of recovering 40 percent of the energy in the gas as electricity. An alternative analysis was also performed using Department of Energy guidance, which reflected the methods actually used in the Washington State to generate electricity. So while some credit is given for the avoided emissions, it is not as much as might be given if all the avoided emissions were assumed to result from the national average electrical generation methods, where a large fraction is assumed to result from coal combustion, a method having much greater greenhouse gas emissions per unit of electricity than either of the two methods considered here. This single factor contributes to the differing conclusions that other researchers have published that indicate Conversion Facilities are on par or better than landfills in terms of greenhouse gas emissions. If national average energy displacement factors are substituted in our calculation spreadsheet, the Conversion Technologies have lower greenhouse gas emissions than flaring, but energy recovery from landfill gas is still lower in greenhouse gas emissions than the Conversion Technologies. If, however, the gas collection percentage is lowered to 70 percent for the landfill gas technologies and the further assumption is made that national average energy displacement factors (including coal burning) are appropriate, then the Conversion Technologies have lower greenhouse gas emissions than either of the two landfill gas technologies.

However, we believe that the current analysis should reflect realistic energy generation methods in Washington State and we think it is unrealistic to assume that large quantities of coal combustion would be offset by the combustion of solid waste or landfill gas. Accordingly, the current analysis has focused on avoided emissions using the two methods described above.

In addition, the future may hold opportunities for new technologies such as carbon sequestration and other means to avoid greenhouse gas emissions. The current analysis gave no consideration to the possible implementation of any of these new technologies.

In summary, both disposal options have emissions of greenhouse gas, but it should be recognized that solid waste is a product of society and, if left unaddressed, it will decompose and generate massive quantities of CH_4 with large global warming implications. Thus, all solid waste disposal technologies considered here reduce global warming impacts when compared with having no plan to deal with the disposal of solid waste. The landfill gas technologies have somewhat lower greenhouse gas emissions than the Conversion Technologies.

Summary

The major conclusions of this air quality analysis are:

1. Criteria pollutant emissions from all disposal technologies would be expected to be well controlled and not produce any significant human health or welfare impacts. Conversion Technologies would generally be expected to have higher emissions than landfill gas technologies, with the exception that VOC emissions from landfills are much higher than Conversion Facilities.
2. Toxic pollutant emissions from all disposal technologies would be expected to be well controlled and not pose any significant human health impacts. Landfill gas technologies would be expected to have significantly higher toxic emissions than Conversion Technologies because of the large volumes of fugitive landfill gas that are unavoidable with even the best operated landfills. Conversion Technologies would be expected to have higher emissions from a few specific toxic pollutants of concern, such as dioxins, that are not produced in significant quantities from landfills. In all cases these toxic emissions would be expected to be very low.
3. Greenhouse gas emissions are an unavoidable consequence of the disposal of solid waste generated by human civilization. All of the disposal technologies reviewed here can be expected to result in reduction of greenhouse gas emissions over any alternative that does not convert or properly dispose of solid waste. Conversion Technologies were seen to have somewhat higher greenhouse gas emissions than the landfill gas technologies, but the actual relative difference is a strong function of the assumptions used in the analysis.

Section 11
ESTIMATED CAPITAL COSTS AND OPERATING EXPENSES

R·W·BECK

Section 11
ESTIMATED CAPITAL COSTS AND OPERATING EXPENSES

This section of the report presents the results of R. W. Beck's review of the estimated range of capital costs and annual operating expenses for the three Conversion Facilities and the Waste Export Option. These estimates are also used in Section 15 as a part of a comparative cost analysis.

All of the options will require continued use of the County's existing solid waste transfer stations. As discussed in the County's Waste Export Plan, if the County chooses the Waste Export Disposal Option, it will likely also need to plan for the construction of a new intermodal facility. If the County elects to utilize a Conversion Technology, it will still need to transport bypassed waste and residue ash via rail-haul. Therefore, an intermodal facility may still be required, although the County would want to carefully consider whether it would be better for the County or a private company to own and operate the intermodal facility under this option.

Estimated Capital Costs

Conversion Technologies

It is important to note that the last new waste-to-energy facility utilizing mass burn technology was constructed in the United States between 1993 and 1995 in Montgomery County, Maryland. The last new waste-to-energy facility utilizing RDF technology was constructed between 1987 and 1990 in the City and County of Honolulu, Hawaii. During the last 20 years, many waste-to-energy full service (design-build-operate) contractors have exited the business. These companies include but are not limited to Westinghouse, Foster Wheeler, Raytheon, and General Electric. With Covanta Energy's recent acquisition of American Ref-Fuel, only four major companies in the United States have experience in the construction and operation of waste-to-energy facilities: Covanta Energy, Energy Answers, Montenay Power, and Wheelabrator Technologies. In the early 2000s, a number of older waste-to-energy facilities began to implement retrofits to continue operating beyond 20 years. For example, Lee and Hillsborough Counties, Florida are adding 600-TPD units to expand their waste-to-energy facilities. In 2006, a complete retrofit was undertaken to an 800-TPD waste-to-energy facility in the City of Harrisburg, Pennsylvania. In Maryland, the Northeast Maryland Waste Disposal Authority is procuring a new waste-to-energy facility to serve Carroll and Fredrick Counties, and an expansion or upgrade to a 360-TPD waste-to-energy facility in Harford County.

Due to the lack of development activity in the last 10 to 15 years, the major companies in the waste-to-energy industry reduced their engineering staffs, thus depleting institutional knowledge. For this reason, capital construction cost information in the United States is over 15 years old.

A Conversion Facility utilizing advanced thermal recycling technology has not been constructed in the United States. Worldwide, the last new facility to commence commercial operation was the MVR facility in Hamburg, Germany, which started operating in 1999.

The development of detailed construction cost estimates for three Conversion Facilities and the Waste Export Option was well beyond the scope of services to be provided as part of the preparation of this report. Such estimates would require three to six months to develop and would cost well in excess of $100,000 to prepare.

Therefore, for the purpose of preparing this report, we contacted vendors in the Conversion Technology industry to obtain updated estimates of capital costs for Conversion Facilities. We also obtained and analyzed cost and performance information related to numerous existing waste-to-energy facilities in the United States from their in-house information and from industry data.[1] It is important to note that the cost data that we reviewed for this assignment varied widely, which should serve as a warning that the cost of constructing and operating a Conversion Facility is quite project-specific. Based on all of this, as well as our engineering judgment, we prepared the planning-level estimates contained in this report. This data is intended only to be used for comparison purposes with the other alternatives. If the County decides to move forward with the development of a Conversion Facility, a more detailed analysis of the construction costs would need to be completed. The following sections provide background information and our key assumptions.

Capital Cost

The capital costs for the three Conversion Facilities include provision to construct the facility, excluding electrical interconnection. Capital cost estimates are expressed in 2007 dollars. Actual future costs are likely to vary from the estimates presented herein. The planning-level estimate for each Conversion Facility included the following components:

- No direct costs to purchase land for the facility site – given the varying and speculative nature of land prices in the County, and the comparatively small expense, direct land costs were not included;
- Waste Receiving and Storage – three days enclosed waste storage;
- Waste Processing (RDF only) – two-stage shredding for size reduction, screening to remove glass and inert fines, two-stage magnetic separation to remove ferrous metal, and an eddy current separator to remove aluminum;

[1] Eileen Berenyi, *The Municipal Waste Combustion Industry in the United States: 1997-98 Resource Recovery Yearbook and Directory*, 7th ed. (Westport, CT: Governmental Advisory Associates, Inc., 1997).

- Building – enclosures for the tipping and waste storage areas, a furnace-boiler room, a residue handling and ash storage building, a turbine-generator hall, an administration area, and a maintenance shop (note that air emissions control equipment, cooling towers, and electrical switchyard are typically located outdoors or partially enclosed by a screen wall);
- Waterwall Furnace-Boilers – grate systems, superheater sections, steam generating convection banks, feedwater economizers, combustion air systems, steam coil air heaters for underfire air, auxiliary fuel burners, and selective non-catalytic reduction (SNCR) systems for nitrogen oxides (NOx) removal;
- Air Emissions Control Equipment (mass burn and RDF) – spray dryers with lime handling system for acid gas removal, fabric filter baghouses for particulate removal, carbon injection system for mercury removal, continuous emissions monitoring system, and stack;
- Air Emissions Control Equipment (advanced thermal recycling) – two-stage fabric filter baghouses for particulate removal, hydrochloric acid (HCl) removal scrubber with HCl recovery/polishing system, sulfur dioxide (SO_2) removal scrubber with gypsum recovery/polishing system and lime handling system, carbon injection system for mercury removal, continuous emissions monitoring system, and stack;
- Balance of Plant – scale facility, operations control center, ferrous metals recovery from residue ash, turbine-generator, shell and tube condenser, air-cooled condenser, and water treatment system;
- Full Service Contractor's Project Development "Soft" Costs – engineering, permitting, start-up, performance testing, spare parts, and contingency.

Table 11-1 presents the estimated range of capital costs for the three Conversion Technologies expressed in 2007 dollars. The costs are expressed in terms of: 1) the dollars per ton of daily disposal capacity (for example, a mass burn facility is estimated to cost between $145,000 and $160,000 per ton of daily disposal capacity), and 2) the cost of the entire facility.

Table 11-1
2007 Estimated Capital Costs

Conversion Technology	Daily Rated Capacity (TPD)	2007 Capital Unit Cost Range ($/TPD)	2007 Capital Cost Range ($ millions)[1]
Mass Burn	3,200	~145,000 – ~160,000	$460 – $520
RDF	3,200	~175,000 – ~190,000	$560 – $610
Advanced Thermal Recycling	3,200	~160,000 – ~175,000	$520 – $560

To develop an estimate of the cost to construct a Conversion Facility commencing construction in 2013 that would be ready for commercial operation in 2016, the estimated costs in Table 11-1 would have to be increased from 2007 to 2013 by the appropriate index. It should be noted that in recent years, the increase in the cost of steel has significantly exceeded the rate of inflation.

It should be noted that we have not included provisions for the cost of land in the capital cost estimate. This was done for the following reasons:

1. The cost of land can vary significantly from site to site throughout the County.
2. In today's real estate market it would be difficult to develop a meaningful estimate of the cost of land four or five years in the future.
3. The amount of land that would be required could vary depending upon policy decisions the County must make regarding the types of vehicles that would access the site of the Conversion Facility or Intermodal Facility. For example, would collection vehicles be allowed to deliver directly or would only transfer vehicles from transfer stations have access to the sites.

Intermodal Facility

The Waste Export Option would require a truck-to-rail intermodal facility at which waste containers from the County's transfer station system would be loaded onto a train for transshipment to a remote landfill and empty containers would be off-loaded from the train. Since the Waste Export Option will depend on the availability of efficient and cost effective operation of an intermodal facility, the County will need to consider the cost and operational advantages of adding an intermodal facility before the Waste Export Option begins. The Waste Export Option has been discussed in the County's Waste Export Plan, as well as other Solid Waste Division publications during the last five years. For this section of the report we have developed a planning estimate of the capital cost of an intermodal facility based on certain specific assumptions.

An intermodal facility located in King County is assumed to be designed to move sealed waste containers from trucks to rail cars since the regional landfills available to King County are most easily and cost effectively accessible by rail. In a 2005 report for the Solid Waste Division,[2] R. W. Beck developed an estimate of the capital costs of a truck-to-rail intermodal facility assumed to be constructed at the King County Road Division's Covington Pit Site and owned by the County. Based on this analysis, we estimated that in 2005 a suitably sized intermodal facility would cost the Solid Waste Division approximately $14,600,000 for the facility and an additional $1,200,000 for the cost of equipment. Escalating these numbers to 2007 dollars at 2.4% per year results in an estimated capital cost of approximately $16,500,000. As with the Conversion Technology costs listed previously, this estimate does not include the cost of the land on which the facility would be built.

Estimated Annual Operating Expenses

Conversion Technologies

Similar to the methodology used to develop estimated capital costs, for the purpose of developing estimates of operating and maintenance expenses, we contacted full-service contractors in the Conversion Technology industry to obtain information on estimated operating expenses. The operating expenses include provision for operating labor, routine maintenance labor, parts and supplies, outside service and maintenance contracts, major maintenance fund for renewals and replacements, general and administration, contractor's profit, electricity, fuel, and "normal" pass-throughs such as chemicals, insurance, and utilities. The estimate does not include property taxes or host fees, which are site-specific. Table 11-2 presents estimated operating expenses for the three Conversion Technology alternatives as unit rates ($/ton) expressed in 2007 dollars. These estimates are for planning purposes and are meant primarily to show the relationship between the three Conversion Technology alternatives. Actual future costs are likely to vary from our estimates.

[2] R. W. Beck, "Work Order No. 2 - King County Roads Division Covington Pit Site Feasibility Evaluation (Draft)," October 28, 2005, technical memorandum.

Table 11-2
2007 Estimated Operating Expense Unit Rates

Conversion Technology	2007 Operating Expense Unit Rate Range ($/ton processed)
Mass Burn	$29 - $35
RDF	$42 - $47
Advanced Thermal Recycling	$39 - $46

Note: Operating expense unit rates exclude residue ash transport and disposal costs, which are shown on Table 11-3.

Major maintenance funds are for repairs and the replacement of major equipment, systems, and structures that have useful lives greater than one year. Most Conversion Technology facilities in the United States are either privately owned or operated by the private sector in accordance with long-term operating agreements. As such, the private operator is responsible for repair and replacement of the equipment. The estimated operating costs for the three Conversion Technologies include provisions for the maintenance funds as part of the operating expenses, which could vary widely from project to project. The publicly owned and operated facilities with which we are involved would normally include the costs of such repair and replacement in a major maintenance fund. When we estimate the funding levels required for these maintenance funds, we normally use annual contributions in the range of $2.00 to $3.00 per annual ton processed depending on the size of the facility. The unit operating expenses in Table 11-2 include $2.00 per ton for major maintenance funds. In addition to repair and replacement costs, owners of facilities are prudent to establish funds for unknown future capital costs related to changes in regulations and other uncontrollable circumstances. The level of funding of this capital reserve fund varies from owner to owner and is not included in the annual operating expense estimates.

Cost of Residue Ash Disposal Out-of-County

In order to estimate the cost of residue ash disposal, R. W. Beck contacted representatives of the owners of the two operating Conversion Facilities which are closest to King County. These are located in Spokane, Washington and Marion County, Oregon. We discussed the methods these facilities use to dispose of their residue ash and obtained information regarding current costs. Since each facility uses its own method for residue disposal, each is discussed separately.

When Marion County began operating its mass burn facility, it also used a county-owned piece of property to develop a residue ash monofill. Currently, all residue ash produced by the Marion County facility is brought to this monofill via truck, where it is disposed of. Marion County opted for this method of disposal because the local, privately owned regional landfill does not have an ash monofill and the owner of that landfill would have charged Marion County higher tipping fees for the development of one. Marion County estimates that the cost of residue ash disposal in its monofill is between $28 and $30 per ton.

As discussed in Section 9 and Appendix B, the Spokane System[3] facility uses rail-haul to transport its residue ash to the Roosevelt Regional Landfill in Klickitat County, where it is disposed of in a monofill. Recently, the Spokane System submitted a request to change its residue classification from "Special Incinerator Ash" to "Solid Waste." This modification will result in a change in the requirement that its residue ash be disposed of in the monofill. The residue ash can now be disposed of with other MSW at the landfill, or potentially be used as an alternate daily cover material. Disposal of residue ash at the monofill currently costs the Spokane System $22.26 per ton to transport and a $23.23 per ton tipping fee at the landfill ($45.49 per ton total). With the new classification, the cost of transport and disposal of the residue ash will be similar to the Spokane System's cost of $45.44 per ton for disposal of bypassed waste. However, preliminary indications are that if the residue ash is deemed by DOE to be usable as alternate daily cover, the price would be reduced by around $5 per ton to around $40 per ton.

Since the transport and disposal of residue ash is usually contracted through a competitive bidding process, the cost of managing residue ash from a King County facility will be significantly impacted by the business decisions made in 2016 by private landfill and rail owners and operators. Table 11-3 outlines our current estimate of the potential cost of residue ash disposal based on the information we received from other municipalities.

Table 11-3
2007 Estimated Residue Ash Disposal Rates
($/ton disposal)

Transport	Disposal	Total
$18 – $25	$22 – $30	$40 – $55

Cost of Waste Export

In order to estimate the cost of exporting waste, we contacted representatives of Snohomish County, Kitsap County, and Seattle Public Utilities, which currently export their waste to large regional landfills. Waste from the City of Seattle and Kitsap County is hauled via rail to the Columbia Ridge Landfill located in northern Oregon. Snohomish County also uses the rail system but exports its waste to Roosevelt Regional Landfill in eastern Washington. Table 11-4 sets forth the reported costs for each municipality, separated into "transport" and "disposal" pieces where the information was available. The information for the Spokane System in Table 11-4 represents the cost of transport and disposal of bypassed waste from the Spokane Facility to the Roosevelt Regional Landfill.

[3] The Spokane Regional Solid Waste System ("Spokane System") includes Spokane County, the City of Spokane, 12 other cities and towns, and Fairchild Air Force Base.

Table 11-4
Representative Waste Export Rates
($/ton disposal)

Municipality	Transport	Disposal	Total
Snohomish County(1)	$27.78 – $28.96	$19.99	$47.77 – $48.95
Seattle Public Utilities(1)	NA	NA	$43.50
Kitsap County(1)	$14.72(2)	$17.47	$32.19
City of Spokane(3)	NA	NA	$45.44

(1) Prices are for 2006
(2) Transport does not include operation of the intermodal facility.
(3) Price for bypassed MSW.

We anticipate that waste transport and disposal services would likely be competitively bid by the Solid Waste Division. Therefore, the bids prepared by private disposal companies, including but not limited to those used by Snohomish County and Seattle Public Utilities, can be expected to be affected by the markets for waste, the amount of waste expected, and business goals of specific companies at the time of bid. Also, since Seattle Public Utilities and Snohomish County use privately owned and operated intermodal facilities, these costs are included in the transport price listed in Table 11-4. Kitsap County considers the cost of operating the intermodal facility to be a part of the transfer station operation and therefore such cost is not included in the transport price in Table 11-4. If the County chooses to construct and own an intermodal facility, it is possible that the transport costs could be reduced. Table 11-5 presents our estimates, based on current market conditions, of the range of waste export costs assuming that the transport component includes the cost of intermodal services. Also, in our rate estimate, we assume the waste containers and rail cars are owned by the private disposal and railroad companies respectively. This assumption is consistent with the Seattle Public Utilities and Snohomish County contracts. As noted above, it is possible that market conditions could change by 2016.

Table 11-5
2007 Estimated Waste Export Rates
($/ton disposal)

Transport	Disposal	Total
$25 – $30	$17 – $20	$45 – $50

Section 12
PROJECTED ENERGY REVENUES

Section 12
PROJECTED ENERGY REVENUES

Assuming that at some future time the County decides to utilize a Conversion Technology for waste disposal, and that it selects one of the three current commercially proven Conversion Technologies discussed at length in this report, that Conversion Technology would be capable of generating energy in the form of either steam or electricity. Similarly, under the Waste Export Disposal Option the decomposition of the County's solid waste in a landfill would result in the creation of methane gas, which can be captured and used to generate electricity. The purpose of this section is: 1) to provide an estimate of the potential amount of energy that could be generated during the 20-year study period by both the Conversion Facilities and the landfilled waste; 2) to provide a forecast of wholesale power market prices and the implied value of the landfill gas during the study period; and 3) to estimate the potential annual revenues that could be realized through the sale of electricity and/or landfill gas. These annual revenues are used in Section 15 as a part of the comparative cost analysis.

Potential Energy Generation

Conversion Technology Disposal Option

Electricity Generation

For the purpose of this report, we have developed a planning estimate of the amount of electricity that could be generated by a Conversion Facility.

We have found that for planning purposes, and based on our experience with currently operating Conversion Facilities, it is reasonable to assume that a Conversion Facility could generate approximately a net of 500 kWh to 550 kWh per ton of waste. Such a generation rate is net of the Conversion Facility's in-plant power requirements. This estimate assumes an annual average heating value of the solid waste of approximately 5,000 Btu per pound. It should be anticipated that the heating value of solid waste will fluctuate throughout the course of the year depending upon the amount of precipitation, variations in the composition of the incoming waste, and future changes in packaging.

For the two Conversion Facilities sized at 3,200 TPD with a 90 percent annual availability, we calculate that the following annual quantities of electricity could be generated:

1. 500 kWh/ton: 525,600,000 kWh/year
2. 550 kWh/ton: 578,200,000 kWh/year

An RDF Conversion Facility is assumed to have an annual plant availability of 87 percent, compared to 90 percent for mass burn and advanced thermal recycling, but net energy generation values for RDF facilities are generally slightly higher than mass burn or advanced thermal recycling facilities. Therefore, for the purpose of this section of the report, we have treated the three Conversion Technologies equivalent from an energy generation perspective.

Steam Generation

It is possible for a Conversion Facility to generate steam for sale to a steam user. However, we have focused the discussion on the sale of electricity, rather than the sale of steam, for the following reasons:

1. Finding a suitably sized facility site adjacent to a steam customer could significantly complicate the entire siting process for a Conversion Facility, as it will limit potential sites to only those very near or adjacent to large steam users.
2. A single Conversion Facility sized at 3,200 TPD would be capable of generating approximately 600,000 pounds of steam per hour. This quantity of steam is likely to exceed the steam requirements of most potential steam customers.
3. Conversion Facilities are intended to operate 24 hours per day, seven days a week in order to dispose of the solid waste. They would not stop operations because the steam customer is unable to take steam for some reason due to an upset condition in the processing facility.

For informational purposes, we estimate that a Conversion Facility of 3,200 TPD could reasonably be expected to be able to generate approximately 5,250,000,000 pounds of steam per year. What a potential steam customer would be willing to pay for such steam will depend upon the type of fuel the steam customer is currently using, whether the steam customer can avoid major capital expenditures associated with the steam customer’s existing steam plant, and the potential savings in operating and maintenance expenses of no longer having to operate a steam plant.

Waste Export Disposal Option

Landfill Gas Production and Electricity Generation

For the purpose of being able to compare energy generation options, we have assumed for the Waste Export Disposal Option that all of the County’s solid waste will be disposed of in its own operating cell at a privately owned landfill. We have made this assumption in order to develop an estimate of the amount of landfill gas that could be generated and collected from just the County’s waste. It should be noted that under actual operation, County waste will likely be mixed with other sources of solid waste. We have further assumed that the collected landfill gas will be used on-site by a private party to generate electricity that will be transmitted to the grid. The analysis assumes that the County does not own the generation equipment itself.

In developing an estimate of the amount of landfill gas that could be collected and burned to generate electricity for the planning period 2016 through 2036, we have utilized the estimated quantities of County waste discussed in Section 2. It is important to note that unlike the Conversion Facilities, where the energy revenues will accrue to the benefit of the County, the revenues from the sale of landfill gas will not be under the control of the County. This is because under the Waste Export Disposal Option it is assumed that the County will not own: 1) the land where the waste is disposed of, 2) the landfill gas collection and cleanup equipment, or 3) the electricity generation equipment. We are not able to determine whether the County will realize any financial benefit in the form of decreased tipping fees associated with the sale of the landfill gas or electricity therefrom. It has been our experience that the tipping fees charged by private waste disposal companies are more a function of what the market will allow rather than the net cost of operation.

It should also be noted that, as discussed in Section 10, landfill gas will continue to be generated in measurable quantities for more than 40 years after it has been disposed of in a landfill. Therefore, landfill gas will continue to be generated well after 2036, the end of this study period. We have calculated the energy revenues from landfill gas sales for only the period 2016 through 2036 in order to provide a comparison of revenues generated by landfill gas with the revenues estimated to be generated by the Conversion Facilities during the same time period. It is also worth noting that properly operated Conversion Facilities can be expected to have useful operating lives of up to 50 years, which is 30 years more than the planning period.

We have also utilized an existing computer model (called the “Landfill Gas Program”) which we previously developed. The Landfill Gas Program considers the annual quantity of waste disposed of, the moisture content, the organics content, a landfill gas generation rate coefficient factor, assumed number of Btus per cubic foot of gas generated, the biochemical methane potential expressed in cubic feet per pound, the percentage of landfill gas that is able to be collected, the generation period, and the amount of landfill gas required to generate a kWh of electricity. The Landfill Gas Program considers the fact that the amount of landfill gas generated from a specific delivery of solid waste generally peaks after the first five years in the landfill and decreases thereafter. It also considers the fact that additional quantities of solid waste are being disposed of during the study period. Therefore, while the amount of landfill gas generated by a specific delivery of solid waste decreases with time, the total amount of landfill gas generated will increase each year of the study period with additional deliveries of solid waste.

The results of our estimate of the annual quantities of landfill gas that could be generated and collected each year from just County waste are presented in Table 12-1.

Table 12-1
Estimated Landfill Gas Generation

Year	Tons of Waste Landfilled	Amount of Landfill Gas Generated (cubic feet/ minute)	Amount of Landfill Gas Collected (cubic feet/ minute)	MMBtu/hour Collected and Sold
2016	1,164,301	538	431	12
2017	1,186,079	1,414	1,131	31
2018	1,208,538	2,407	2,287	63
2019	1,225,386	3,463	3,290	91
2020	1,249,642	4,487	4,263	117
2021	1,255,030	5,407	5,137	149
2022	1,277,946	6,238	5,926	163
2023	1,275,651	6,990	6,641	183
2024	1,299,948	7,674	7,290	201
2025	1,324,825	8,319	7,903	218
2026	1,324,286	8,902	8,457	233
2027	1,349,746	9,438	8,966	247
2028	1,362,825	9,933	9,437	260
2029	1,389,346	10,406	9,886	272
2030	1,416,287	10,868	10,325	284
2031	1,438,772	11,321	10,755	296
2032	1,461,558	11,759	11,171	308
2033	1,484,647	12,194	11,584	319
2034	1,507,747	12,611	11,981	330
2035	1,531,144	13,019	12,368	341
2036	1,554,841	13,409	12,739	351

Projected Energy Prices

R. W. Beck developed long-range energy price forecasts for: 1) the electricity that could be generated by the Conversion Facilities; and 2) the landfill gas produced by County waste at a landfill.

Presented below is a discussion of the methodology and principal assumptions we used to conduct the Pacific Northwest market price forecast. In preparing the price forecast, we have made certain assumptions with respect to conditions that may exist or events that may occur in the future. While we believe the use of these assumptions to be reasonable for the purposes of this report, we offer no other assurances with respect to these forecasts, and it should be anticipated that some future conditions may vary significantly from those assumed due to unanticipated events and circumstances. To the extent that future conditions differ from those assumed in the analysis, actual results and outcomes may vary from those projected.

Projected Electricity Prices

We have assumed the Conversion Facilities will generate electricity which the County will be able to sell to reduce the cost of waste disposal. Presented below is the methodology that was used to project the price of electricity in the Pacific Northwest.

Methodology

Energy Price Forecast

The prices that utilities pay for electricity generated by plants such as the Conversion Facilities are generally comprised of both energy and capacity components. In some U.S. markets, energy and capacity can be traded separately, while in other markets energy and capacity prices are combined and traded as a single commodity. To forecast market-clearing prices, we used a customized PowerBase™ database and the MarketPower™ and PROMOD™ simulation models. The PowerBase database is updated by R. W. Beck to make the database consistent with our general knowledge of the North American power markets and to agree with the principal study assumptions outlined in this report.

The MarketPower model performs a chronological economic dispatch of the multiple, interconnected market areas, simulating all loads and resources, transmission interconnections, and unit outages on an hourly basis for all years of the projections. As part of the preparation of this report, the entire Western Electricity Coordinating Council Region (WECC) was modeled simultaneously. This includes the Northwest Power Pool subregion, the California-Mexico Power Area, the Arizona-New Mexico-Southern Nevada subregion, and the Rocky Mountain Power Area. From this simulation, the model produces hourly, monthly, and annual average energy prices for individual market areas. The model also simulates the mothballing of uneconomic plants, forecasts additions of new capacity, and calculates initial capacity prices.

We use the PROMOD production costing model to test and evaluate the market prices and the capacity forecast developed by MarketPower. PROMOD also allows for the creation of hourly prices that reflect a more sophisticated unit commitment and dispatch algorithm; this is because PROMOD uses more detailed operating characteristics of generation units than those used in MarketPower. We have found that using these particular models in combination produces better, more robust price forecasts and asset valuations.

In this report, the calculation of the market prices for energy assumes that energy prices are based on the variable operating cost of the highest cost unit serving load during each hour. The variable cost includes all fuel costs, variable operating and maintenance (O&M) costs, and emission costs, and does not include any bidding adjustments to artificially increase or decrease the modeled marginal cost of power.

Capacity Price Forecast

Capacity value in a market is a reflection of the scarcity value of generating capacity during peak load hours of the year. Capacity value may manifest itself as price spikes in the energy market, as a separate capacity product (such as is traded in the PJM, New York, and New England power pools), or both. Long-term capacity value will be driven primarily by the overall load and resource balance within the region and the incremental cost of investment in generation additions. Over the long term, sufficient resources must be built to satisfy the demand within a given reliability region or transmission-congested area. In a competitive market, the selected resources will be the least, total-cost option for incremental generation within that region.

Modeled capacity prices within a given market area are determined by a residual fixed cost curve, defined as follows. Modeled energy market revenues earned by a resource are used to first offset the variable operating costs of the resource, with any surplus energy revenue being used to offset the fixed operating and maintenance costs and capital costs (if any) of the resource, including a reasonable rate of return. Any remaining unrecovered fixed costs represent a capacity component that the resource would have to recover from the marketplace to remain solvent. When the resources are sorted by their unrecovered fixed costs, the capacity value can be determined by the peak demand and required reserves in a given market area, as depicted in Figure 12-1.

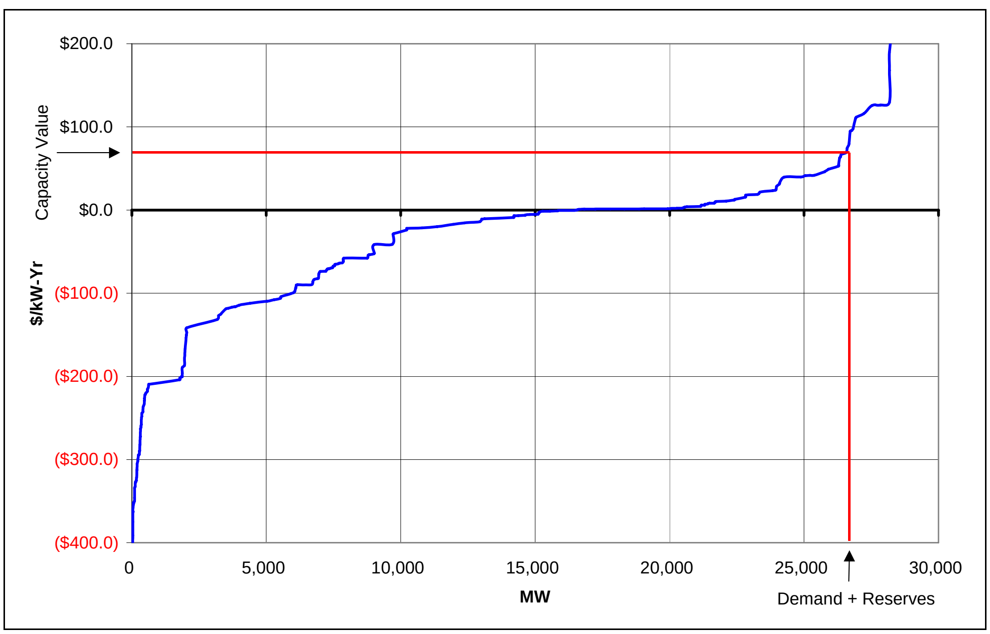

Figure 12-1
Example Residual Fixed Cost Curve

Within a competitive market, and based on an assumption of equilibrium over the long term, sellers should be able to recover the full fixed costs of the most cost-effective capacity resource in the market. In markets where surplus supply exists, owners of existing generating assets should reasonably expect to recover all variable and fixed operating costs. If operating costs cannot be fully recovered from the market, then the resource is a candidate for mothballing or retirement. In markets where supply and demand are in equilibrium, owners of newly installed generating assets should reasonably expect to obtain all operating and capital costs, including a reasonable rate of return. Otherwise, no new resources would be built and the market would enter a period a supply deficiency under which demand for power could drive market prices to values exceeding long-run marginal costs. We assume that over the long term, total market prices will not exceed those required by the least-cost new entrant.

We have developed the wholesale power price forecast and all asset-specific projections for electricity that would be generated by the Conversion Facilities. The prices in the power price forecast are based on assumptions about future market conditions, such as load growth and fuel prices, which we have assumed to represent a reasonable expectation of future conditions.

Prices were developed for the Western Washington market area, which is a market area defined by transmission constraints which separate it from the British Columbia market to the north, Eastern Washington to the east, and Eastern and Western Oregon to the south. Appendix A explains the principal assumptions that we used in the development of the power price forecast.

The results of the power price forecast are presented in Table 12-2.

Table 12-2
Base Case Power Price Forecast
($2007 per MWh)

Year	All-Hours Price
2007	49.87
2008	49.09
2009	44.86
2010	45.03
2011	46.82
2012	46.29
2013	46.62
2014	52.90
2015	52.31
2016	55.23
2017	56.73
2018	54.47
2019	54.09
2020	54.41
2021	54.59
2022	55.43
2023	56.45
2024	57.46
2025	56.66
2026	56.91
2027	57.24
2028	57.58
2029	57.91
2030	58.24
2031	58.58
2032	58.92
2033	59.26
2034	59.61
2035	59.95
2036	60.30

Note: Inflation assumed to be 2.4% per year

Implied Value of Landfill Gas

We have developed an estimate of the implied value of landfill gas based on: 1) the estimated power price forecast presented in Table 12-2, 2) the estimated operation and maintenance expenses incurred by a new landfill gas-fired generator, and 3) the required return on the capital investment to construct a new landfill gas-fired generator. We started with the assumption that the landfill gas-fired generator will be owned by a private third party and the calculation of energy revenues for the Waste Export Disposal Option is based on the sale of the landfill gas to the third party electricity generator.

Based on these assumptions, the implied valuation of landfill gas is presented in Table 12-3.

Table 12-3
Implied Value of Landfill Gas
($2007 per MMBtu)

Year	Price
2016	2.80
2017	3.15
2018	2.97
2019	3.06
2020	3.26
2021	3.44
2022	3.73
2023	4.06
2024	4.40
2025	4.44
2026	4.67
2027	4.92
2028	5.17
2029	5.43
2030	5.70
2031	5.98
2032	6.26
2033	6.56
2034	6.86
2035	7.18
2036	7.50

Projected Energy Revenues

Conversion Facilities

Based on an assumed net energy generation range of 500 to 550 kWh/ton of waste processed and the energy price forecasts presented in Table 12-2, we have calculated the range of annual energy revenues that a 3,200-TPD Conversion Facility could generate. The results of that calculation for certain years are presented in Table 12-4.

Table 12-4
Projected Revenues from the Sale of Electricity

		500 kWh/ton		550 kWh/ton	
Year	Price of Electricity (1) ($2007/MWh)	Annual Energy Generated (MWh)	$000	Annual Energy Generated (MWh)	$000
2016	55.23	525,600	29,029	578,200	31,932
2021	54.59	525,600	28,690	578,200	31,560
2026	56.91	525,600	29,914	578,200	32,905
2031	58.58	525,600	30,790	578,200	33,870
2036	60.30	525,600	31,693	578,200	34,862

(1) From Table 12-1.

Our analysis indicates that in 2016, a 3,200-TPD Conversion Facility operating at a 90 percent annual availability factor could be expected to realize between $29,029,000 and $31,932,000 in electricity revenues. By 2036 that estimate is calculated to range from $31,694,000 to $34,865,000. It should be noted that these estimates are all expressed in 2007 dollars.

Over the 20-year planning period, a 3,200-TPD Conversion Facility is calculated to generate between $630 million and $694 million in electricity revenues. Again, these estimates are all expressed in 2007 dollars.

Waste Export Disposal Option

For the Waste Export Disposal Option, we have assumed that collected landfill gas will be sold to a third party who will use the landfill gas at the site of the landfill to generate electricity which can be transmitted to the electrical grid. Based on this assumption, as well as the estimated annual generation of landfill gas as presented in Table 12-1 and the estimated levelized implied value of landfill gas of $4.06 per MMBtu, we have calculated the value of the gross revenues that could be expected to be generated from the landfill gas produced from that solid waste delivered by the County. The results of that calculation for certain years are presented in Table 12-5.

Table 12-5
Gross Energy Revenues from Sale of Landfill Gas

Year	MMBtu Collected and Sold(1)	Implied Value of Landfill Gas ($2007/MMBtu)(2)	Gross Revenues ($)
2016	105,120	$2.80	$294,336
2021	1,305,240	$3.44	$4,490,026
2026	2,041,080	$4.67	$9,531,844
2031	2,592,960	$5.98	$15,505,901
2036	3,074,760	$7.50	$23,060,700

(1) From Table-12-1 and integrated over the year.
(2) From Table 12-3.

Over the 20-year planning period, the Waste Export Disposal Option is calculated to generate approximately $215 million (2007 dollars) in revenues from the sale of landfill gas.

It should be noted that landfill gas generation occurs over a much longer time (over 40 years) than the 20-year planning period of 2016 to 2036. This means that while we have only considered the expected generation, collection and sale of landfill gas during the planning period, revenues could be generated from landfill gas generation through at least 2076. However, R. W. Beck has only considered the revenues that would be expected from the landfill gas during the 20-year planning period in order to facilitate comparison of the relative estimated value of energy revenues for the Conversion Technology Disposal Option and Waste Export Disposal Option. It is important to note again that under the Waste Export Disposal Option, the County would not receive any direct credit for any energy revenues from the sale of landfill gas because the County would own neither the land nor the equipment associated with the production and collection of landfill gas. We are not able to determine whether the tipping fee the County would pay under the Waste Export Disposal Option would be influenced by landfill gas revenues received by the owner of a landfill.

Summary of Revenues

Based on the forecast of the price of electricity discussed in this section, and assuming the operation of a 3,200-TPD Conversion Facility and a landfill that accepts only County waste, we calculate that the two options would generate the following amount of energy and generate the following amount of revenues.

Conversion Technology Disposal Option:

1. Total MWh Generated 2016–2036: 11.6 million
2. Total Revenues (2007 dollars): $662 million

Waste Export Disposal Option:

1. Total MMBtu generated 2016–2036: 39 million
2. Total Revenues (2007 dollars): $215 million

In reviewing the calculation of energy revenues, it is important to note the following:

1. For the purpose of this comparative analysis under the Waste Export Disposal Option, we have assumed the County will stop delivering solid waste to the out-of-county landfill in 2036.
2. The landfill can be expected to continue to generate landfill gas for at least 40 years after 2036, but we have not included years beyond the study period of 2016 to 2036.
3. The Conversion Facilities can be expected to have a useful operating life of 50 years if properly operated and maintained. This would extend the period of electricity generation for 30 years after 2036, but we have not included years beyond the study period of 2016 to 2036.
4. The County can expect to realize the financial benefits of generating electricity, as we have assumed it will own the Conversion Facility.
5. The County will not own the land or equipment associated with the generation of landfill gas. We cannot determine how likely it is that the County would realize any financial benefit from the generation and collection of landfill gas produced from County waste at a privately owned landfill.

Section 13
TRANSFER STATION COLLECTION/ TRANSPORTATION INFRASTRUCTURE

Section 13
TRANSFER STATION COLLECTION/ TRANSPORTATION INFRASTRUCTURE

This section of the report presents a review of the compatibility of the County's planned transfer station and transportation infrastructure with the implementation of a Conversion Facility in the County if a decision was made at some future time to implement this disposal option.

Conversion Technology Implementation

As described in Section 6, we have assumed that if a Conversion Facility were implemented, the County would construct a single Conversion Facility regardless of the technology employed. We have also assumed that the Conversion Facility would be located in an industrially zoned area away from residential neighborhoods, and that this site would not be any more remote from County transfer stations than the current location of the Cedar Hills Regional Landfill. In such a case, we believe the recommendations outlined in the County's Waste Export Plan, that the County should have seven transfer stations in the County (new stations at Bow Lake, Northeast Lake Washington, South County, First Northeast and Factoria/Eastgate and existing stations at Enumclaw and Vashon Island), would correlate well with the implementation of any of the three Conversion Technologies. This scenario will meet the waste transfer priorities of the County as laid out in the Waste Export Plan, and would result in efficient consolidation and transport of waste to a Conversion Facility.

One potential deviation from the Waste Export Plan that could make sense would be to replace one of the planned new stations with the Conversion Facility. Replacement is a potentially viable way to reduce the County's overall capital expenditures and allow for the siting of only one larger facility instead of two separate facilities. In this instance, the Conversion Facility would need a separate on-site public drop-off area for self-haul and commercial customers and would also need to accommodate transfer trailers from the other County transfer stations. This approach would require a larger site than would be necessary for either of the facilities on their own, but it could provide advantages in economies of scale and decreased overall siting efforts. Also the capital cost of such a facility would likely be significantly less that the combined cost of the facilities individually.

According to the Waste Export Plan, "limited intermodal truck-to-rail capacity in the region" and "prospects for greater competition for this limited resource in the years ahead" are important considerations in determining whether to procure a County-owned intermodal facility. If the County were to determine this facility was necessary for the Waste Export Disposal Option, an intermodal facility designed to load a full train would be required. However, if a Conversion Technology was employed in the County for waste disposal, a County-owned intermodal facility would not likely be needed even if rail long-haul is determined to be the best method for transport of the resulting residue ash and bypass waste for disposal. Implementing a Conversion Technology would result in a far smaller quantity of residue ash and any bypass waste than the amount of export waste envisioned in the Waste Export Plan. It is difficult to economically downsize an intermodal facility, since this type of facility is typically sized in order to load a full-length train. With the reduced rail-haul needs of the Conversion Facility, economics would not favor a dedicated intermodal facility for the County. In this situation the County should consider contracting for private intermodal services utilizing the existing intermodal capabilities in the region.

Conclusions

If the County at some future time chooses to implement a Conversion Facility as the primary disposal method in the County, the planned transfer station and transportation infrastructure described in the Waste Export Plan would correspond well with such a disposal method. The County may be able to reduce capital costs and increase operating efficiency by replacing one of its planned transfer stations with a Conversion Facility, as long as a separate self-haul drop-off facility was included on the site. Considering the projected quantities of Conversion Facility residue and bypass waste, it would make sense for the County to consider contracting for intermodal facility services to export this material to an out-of-county disposal site, rather than siting and building a County-owned intermodal facility for this purpose.

Section 14
ESTIMATED FACILITY SITING AND PERMITTING COSTS

Section 14
ESTIMATED FACILITY SITING AND PERMITTING COSTS

This section of the report presents planning estimates of the costs the County may incur as part of the siting and permitting efforts for the implementation of both the Conversion Technology and Waste Export Disposal Options.

Conversion Technology Implementation

If the County decides to implement a Conversion Technology, the siting of a Conversion Facility could be a controversial issue for a variety of reasons. The siting of a Conversion Facility will require that the County consider major policy issues involving land use, traffic impact, noise, odor, host community benefits, and air emissions. In order to properly address these matters, in addition to County staff, the County will likely require the use of a team of professionals with experience in community involvement, traffic engineering, environmental engineering, air quality analysis, civil/structural engineering, and environmental law. Our previous experience has indicated that selecting a site and obtaining the necessary permits to begin construction can take three to four years, or more.

Some specific activities that will be of particular importance to the County related to the siting of a Conversion Facility include, but are not limited to:

- Industrial zoning
- Access to road and rail infrastructure
- Topography
- Utility availability including access to electrical transmission lines, water and sewer
- Sensitive areas
- Adjacent property uses
- Current site uses
- Site area (size)
- Traffic analysis
- Environmental impact studies
- Environmental site assessments
- Hydrologic studies of the selected site

- Site layout
- Preliminary conceptual design
- Permit applications
- Proximity to schools, hospitals, nursing homes, and residential housing

Permitting a Conversion Facility would also likely require a significant amount of effort on the part of the County. Prior to application for the standard building and operational permits, a State Environmental Policy Act (SEPA) environmental review would be necessary as a first step in obtaining environmental and land use permits. Because of the height of Conversion Facilities (as much as 200 feet considering the flue gas stack), it is very likely that a variance would be needed from the height restrictions under the zoning ordinance. The SEPA environmental review would without doubt involve a project-level Environmental Impact Statement (EIS). While not incorporated into our cost estimate, if the project-level EIS was appealed it would add significantly to the legal fees and extend the timeline for approval. Also, since the implementation of a Conversion Technology would be a deviation from the County's current Comprehensive Solid Waste Management Plan, a programmatic EIS would also be necessary for a revision to that plan.

For these reasons it will be important for the County to establish a realistic siting, land use, and environmental permitting timeline and to have reasonable expectations of the level of effort and expense to site and permit a Conversion Facility. We expect that the duration for such efforts would be at least 36 to 60 months. A preliminary planning estimate of the range of costs to obtain permits is outlined in Table 14-1. These costs could vary significantly depending on the location of the facility, the type of technology employed, and a variety of other factors that require further review and consideration by the County. Also, these cost estimates assume a modest amount of air permitting and significant meteorological data already available for the site.

Table 14-1
Estimated Siting and Permitting Costs for Conversion Technologies

	Cost Range ($2007)	Assumptions
County Staff Cost	$800,000 to $1,400,000	1 FTE for 4-7 Years, $200,000/year
Legal Fees	$300,000	Outside Legal Expertise, $300/hour, 1000 hours
Programmatic EIS	$300,000 to $400,000	
Project-Level EIS	$600,000 to $1,000,000	Includes traffic and other supporting studies
Siting/Conceptual Design	$500,000 to $600,000	Includes supporting geologic studies
Permitting	$500,000	Includes $100,000 for NOC Air Quality permit
Total Cost	**$3,000,000 to $4,200,000**	

Waste Export Implementation

If the County chooses to design and construct an intermodal facility, siting and permitting will likely be somewhat less complex than that associated with the siting of a Conversion Facility. Nevertheless, it should be anticipated that this option will also have challenges. Since, an intermodal facility would not require the extensive air and environmental permits required by a Conversion Facility, certain permitting aspects will not be required. However, the County should expect citizens near the selected site to express concerns with traffic, noise, odors, litter, and vectors. While an intermodal facility will not have the tall stacks and visual impact of a Conversion Facility, the same number of collection vehicles will be accessing the site.

One of the biggest issues with siting an intermodal facility is its need for immediate access to one or both railroads. This will significantly limit the number of viable sites and constrain the County's siting flexibility. The County will also need to negotiate connection agreements with railroads that must be in place prior to financing and commencement of construction. We expect that the duration for successfully siting and permitting an intermodal facility would be 18 to 48 months. A planning estimate of the range of costs to obtain the required permits is outlined in Table 14-2.

Table 14-2
Estimated Siting and Permitting Costs for an Intermodal Facility

	Cost Range ($2007)	Assumptions
County Staff Cost	$300,000 to $800,000	1 FTE for 1.5 to 4 Years, $200,000/year
Legal Fees	$100,000	County Legal, .33 years, $300,000/year
SEPA Compliance	$150,000 to $500,000	Checklist/DNS or EIS (higher end of range). Includes traffic and other supporting studies
Siting/Conceptual Design	$100,000 to $200,000	Includes supporting geologic studies
Permitting	$100,000	
Negotiations with Railroad	$100,000	
Total Cost	$800,000 to $1,800,000	

Conclusions

It is likely that the siting and permitting efforts for implementation of a Conversion Technology would be extensive and would require several years of effort. While these efforts would be somewhat less extensive for an intermodal facility in the County as a part of the Waste Export Disposal Option, they would still last for more than a year and a half and could cost nearly $2 million.

Section 15
COMPARATIVE COST ANALYSIS

Section 15
COMPARATIVE COST ANALYSIS

This section of the report presents a summary of the comparative cost analysis done to allow comparison of the costs of the various options. The analysis considers cost and revenue assumptions, as presented in previous sections of this report, and calculates both a Net Present Value and a Net Present Value per ton for each Conversion Technology and for the Waste Export Disposal Option. While these Net Present Values do not represent the actual costs of the options, they are used to place each option on a time equivalent basis that considers the time value of money in the comparison.

Financial Model

A financial model was prepared to determine the range of costs and revenues of each option and technology for the duration of the study period. The model considers most of the aspects discussed in previous sections of this report including tonnage requiring disposal, tonnage processed, bypassed waste, residue ash, and energy generation. Based on the assumptions previously outlined, ranges of costs and revenues were calculated and combined for each year of the study period. Finally, the Net Present Values were calculated to facilitate comparison between options. The financial models for each option (both the low end and high end of the cost range) are presented in Exhibit 15-1 at the end of this section.

Comparative Cost Assumptions

Operating Revenues

The basis of the estimate of annual energy revenues for all disposal options is discussed in Section 12. Note that for the purpose of this report, we have included only the forecasted electricity revenues. In reality, the Conversion Technologies should also be able to realize additional operating revenues, as follows:

1. The RDF facility may be able to realize revenues from:
    a. The recovery of aluminum cans, if the design of the facility includes eddy current separators as part of the front-end processing equipment, and
    b. Pre-combustion ferrous metal, if the design of the facility includes magnets as part of the front-end processing equipment.
2. All of the Conversion Technologies should be able to realize revenues from the sale of ferrous and non-ferrous metals recovered from the residue ash. The

value of these metals will vary significantly during the planning period, depending on the price of scrap metal. Some currently operating Conversion Facilities receive approximately $1 million per year for recovered ferrous and non-ferrous metals.

3. The advanced thermal recycling facility should be able to realize revenues from the sale of gypsum and hydrochloric acid recovered from the flue gas scrubbing systems.

For the purpose of our analysis, we have assumed the Conversion Facilities will realize energy revenues based on energy efficiencies of 500 kWh/ton on the low end and 550 kWh/ton on the high end. Since the energy produces revenue, the high end of the range is considered in determining the low cost and the low end is considered in determining the high cost.

Note that energy revenues for the Waste Export Disposal Option are not carried forward in this analysis. Since the County will have no control over the landfill gas revenues, we are unable to determine the likelihood that such revenues will accrue to the benefit of the County. In our experience, tipping fees are based more on market conditions than the actual net cost of disposal.

Annual Operating and Maintenance Expenses

The estimated operating and maintenance expenses of the waste disposal options are discussed in Section 11. Included in our analysis are the general operation and maintenance costs, the cost of residue ash disposal assuming approximately 25 percent of the incoming waste by weight leaves as residue ash, and the cost of bypassed waste disposal is the same as the assumed cost for the Waste Export Option of $45 to $50 per ton.

For the purpose of developing the comparative analysis for each disposal option, we also escalated the costs by 2.4 percent per year to account for inflation.

Annual Debt Service Payment

In order to convert the estimated capital costs of the Conversion Technologies into a cost per ton of solid waste processed, we have developed an estimate of the total annual debt service payment associated with each of the Conversion Technologies. The annual debt service payment is incorporated in the financial model for each option and considered as a part of the comparative cost analysis.

To develop an estimate of the annual debt service payment, we first escalated the capital cost estimates of the options from 2007 dollars to 2013 dollars since the debt is assumed to be issued in 2013 at the start of construction, assuming a three-year construction period. The next step is to determine the Total Financing Requirement (TFR), which represents the total amount of revenue bonds that will have to be issued to pay for the cost of a Conversion Facility. The TFR is calculated in accordance with the following formula:

$$TFR = TCC + CI + DSRF + COI - IERF$$

where:

TFR = Total Financing Requirement

TCC = Total capital cost of the Conversion Facility

CI = Capitalized interest for the three-year construction period

DSRF = Debt Service Reserve Fund

COI = Cost of insurance of the revenue bonds, assumed to include underwriter's discount, legal fees, printing expenses, Independent Engineer's Report, etc.

IERF = Interest earnings on reserve funds

For the purpose of this report, we have assumed the County will issue revenue bonds with the following provisions:

1. Interest rate: 5 percent
2. Total term of the bonds: 23 years
3. Period of capitalized interest: 3 years
4. Levelized debt service payments for 20 years, commencing at the end of the construction period
5. Debt Service Reserve Fund: one year's debt service payment
6. Cost of Issuance: 3 percent of the TFR
7. Interest Earnings on Reserve Funds: accrue at 4.75 percent
8. Capital Recovery Factor (based on 20-year levelized payments and 5 percent interest): .0802426

Based on these inputs and assumptions, the actual formulas utilized for the calculation of TFR are shown below.

$$CI = 3(.05 \times TFR)$$

$$DSRF = .0802426 \times TFR$$

$$COI = .03 \times TFR$$

IERF[1] $= (3 \times .0475) \times (DSRF + CI / 2 + TCC / 2)$

Therefore:

$$TFR = TCC \times 3(.05 \times TFR) + .0802426 \times TFR + .03 \times TFR - (3 \times .0475) \times [(.0802426 \times TFR) + 3(.05 \times TFR) / 2 + TCC / 2]$$

$$TFR = 1.219024 \times TCC$$

[1] Interest earnings on the decreasing balances of CI and TCC are approximated by assuming that interest is earned on half of the original balance for the duration of the construction period.

Following the determination of the TFR, that amount is multiplied by the Capital Recovery Factor of .0802426 to determine the Annual Debt Service Payment. From this Annual Debt Service Payment we subtract interest earnings from reserve funds to determine the Net Annual Debt Service Payment.

The results of the calculations are summarized in Table 15-1. As can be seen in the table, the same basic formula and approach was also used to develop an estimate of the annual debt service payment associated with the capital cost of constructing and equipping an intermodal facility as part of the Waste Export Disposal Option.

Table 15-1
Estimated Capital Costs

	Estimated Capital Costs		Total Financing Requirement	Net Annual Debt Service Payment
Conversion Technology	($2007 millions)	($2013 millions)[1]	($2013 millions)	($2013 millions)
Mass Burn	$460 – $520	$530 – $600	$647 – $731	$49 – $56
RDF	$560 – $610	$646 – $703	$787 – $857	$60 – $66
Advanced Thermal Recycling	$520 – $560	$600 – $646	$731 – $787	$56 – $60
Waste Export	$16.5	$19.0	$23.1	$1.8

1. Values are escalated from 2007 estimates to 2013 estimates using an inflation of 2.4% per year.

Note that once the County has made a capital investment in 2013 (the assumed start of the construction period), the annual recovery of the capital cost of that investment is assumed to be fixed during the first 20-year operating period of the Conversion Facility. Therefore, while the operating and maintenance expenses of the Conversion Facilities and the Waste Export Disposal Option, and the operating revenues of the Conversion Facilities, will all be increasing over the 20-year period, the annual capital cost component will remain fixed once the revenue bonds have been issued.

Total Net Annual Costs

We have developed estimates of the Total Net Annual Costs for each disposal option, the results of which are presented in Exhibit 15-1. The estimate of the Total Net Annual Cost is equal to the Operating and Maintenance Expenses plus Annual Net Debt Service Payment less the Annual Energy Revenues. The Total Net Annual Cost was divided by the total annual quantity of waste requiring disposal in any given year to calculate the Total Net Annual Cost per ton.

Net Present Value

To assist the County in its evaluation of the comparative costs presented here, we have developed a net present value (NPV) calculation of the net annual revenue requirement for each option. The NPV calculation discounts the future net annual revenue requirement for each option during the 20-year study period based on a discount factor. We used a discount factor of 5 percent in this analysis as that represents the County's assumed cost of borrowing. We also used 2016 as the base year for the analysis because it is the first year that the County would incur expenses or realize revenues from either option.

Net present value is a tool used to compare different alternatives where expenditures vary substantially over time. By using net present values, we can compare the significant but decreasing (over time) capital cost of the Conversion Technology Disposal Options against the more consistent, contract-based Waste Export Disposal Option. It is important to recognize that the NPV is not an estimate of the actual cost to the County of either disposal option; it is an estimate of the value of the option considering the time value of money. The results of the NPV calculation are shown on Exhibit 15-1 and are summarized in Table 15-2.

Table 15-2
Summary of Net Present Value Calculation

Disposal Option	Total Net Present Value Cost ($2016 millions)	Net Present Value Cost per Ton ($2016)
Mass Burn	$1,116 – $1,550	$42 – $58
RDF	$1,570 – $1,967	$59 – $74
Advanced Thermal Recycling	$1,443 – $1,875	$54 – $70
Waste Export	$1,136 – $1,263	$43 – $47

Conclusions

Based on the very preliminary planning estimates presented in this report, the estimated net present value (in 2016 dollars) of disposal for the four options is close enough that it would be difficult to eliminate any of the disposal options at this time based solely on cost.

Exhibit 15-1 Page 1

MASS BURN COSTS - Low End

2007 Metrics

Starting Facility Capacity	1,051,200	tons per year
Percent Residue Ash	25.0%	
Energy Generation	550	kWh/ton
Unit O&M Cost	$29.00	per ton Processed
Residue Ash Management	$40.00	per ton Residue
ByPassed Waste Management	$45.00	per ton Bypassed

YEAR	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Unit Costs										
Unit Operation & Maintenance	$35.90	$36.76	$37.64	$38.55	$39.47	$40.42	$41.39	$42.38	$43.40	$44.44
Unit Residue Ash Management	$49.52	$50.71	$51.92	$53.17	$54.45	$55.75	$57.09	$58.46	$59.86	$61.30
Unit ByPassed Waste Management	$49.52	$50.71	$51.92	$53.17	$54.45	$55.75	$57.09	$58.46	$59.86	$61.30
Energy Price ($/MWh)	$68.37	$71.91	$70.70	$71.89	$74.06	$76.08	$79.11	$82.50	$85.99	$86.84
Tonnages										
Tonnage Requiring Disposal	1,164,301	1,186,079	1,208,538	1,225,386	1,249,642	1,255,030	1,277,946	1,275,651	1,299,948	1,324,825
Tonnage Processed	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200
Tonnage Bypassed	113,101	134,879	157,338	174,186	198,442	203,830	226,746	224,451	248,748	273,625
Residue Ash Tonnage	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800
Energy Generated (MWh)	578,160	578,160	578,160	578,160	578,160	578,160	578,160	578,160	578,160	578,160
Total Costs										
Total Operation & Maintenance	37,738,355	43,602,479	45,494,388	47,235,704	49,326,812	50,728,439	52,894,419	54,066,615	56,418,722	58,878,364
Total Residue Ash Management	13,013,226	13,325,543	13,645,356	13,972,845	14,308,193	14,651,590	15,003,228	15,363,305	15,732,025	16,109,593
ByPassed Waste Disposal	5,600,490	6,839,178	8,169,456	9,261,316	10,804,210	11,363,902	12,944,908	13,121,420	14,890,828	16,773,164
Debt Service	49,412,864	49,412,864	49,412,864	49,412,864	49,412,864	49,412,864	49,412,864	49,412,864	49,412,864	49,412,864
Total Cost	105,764,935	113,180,064	116,722,065	119,882,729	123,852,079	126,156,795	130,255,419	131,964,204	136,454,438	141,173,985
less Energy Revenue	39,529,441	41,577,147	40,878,600	41,566,029	42,819,998	43,987,535	45,737,451	47,698,704	49,718,401	50,206,110
Total Net Annual Cost	$66,235,494	$71,602,917	$75,843,464	$78,316,700	$81,032,081	$82,169,260	$84,517,968	$84,265,501	$86,736,038	$90,967,874
Total Net Annual Cost per ton	$56.89	$60.37	$62.76	$63.91	$64.84	$65.47	$66.14	$66.06	$66.72	$68.66

YEAR	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Unit Costs										
Unit Operation & Maintenance	$45.51	$46.60	$47.72	$48.86	$50.04	$51.24	$52.47	$53.73	$55.02	$56.34
Unit Residue Ash Management	$62.77	$64.28	$65.82	$67.40	$69.02	$70.67	$72.37	$74.11	$75.89	$77.71
Unit ByPassed Waste Management	$62.77	$64.28	$65.82	$67.40	$69.02	$70.67	$72.37	$74.11	$75.89	$77.71
Energy Price ($/MWh)	$89.31	$91.99	$94.74	$97.58	$100.50	$103.50	$106.60	$109.79	$113.08	$116.46
Tonnages										
Tonnage Requiring Disposal	1,324,286	1,349,746	1,362,825	1,389,346	1,416,287	1,438,772	1,461,558	1,484,647	1,507,747	1,531,144
Tonnage Processed	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200
Tonnage Bypassed	273,086	298,546	311,625	338,146	365,087	387,572	410,358	433,447	456,547	479,944
Residue Ash Tonnage	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800
Energy Generated (MWh)	578,160	578,160	578,160	578,160	578,160	578,160	578,160	578,160	578,160	578,160
Total Costs										
Total Operation & Maintenance	60,266,915	62,899,788	65,033,508	67,890,258	70,867,689	73,720,612	76,685,450	79,766,415	82,951,702	86,260,669
Total Residue Ash Management	16,496,223	16,892,133	17,297,544	17,712,685	18,137,789	18,573,096	19,018,851	19,475,303	19,942,710	20,421,335
ByPassed Waste Disposal	17,141,886	19,189,797	20,511,214	22,790,995	25,197,379	27,391,218	29,697,631	32,121,430	34,645,299	37,294,891
Debt Service	49,412,864	49,412,864	49,412,864	49,412,864	49,412,864	49,412,864	49,412,864	49,412,864	49,412,864	49,412,864
Total Cost	143,317,889	148,394,582	152,255,130	157,806,802	163,615,721	169,097,791	174,814,796	180,776,012	186,952,575	193,389,759
less Energy Revenue	51,637,450	53,183,068	54,774,949	56,414,479	58,103,084	59,842,233	61,633,439	63,478,260	65,378,301	67,335,214
Total Net Annual Cost	$91,680,438	$95,211,514	$97,480,181	$101,392,323	$105,512,637	$109,255,558	$113,181,357	$117,297,752	$121,574,275	$126,054,545
Total Net Annual Cost per ton	$69.23	$70.54	$71.53	$72.98	$74.50	$75.94	$77.44	$79.01	$80.63	$82.33

Key Net Present Values	
Total Cost	$1,731,840,267
Total Cost per ton	$64.78
Energy Revenue	$616,130,204
Energy Revenue per ton	$23.05
Total Net Present Value	$1,115,710,063
Net Present Value per ton	$41.73

Exhibit 15-1 Page 2

MASS BURN COSTS - High End

2007 METRICS

Starting Facility Capacity	1,051,200	tons per year
Percent Residue Ash	25.0%	
Energy Generation	500	kWh/ton
Unit O&M Cost	$35.00	per ton Processed
Residue Ash Management	$55.00	per ton Residue
ByPassed Waste Management	$50.00	per ton Bypassed

YEAR	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Unit Costs										
Unit Operation & Maintenance	$43.33	$44.37	$45.43	$46.52	$47.64	$48.78	$49.95	$51.15	$52.38	$53.64
Unit Residue Ash Management	$68.09	$69.72	$71.39	$73.11	$74.86	$76.66	$78.50	$80.38	$82.31	$84.29
Unit ByPassed Waste Management	$68.09	$69.72	$71.39	$73.11	$74.86	$76.66	$78.50	$80.38	$82.31	$84.29
Energy Price ($/MWh)	$68.37	$71.91	$70.70	$71.89	$74.06	$76.08	$79.11	$82.50	$85.99	$86.84
Tonnages										
Tonnage Requiring Disposal	1,164,301	1,186,079	1,208,538	1,225,386	1,249,642	1,255,030	1,277,946	1,275,651	1,299,948	1,324,825
Tonnage Processed	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200
Tonnage Bypassed	113,101	134,879	157,338	174,186	198,442	203,830	226,746	224,451	248,748	273,625
Residue Ash Tonnage	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800
Energy Generated (MWh)	525,600	525,600	525,600	525,600	525,600	525,600	525,600	525,600	525,600	525,600
Total Costs										
Total Operation & Maintenance	45,546,290	52,623,681	54,907,021	57,008,608	59,532,359	61,223,978	63,838,092	65,252,811	68,091,561	71,060,094
Total Residue Ash Management	17,893,185	18,322,622	18,762,365	19,212,661	19,673,765	20,145,936	20,629,438	21,124,545	21,631,534	22,150,691
ByPassed Waste Disposal	7,700,674	9,403,869	11,233,002	12,734,310	14,855,789	15,625,366	17,799,249	18,041,953	20,474,889	23,063,100
Debt Service	55,858,020	55,858,020	55,858,020	55,858,020	55,858,020	55,858,020	55,858,020	55,858,020	55,858,020	55,858,020
Total Cost	126,998,170	136,208,193	140,760,408	144,813,600	149,919,934	152,853,300	158,124,799	160,277,329	166,056,003	172,131,905
less Energy Revenue	35,935,855	37,797,407	37,162,364	37,787,299	38,927,271	39,988,668	41,579,501	43,362,458	45,198,546	45,641,918
Total Net Annual Cost	$91,062,315	$98,410,787	$103,598,044	$107,026,301	$110,992,663	$112,864,631	$116,545,298	$116,914,871	$120,857,457	$126,489,987
Total Net Annual Cost per ton	$78.21	$82.97	$85.72	$87.34	$88.82	$89.93	$91.20	$91.65	$92.97	$95.48

YEAR	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Unit Costs										
Unit Operation & Maintenance	$54.92	$56.24	$57.59	$58.97	$60.39	$61.84	$63.32	$64.84	$66.40	$67.99
Unit Residue Ash Management	$86.31	$88.38	$90.50	$92.67	$94.90	$97.18	$99.51	$101.90	$104.34	$106.85
Unit ByPassed Waste Management	$86.31	$88.38	$90.50	$92.67	$94.90	$97.18	$99.51	$101.90	$104.34	$106.85
Energy Price ($/MWh)	$89.31	$91.99	$94.74	$97.58	$100.50	$103.50	$106.60	$109.79	$113.08	$116.46
Tonnages										
Tonnage Requiring Disposal	1,324,286	1,349,746	1,362,825	1,389,346	1,416,287	1,438,772	1,461,558	1,484,647	1,507,747	1,531,144
Tonnage Processed	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200
Tonnage Bypassed	273,086	298,546	311,625	338,146	365,087	387,572	410,358	433,447	456,547	479,944
Residue Ash Tonnage	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800
Energy Generated (MWh)	525,600	525,600	525,600	525,600	525,600	525,600	525,600	525,600	525,600	525,600
Total Costs										
Total Operation & Maintenance	72,735,932	75,913,537	78,488,716	81,936,518	85,529,969	88,973,153	92,551,405	96,269,812	100,114,123	104,107,704
Total Residue Ash Management	22,682,307	23,226,682	23,784,123	24,354,942	24,939,460	25,538,007	26,150,920	26,778,542	27,421,227	28,079,336
ByPassed Waste Disposal	23,570,093	26,385,971	28,202,920	31,337,619	34,646,396	37,662,925	40,834,243	44,166,966	47,637,286	51,280,475
Debt Service	55,858,020	55,858,020	55,858,020	55,858,020	55,858,020	55,858,020	55,858,020	55,858,020	55,858,020	55,858,020
Total Cost	174,846,353	181,384,211	186,333,779	193,487,099	200,973,846	208,032,106	215,394,588	223,073,339	231,030,656	239,325,535
less Energy Revenue	46,943,137	48,348,243	49,795,408	51,285,890	52,820,986	54,402,030	56,030,399	57,707,509	59,434,819	61,213,831
Total Net Annual Cost	$127,903,216	$133,035,967	$136,538,371	$142,201,209	$148,152,860	$153,630,075	$159,364,189	$165,365,830	$171,595,837	$178,111,704
Total Net Annual Cost per ton	$96.58	$98.56	$100.19	$102.35	$104.61	$106.78	$109.04	$111.38	$113.81	$116.33

Key Net Present Values	
Total Cost	$2,110,368,096
Total Cost per ton	$78.94
Energy Revenue	$560,118,368
Energy Revenue per ton	$20.95
Total Net Present Value	$1,550,249,728
Net Present Value per ton	$57.99

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RDF COSTS - Low End

2007 METRICS

Starting Facility Capacity	1,051,200	tons per year
Percent Residue Ash	25.0%	
Energy Generation	550	kWh/ton
Unit O&M Cost	$42.00	per ton Processed
Residue Ash Management	$40.00	per ton Residue
ByPassed Waste Management	$45.00	per ton Bypassed

YEAR	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Unit Costs										
Unit Operation & Maintenance	$51.99	$53.24	$54.52	$55.83	$57.17	$58.54	$59.94	$61.38	$62.86	$64.36
Unit Residue Ash Management	$49.52	$50.71	$51.92	$53.17	$54.45	$55.75	$57.09	$58.46	$59.86	$61.30
Unit ByPassed Waste Management	$49.52	$50.71	$51.92	$53.17	$54.45	$55.75	$57.09	$58.46	$59.86	$61.30
Energy Price ($/MWh)	$68.37	$71.91	$70.70	$71.89	$74.06	$76.08	$79.11	$82.50	$85.99	$86.84
Tonnages										
Tonnage Requiring Disposal	1,164,301	1,186,079	1,208,538	1,225,386	1,249,642	1,255,030	1,277,946	1,275,651	1,299,948	1,324,825
Tonnage Processed	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200
Tonnage Bypassed	113,101	134,879	157,338	174,186	198,442	203,830	226,746	224,451	248,748	273,625
Residue Ash Tonnage	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800
Energy Generated (MWh)	578,160	578,160	578,160	578,160	578,160	578,160	578,160	578,160	578,160	578,160
Total Costs										
Total Operation & Maintenance	54,655,548	63,148,418	65,888,425	68,410,330	71,438,831	73,468,774	76,605,710	78,303,373	81,709,873	85,272,113
Total Residue Ash Management	13,013,226	13,325,543	13,645,356	13,972,845	14,308,193	14,651,590	15,003,228	15,363,305	15,732,025	16,109,593
ByPassed Waste Disposal	5,600,490	6,839,178	8,169,456	9,261,316	10,804,210	11,363,902	12,944,908	13,121,420	14,890,828	16,773,164
Debt Service	60,154,791	60,154,791	60,154,791	60,154,791	60,154,791	60,154,791	60,154,791	60,154,791	60,154,791	60,154,791
Total Cost	133,424,055	143,467,930	147,858,028	151,799,282	156,706,025	159,639,057	164,708,637	166,942,890	172,487,516	178,309,661
less Energy Revenue	39,529,441	41,577,147	40,878,600	41,566,029	42,819,998	43,987,535	45,737,451	47,698,704	49,718,401	50,206,110
Total Net Annual Cost	$93,894,614	$101,890,783	$106,979,428	$110,233,253	$113,886,027	$115,651,521	$118,971,187	$119,244,186	$122,769,116	$128,103,551
Total Net Annual Cost per ton	$80.64	$85.91	$88.52	$89.96	$91.13	$92.15	$93.10	$93.48	$94.44	$96.69

YEAR	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Unit Costs										
Unit Operation & Maintenance	$65.91	$67.49	$69.11	$70.77	$72.47	$74.21	$75.99	$77.81	$79.68	$81.59
Unit Residue Ash Management	$62.77	$64.28	$65.82	$67.40	$69.02	$70.67	$72.37	$74.11	$75.89	$77.71
Unit ByPassed Waste Management	$62.77	$64.28	$65.82	$67.40	$69.02	$70.67	$72.37	$74.11	$75.89	$77.71
Energy Price ($/MWh)	$89.31	$91.99	$94.74	$97.58	$100.50	$103.50	$106.60	$109.79	$113.08	$116.46
Tonnages										
Tonnage Requiring Disposal	1,324,286	1,349,746	1,362,825	1,389,346	1,416,287	1,438,772	1,461,558	1,484,647	1,507,747	1,531,144
Tonnage Processed	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200
Tonnage Bypassed	273,086	298,546	311,625	338,146	365,087	387,572	410,358	433,447	456,547	479,944
Residue Ash Tonnage	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800
Energy Generated (MWh)	578,160	578,160	578,160	578,160	578,160	578,160	578,160	578,160	578,160	578,160
Total Costs										
Total Operation & Maintenance	87,283,118	91,096,244	94,186,459	98,323,822	102,635,963	106,767,784	111,061,686	115,523,774	120,136,947	124,929,244
Total Residue Ash Management	16,496,223	16,892,133	17,297,544	17,712,685	18,137,789	18,573,096	19,018,851	19,475,303	19,942,710	20,421,335
ByPassed Waste Disposal	17,141,886	19,189,797	20,511,214	22,790,995	25,197,379	27,391,218	29,697,631	32,121,430	34,645,299	37,294,891
Debt Service	60,154,791	60,154,791	60,154,791	60,154,791	60,154,791	60,154,791	60,154,791	60,154,791	60,154,791	60,154,791
Total Cost	181,076,019	187,332,965	192,150,009	198,982,293	206,125,922	212,886,889	219,932,959	227,275,298	234,879,748	242,800,262
less Energy Revenue	51,637,450	53,183,068	54,774,949	56,414,479	58,103,084	59,842,233	61,633,439	63,478,260	65,378,301	67,335,214
Total Net Annual Cost	$129,438,569	$134,149,897	$137,375,060	$142,567,814	$148,022,838	$153,044,656	$158,299,520	$163,797,038	$169,501,447	$175,465,048
Total Net Annual Cost per ton	$97.74	$99.39	$100.80	$102.62	$104.51	$106.37	$108.31	$110.33	$112.42	$114.60

Key Net Present Values	
Total Cost	$2,186,536,683
Total Cost per ton	$81.79
Energy Revenue	$616,130,204
Energy Revenue per ton	$23.05
Total Net Present Value	$1,570,406,479
Net Present Value per ton	$58.74

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RDF COSTS - High End

2007 METRICS

Starting Facility Capacity	1,051,200	tons per year
Percent Residue Ash	25.0%	
Energy Generation	500	kWh/ton
Unit O&M Cost	$47.00	per ton Processed
Residue Ash Management	$55.00	per ton Residue
ByPassed Waste Management	$50.00	per ton Bypassed

YEAR	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Unit Costs																				
Unit Operation & Maintenance	$58.18	$59.58	$61.01	$62.47	$63.97	$65.51	$67.08	$68.69	$70.34	$72.03	$73.76	$75.53	$77.34	$79.19	$81.10	$83.04	$85.03	$87.08	$89.17	$91.31
Unit Residue Ash Management	$68.09	$69.72	$71.39	$73.11	$74.86	$76.66	$78.50	$80.38	$82.31	$84.29	$86.31	$88.38	$90.50	$92.67	$94.90	$97.18	$99.51	$101.90	$104.34	$106.85
Unit ByPassed Waste Management	$68.09	$69.72	$71.39	$73.11	$74.86	$76.66	$78.50	$80.38	$82.31	$84.29	$86.31	$88.38	$90.50	$92.67	$94.90	$97.18	$99.51	$101.90	$104.34	$106.85
Energy Price ($/MWh)	$68.37	$71.91	$70.70	$71.89	$74.06	$76.08	$79.11	$82.50	$85.99	$86.84	$89.31	$91.99	$94.74	$97.58	$100.50	$103.50	$106.60	$109.79	$113.08	$116.46
Tonnages																				
Tonnage Requiring Disposal	1,164,301	1,186,079	1,208,538	1,225,386	1,249,642	1,255,030	1,277,946	1,275,651	1,299,948	1,324,825	1,324,286	1,349,746	1,362,825	1,389,346	1,416,287	1,438,772	1,461,558	1,484,647	1,507,747	1,531,144
Tonnage Processed	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200
Tonnage Bypassed	113,101	134,879	157,338	174,186	198,442	203,830	226,746	224,451	248,748	273,625	273,086	298,546	311,625	338,146	365,087	387,572	410,358	433,447	456,547	479,944
Residue Ash Tonnage	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800
Energy Generated (MWh)	525,600	525,600	525,600	525,600	525,600	525,600	525,600	525,600	525,600	525,600	525,600	525,600	525,600	525,600	525,600	525,600	525,600	525,600	525,600	525,600
Total Costs																				
Total Operation & Maintenance	61,162,161	70,666,087	73,732,285	76,554,417	79,943,454	82,215,056	85,725,438	87,625,203	91,437,238	95,423,555	97,673,966	101,941,035	105,399,133	110,029,039	114,854,530	119,478,234	124,283,315	129,276,604	134,438,965	139,801,773
Total Residue Ash Management	17,893,185	18,322,622	18,762,365	19,212,661	19,673,765	20,145,936	20,629,438	21,124,545	21,631,534	22,150,691	22,682,307	23,226,682	23,784,123	24,354,942	24,939,460	25,538,007	26,150,920	26,778,542	27,421,227	28,079,336
ByPassed Waste Disposal	7,700,674	9,403,869	11,233,002	12,734,310	14,855,789	15,625,366	17,799,249	18,041,953	20,474,889	23,063,100	23,570,093	26,385,971	28,202,920	31,337,619	34,646,396	37,662,925	40,834,243	44,166,966	47,637,286	51,280,475
Debt Service	65,525,755	65,525,755	65,525,755	65,525,755	65,525,755	65,525,755	65,525,755	65,525,755	65,525,755	65,525,755	65,525,755	65,525,755	65,525,755	65,525,755	65,525,755	65,525,755	65,525,755	65,525,755	65,525,755	65,525,755
Total Cost	152,281,775	163,918,332	169,253,406	174,027,143	179,998,763	183,512,112	189,679,879	192,317,455	199,069,415	206,163,100	209,452,121	217,079,443	222,911,930	231,247,354	239,966,141	248,204,921	256,794,232	265,747,866	275,023,232	284,687,340
less Energy Revenue	35,935,855	37,797,407	37,162,364	37,787,299	38,927,271	39,988,668	41,579,501	43,362,458	45,198,546	45,641,918	46,943,137	48,348,243	49,795,408	51,285,890	52,820,986	54,402,030	56,030,399	57,707,509	59,434,819	61,213,831
Total Net Annual Cost	$116,345,920	$126,120,926	$132,091,042	$136,239,844	$141,071,492	$143,523,444	$148,100,379	$148,954,997	$153,870,870	$160,521,182	$162,508,984	$168,731,200	$173,116,522	$179,961,464	$187,145,155	$193,802,891	$200,763,833	$208,040,357	$215,588,414	$223,473,508
Total Net Annual Cost per ton	$99.93	$106.33	$109.30	$111.18	$112.89	$114.36	$115.89	$116.77	$118.37	$121.16	$122.71	$125.01	$127.03	$129.53	$132.14	$134.70	$137.36	$140.13	$142.99	$145.95

Key Net Present Values	
Total Cost	$2,526,998,600
Total Cost per ton	$94.52
Energy Revenue	$560,118,368
Energy Revenue per ton	$20.95
Total Net Present Value	$1,966,880,232
Net Present Value per ton	$73.57

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ADVANCED THERMAL RECYCLING COSTS - Low End

2007 METRICS

Starting Facility Capacity	1,051,200	tons per year
Percent Residue Ash	25.0%	
Energy Generation	550	kWh/ton
Unit O&M Cost	$39.00	per ton Processed
Residue Ash Management	$40.00	per ton Residue
ByPassed Waste Management	$45.00	per ton Bypassed

YEAR	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Unit Costs																				
Unit Operation & Maintenance	$48.28	$49.44	$50.62	$51.84	$53.08	$54.36	$55.66	$57.00	$58.37	$59.77	$61.20	$62.67	$64.17	$65.71	$67.29	$68.91	$70.56	$72.25	$73.99	$75.76
Unit Residue Ash Management	$49.52	$50.71	$51.92	$53.17	$54.45	$55.75	$57.09	$58.46	$59.86	$61.30	$62.77	$64.28	$65.82	$67.40	$69.02	$70.67	$72.37	$74.11	$75.89	$77.71
Unit ByPassed Waste Management	$49.52	$50.71	$51.92	$53.17	$54.45	$55.75	$57.09	$58.46	$59.86	$61.30	$62.77	$64.28	$65.82	$67.40	$69.02	$70.67	$72.37	$74.11	$75.89	$77.71
Energy Price ($/MWh)	$68.37	$71.91	$70.70	$71.89	$74.06	$76.08	$79.11	$82.50	$85.99	$86.84	$89.31	$91.99	$94.74	$97.58	$100.50	$103.50	$106.60	$109.79	$113.08	$116.46
Tonnages																				
Tonnage Requiring Disposal	1,164,301	1,186,079	1,208,538	1,225,386	1,249,642	1,255,030	1,277,946	1,275,651	1,299,948	1,324,825	1,324,286	1,349,746	1,362,825	1,389,346	1,416,287	1,438,772	1,461,558	1,484,647	1,507,747	1,531,144
Tonnage Processed	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200
Tonnage Bypassed	113,101	134,879	157,338	174,186	198,442	203,830	226,746	224,451	248,748	273,625	273,086	298,546	311,625	338,146	365,087	387,572	410,358	433,447	456,547	479,944
Residue Ash Tonnage	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800
Energy Generated (MWh)	578,160	578,160	578,160	578,160	578,160	578,160	578,160	578,160	578,160	578,160	578,160	578,160	578,160	578,160	578,160	578,160	578,160	578,160	578,160	578,160
Total Costs																				
Total Operation & Maintenance	50,751,580	58,637,816	61,182,109	63,523,878	66,336,057	68,221,004	71,133,874	72,710,275	75,873,453	79,181,248	81,048,610	84,589,370	87,458,855	91,300,692	95,304,823	99,141,513	103,128,708	107,272,076	111,555,737	116,005,727
Total Residue Ash Management	13,013,226	13,325,543	13,645,356	13,972,845	14,308,193	14,651,590	15,003,228	15,363,305	15,732,025	16,109,593	16,496,223	16,892,133	17,297,544	17,712,685	18,137,789	18,573,096	19,018,851	19,475,303	19,942,710	20,421,335
ByPassed Waste Disposal	5,600,490	6,839,178	8,169,456	9,261,316	10,804,210	11,363,902	12,944,908	13,121,420	14,890,828	16,773,164	17,141,886	19,189,797	20,511,214	22,790,995	25,197,379	27,391,218	29,697,631	32,121,430	34,645,299	37,294,891
Debt Service	55,858,020	55,858,020	55,858,020	55,858,020	55,858,020	55,858,020	55,858,020	55,858,020	55,858,020	55,858,020	55,858,020	55,858,020	55,858,020	55,858,020	55,858,020	55,858,020	55,858,020	55,858,020	55,858,020	55,858,020
Total Cost	125,223,316	134,660,558	138,854,941	142,616,059	147,306,481	150,094,516	154,940,030	157,053,021	162,354,326	167,922,025	170,544,740	176,529,320	181,125,634	187,662,392	194,498,011	200,963,848	207,703,210	214,726,829	222,001,767	229,579,974
less Energy Revenue	39,529,441	41,577,147	40,878,600	41,566,029	42,819,998	43,987,535	45,737,451	47,698,704	49,718,401	50,206,110	51,637,450	53,183,068	54,774,949	56,414,479	58,103,084	59,842,233	61,633,439	63,478,260	65,378,301	67,335,214
Total Net Annual Cost	$85,693,876	$93,083,411	$97,976,341	$101,050,030	$104,486,483	$106,106,981	$109,202,579	$109,354,317	$112,635,926	$117,715,915	$118,907,289	$123,346,252	$126,350,685	$131,247,913	$136,394,927	$141,121,615	$146,069,771	$151,248,569	$156,623,466	$162,244,760
Total Net Annual Cost per ton	$73.60	$78.48	$81.07	$82.46	$83.61	$84.55	$85.45	$85.72	$86.65	$88.85	$89.79	$91.38	$92.71	$94.47	$96.30	$98.08	$99.94	$101.88	$103.88	$105.96

Key Net Present Values	
Total Cost	$2,058,952,130
Total Cost per ton	$77.02
Energy Revenue	$616,130,204
Energy Revenue per ton	$23.05
Total Net Present Value	$1,442,821,926
Net Present Value per ton	$53.97

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ADVANCED THERMAL RECYCLING COSTS - High End

2007 METRICS

Starting Facility Capacity	1,051,200	tons per year
Percent Residue Ash	25.0%	
Energy Generation	500	kWh/ton
Unit O&M Cost	$46.00	per ton Processed
Residue Ash Management	$55.00	per ton Residue
ByPassed Waste Management	$50.00	per ton Bypassed

YEAR	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Unit Costs										
Unit Operation & Maintenance	$56.95	$58.31	$59.71	$61.14	$62.61	$64.11	$65.65	$67.23	$68.84	$70.49
Unit Residue Ash Management	$68.09	$69.72	$71.39	$73.11	$74.86	$76.66	$78.50	$80.38	$82.31	$84.29
Unit ByPassed Waste Management	$68.09	$69.72	$71.39	$73.11	$74.86	$76.66	$78.50	$80.38	$82.31	$84.29
Energy Price ($/MWh)	$68.37	$71.91	$70.70	$71.89	$74.06	$76.08	$79.11	$82.50	$85.99	$86.84
Tonnages										
Tonnage Requiring Disposal	1,164,301	1,186,079	1,208,538	1,225,386	1,249,642	1,255,030	1,277,946	1,275,651	1,299,948	1,324,825
Tonnage Processed	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200
Tonnage Bypassed	113,101	134,879	157,338	174,186	198,442	203,830	226,746	224,451	248,748	273,625
Residue Ash Tonnage	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800
Energy Generated (MWh)	525,600	525,600	525,600	525,600	525,600	525,600	525,600	525,600	525,600	525,600
Total Costs										
Total Operation & Maintenance	59,860,838	69,162,553	72,163,513	74,925,599	78,242,529	80,465,800	83,901,492	85,760,837	89,491,765	93,393,267
Total Residue Ash Management	17,893,185	18,322,622	18,762,365	19,212,661	19,673,765	20,145,936	20,629,438	21,124,545	21,631,534	22,150,691
ByPassed Waste Disposal	7,700,674	9,403,869	11,233,002	12,734,310	14,855,789	15,625,366	17,799,249	18,041,953	20,474,889	23,063,100
Debt Service	60,154,791	60,154,791	60,154,791	60,154,791	60,154,791	60,154,791	60,154,791	60,154,791	60,154,791	60,154,791
Total Cost	145,609,489	157,043,835	162,313,671	167,027,362	172,926,875	176,391,892	182,484,970	185,082,126	191,752,979	198,761,848
less Energy Revenue	35,935,855	37,797,407	37,162,364	37,787,299	38,927,271	39,988,668	41,579,501	43,362,458	45,198,546	45,641,918
Total Net Annual Cost	$109,673,634	$119,246,429	$125,151,307	$129,240,063	$133,999,604	$136,403,224	$140,905,470	$141,719,668	$146,554,433	$153,119,930
Total Net Annual Cost per ton	$94.20	$100.54	$103.56	$105.47	$107.23	$108.69	$110.26	$111.10	$112.74	$115.58

YEAR	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Unit Costs										
Unit Operation & Maintenance	$72.19	$73.92	$75.69	$77.51	$79.37	$81.27	$83.23	$85.22	$87.27	$89.36
Unit Residue Ash Management	$86.31	$88.38	$90.50	$92.67	$94.90	$97.18	$99.51	$101.90	$104.34	$106.85
Unit ByPassed Waste Management	$86.31	$88.38	$90.50	$92.67	$94.90	$97.18	$99.51	$101.90	$104.34	$106.85
Energy Price ($/MWh)	$89.31	$91.99	$94.74	$97.58	$100.50	$103.50	$106.60	$109.79	$113.08	$116.46
Tonnages										
Tonnage Requiring Disposal	1,324,286	1,349,746	1,362,825	1,389,346	1,416,287	1,438,772	1,461,558	1,484,647	1,507,747	1,531,144
Tonnage Processed	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200	1,051,200
Tonnage Bypassed	273,086	298,546	311,625	338,146	365,087	387,572	410,358	433,447	456,547	479,944
Residue Ash Tonnage	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800	262,800
Energy Generated (MWh)	525,600	525,600	525,600	525,600	525,600	525,600	525,600	525,600	525,600	525,600
Total Costs										
Total Operation & Maintenance	95,595,796	99,772,077	103,156,598	107,687,995	112,410,817	116,936,144	121,638,989	126,526,038	131,578,561	136,827,268
Total Residue Ash Management	22,682,307	23,226,682	23,784,123	24,354,942	24,939,460	25,538,007	26,150,920	26,778,542	27,421,227	28,079,336
ByPassed Waste Disposal	23,570,093	26,385,971	28,202,920	31,337,619	34,646,396	37,662,925	40,834,243	44,166,966	47,637,286	51,280,475
Debt Service	60,154,791	60,154,791	60,154,791	60,154,791	60,154,791	60,154,791	60,154,791	60,154,791	60,154,791	60,154,791
Total Cost	202,002,988	209,539,522	215,298,432	223,535,347	232,151,464	240,291,867	248,778,943	257,626,337	266,791,865	276,341,870
less Energy Revenue	46,943,137	48,348,243	49,795,408	51,285,890	52,820,986	54,402,030	56,030,399	57,707,509	59,434,819	61,213,831
Total Net Annual Cost	$155,059,851	$161,191,278	$165,503,024	$172,249,457	$179,330,478	$185,889,837	$192,748,544	$199,918,828	$207,357,047	$215,128,039
Total Net Annual Cost per ton	$117.09	$119.42	$121.44	$123.98	$126.62	$129.20	$131.88	$134.66	$137.53	$140.50

Key Net Present Values	
Total Cost	$2,435,385,426
Total Cost per ton	$91.10
Energy Revenue	$560,118,368
Energy Revenue per ton	$20.95
Total Net Present Value	$1,875,267,058
Net Present Value per ton	$70.15

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WASTE EXPORT COSTS - Low End

2007 METRICS

Starting Facility Capacity	1,051,200	tons per year
Unit O&M Cost	$45.00	per ton Processed

YEAR	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Unit Costs										
Unit Operation & Maintenance	$55.71	$57.04	$58.41	$59.82	$61.25	$62.72	$64.23	$65.77	$67.35	$68.96
LFG Price ($/MMBTU)	$2.73	$3.09	$2.91	$3.00	$3.20	$3.37	$3.67	$4.00	$4.34	$4.38
Tonnages										
Tonnage Requiring Disposal	1,164,301	1,186,079	1,208,538	1,225,386	1,249,642	1,255,030	1,277,946	1,275,651	1,299,948	1,324,825
LFG Generation (MMBTU/hr)	12	31	63	91	117	149	163	183	201	218
Total LFG Collected and Sold (MMBTU)	105,120	271,560	551,880	797,160	1,024,920	1,305,240	1,427,880	1,603,080	1,760,760	1,909,680
Total LFG Revenues	286,978	839,120	1,605,971	2,391,480	3,279,744	4,398,659	5,240,320	6,412,320	7,641,698	8,364,398
Total Costs										
Total Operation & Maintenance	64,860,067	67,659,019	70,594,741	73,296,782	76,541,605	78,716,543	82,077,547	83,896,471	87,546,292	91,362,978
Debt Service	1,768,405	1,768,405	1,768,405	1,768,405	1,768,405	1,768,405	1,768,405	1,768,405	1,768,405	1,768,405
Total Net Annual Cost	$66,628,472	$69,427,424	$72,363,146	$75,065,187	$78,310,010	$80,484,948	$83,845,952	$85,664,876	$89,314,697	$93,131,383
Total Net Annual Cost per ton	$57.23	$58.54	$59.88	$61.26	$62.67	$64.13	$65.61	$67.15	$68.71	$70.30

YEAR	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Unit Costs										
Unit Operation & Maintenance	$70.62	$72.31	$74.05	$75.82	$77.64	$79.51	$81.42	$83.37	$85.37	$87.42
LFG Price ($/MMBTU)	$4.61	$4.85	$5.11	$5.37	$5.64	$5.91	$6.20	$6.50	$6.80	$7.11
Tonnages										
Tonnage Requiring Disposal	1,324,286	1,349,746	1,362,825	1,389,346	1,416,287	1,438,772	1,461,558	1,484,647	1,507,747	1,531,144
LFG Generation (MMBTU/hr)	233	247	260	272	284	296	308	319	330	341
Total LFG Collected and Sold (MMBTU)	2,041,080	2,163,720	2,277,600	2,382,720	2,487,840	2,592,960	2,698,080	2,794,440	2,890,800	2,987,160
Total LFG Revenues	9,409,379	10,494,042	11,638,536	12,795,206	14,031,418	15,324,394	16,728,096	18,163,860	19,657,440	21,238,708
Total Costs										
Total Operation & Maintenance	93,517,627	97,603,119	100,914,064	105,346,952	109,967,103	114,394,054	118,994,663	123,775,472	128,718,158	133,852,762
Debt Service	1,768,405	1,768,405	1,768,405	1,768,405	1,768,405	1,768,405	1,768,405	1,768,405	1,768,405	1,768,405
Total Net Annual Cost	$95,286,032	$99,371,524	$102,682,469	$107,115,357	$111,735,508	$116,162,459	$120,763,068	$125,543,877	$130,486,563	$135,621,167
Total Net Annual Cost per ton	$71.95	$73.62	$75.35	$77.10	$78.89	$80.74	$82.63	$84.56	$86.54	$88.58

Key Net Present Values	
Total Net Present Value	$1,138,598,131
Total Net Present Value per ton	$42.59

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WASTE EXPORT COSTS - High End

2007 METRICS

Starting Facility Capacity	1,051,200	tons per year
Unit O&M Cost	$50.00	per ton Processed

YEAR	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Unit Costs																				
Unit Operation & Maintenance	$61.90	$63.38	$64.90	$66.46	$68.06	$69.69	$71.36	$73.08	$74.83	$76.62	$78.46	$80.35	$82.28	$84.25	$86.27	$88.34	$90.46	$92.63	$94.86	$97.13
LFG Price ($/MMBTU)	$2.73	$3.09	$2.91	$3.00	$3.20	$3.37	$3.67	$4.00	$4.34	$4.38	$4.61	$4.85	$5.11	$5.37	$5.64	$5.91	$6.20	$6.50	$6.80	$7.11
Tonnages																				
Tonnage Requiring Disposal	1,164,301	1,186,079	1,208,538	1,225,386	1,249,642	1,255,030	1,277,946	1,275,651	1,299,948	1,324,825	1,324,286	1,349,746	1,362,825	1,389,346	1,416,287	1,438,772	1,461,558	1,484,647	1,507,747	1,531,144
LFG Generation (MMBTU/hr)	12	31	63	91	117	149	163	183	201	218	233	247	260	272	284	296	308	319	330	341
Total LFG Collected and Sold (MMBTU)	105,120	271,560	551,880	797,160	1,024,920	1,305,240	1,427,880	1,603,080	1,760,760	1,909,680	2,041,080	2,163,720	2,277,600	2,382,720	2,487,840	2,592,960	2,698,080	2,794,440	2,890,800	2,987,160
Total LFG Revenues	286,978	839,120	1,605,971	2,391,480	3,279,744	4,398,659	5,240,320	6,412,320	7,641,698	8,364,398	9,409,379	10,494,042	11,638,536	12,795,206	14,031,418	15,324,394	16,728,096	18,163,860	19,657,440	21,238,708
Total Costs																				
Total Operation & Maintenance	72,066,741	75,176,688	78,438,601	81,440,869	85,046,228	87,462,826	91,197,274	93,218,301	97,273,658	101,514,420	103,908,474	108,447,910	112,126,737	117,052,169	122,185,670	127,104,504	132,216,292	137,528,302	143,020,176	148,725,291
Debt Service	1,768,405	1,768,405	1,768,405	1,768,405	1,768,405	1,768,405	1,768,405	1,768,405	1,768,405	1,768,405	1,768,405	1,768,405	1,768,405	1,768,405	1,768,405	1,768,405	1,768,405	1,768,405	1,768,405	1,768,405
Total Net Annual Cost	$73,835,146	$76,945,093	$80,207,006	$83,209,274	$86,814,633	$89,231,231	$92,965,679	$94,986,706	$99,042,063	$103,282,825	$105,676,879	$110,216,315	$113,895,143	$118,820,574	$123,954,075	$128,872,909	$133,984,698	$139,296,707	$144,788,581	$150,493,696
Total Net Annual Cost per ton	$63.42	$64.87	$66.37	$67.90	$69.47	$71.10	$72.75	$74.46	$76.19	$77.96	$79.80	$81.66	$83.57	$85.52	$87.52	$89.57	$91.67	$93.82	$96.03	$98.29

Key Net Present Values	
Total Net Present Value	$1,262,660,342
Total Net Present Value per ton	$47.23

Section 16
SUMMARY OF PRINCIPAL FINDINGS

Section 16
SUMMARY OF PRINCIPAL FINDINGS

This section presents R. W. Beck's principal findings and opinions regarding the comparative evaluation of Waste Export and Conversion Technologies disposal options. The bases of these findings are discussed in the various sections of this report. For a complete understanding of the findings, their bases and underlying assumptions, the report should be read in its entirety.

1. The quantity of solid waste the County will be required to dispose of is projected to increase from approximately 1,164,000 TPY in 2016 to 1,555,000 TPY in 2036 under the base case assumption that the recycling rate in the County increases at an average annual rate of 0.3%. This represents an increase of approximately 34 percent in waste disposal requirements during the study period.

2. Fourteen different solid waste Conversion Technologies were identified that are currently being discussed in the marketplace. We have categorized these as either Thermal Technologies or Biological and Chemical Technologies, as follows:

   Thermal Technologies:

   Pyrolysis

   Gasification

   Plasma Arc

   Mass Burn Waste-to-Energy:
   - Modular Starved Air
   - Rotary Combustors
   - Field Erected

   Refuse-Derived Fuel Waste-to-Energy

   Advanced Thermal Recycling

   Biological and Chemical Technologies:

   Anaerobic Digestion

   Waste-to-Ethanol

   Aerobic Digestion/Municipal Solid Waste Composting

   Thermal Deploymerization/Plastics to Oil

   Steam Classification/Autoclave

   Catalytic Cracking

3. Only three of the 14 Conversion Technologies meet the County's criteria of previously demonstrated capability of the technology over a minimum three-year period to process the quantities and composition of the solid waste the County is currently disposing of at the Cedar Hills Regional Landfill. These three proven Conversion Technologies are:

   Mass Burn Waste-to-Energy – Field Erected

   Refuse-Derived Fuel Waste-to-Energy (RDF)

   Advanced Thermal Recycling

4. Of the remaining 11 Conversion Technologies, the County should continue to monitor the progress of the following technologies:

   Gasification

   Plasma Arc

   Anaerobic Digestion

   Waste-to-Ethanol

   Steam Classification/Auto Clave

5. A properly designed, constructed, operated and maintained Conversion Technology could reasonably be expected to achieve the following annual availability rates:

   Mass Burn Waste-to-Energy – 90%

   RDF Waste-to-Energy – 87% to 90%

   Advanced Thermal Recycling – 90%

Findings 6 through 18 are applicable should the County at some future time decide to proceed with implementation of a Conversion Facility:

6. Based on (a) the projected quantity of County waste, (b) the County's assumed increase in the level of recycling of 0.3 percent per year, (c) the assumed annual availability of a Conversion Facility, and (d) seasonal fluctuations in the generation of solid waste, a Conversion Facility sized at approximately 3,200 TPD would meet most of the County's waste disposal requirements in 2016.

7. Designing a 3,200 TPD Conversion Facility with four processing units of 800 TPD per unit would provide required redundancy and operational flexibility.

8. Due to economies of scale, a single Conversion Facility of 3,200 TPD would be the most economic option in terms of lower unit capital costs and operation and maintenance expenses.

9. Due to the potential challenges associated with finding multiple sites for Conversion Facilities, a single facility would be less complicated to site and permit.

10. It is possible that one planned transfer station could be replaced by a Conversion Facility. This could offset approximately 10 percent of the capital cost of the Conversion Facility.
11. The County will need access to backup landfill disposal capacity for the disposal of bypass waste and residue ash.
12. We estimate that the County should expect that anywhere from 5 to 9 percent of the solid waste will not be able to be processed at a Conversion Facility and will have to be landfilled.
13. A Conversion Facility can be expected to reduce the volume of incoming solid waste by 90 percent. The weight of the remaining residue ash can be expected to be equal to 20 to 25 percent of the weight of the incoming solid waste.
14. Residue ash from Conversion Facilities in the United States has consistently met the permit requirements for disposal in sanitary landfills.
15. The residue ash from the Conversion Facility in Spokane, Washington has always met the permit requirements established by the Washington State Department of Ecology (DOE). The Spokane System recently received permission from DOE to modify the designation of its residue ash from “Special Incinerator Ash” to “Solid Waste.” This re-designation increases the potential to find either some possible beneficial use for the residue ash or an alternative means of disposal.
16. The County would need to add additional disposal capacity after the initial installation in 2016 of a 3,200 TPD Conversion Facility to keep up with projected growth in the amount of waste under the base case assumption for increased recycling. The timing of the addition of disposal capacity would depend to a significant degree on the growth in the County’s recycling program.
17. Depending upon the specific items targeted by the County, the County could increase the recycling program to 60 percent without having an adverse impact on the solid waste processing and energy generation capability of a Conversion Facility sized at 3,200 TPD.
18. If the County increased the level of recycling to 70 percent, our analysis indicates that the complete processing capacity of a 3,200 TPD facility would not be fully utilized and the energy production capability could be impacted depending upon the components of the waste stream that are targeted by the County for recycling. The County would have the option to accept waste from other jurisdictions to make full use of the processing capacity of the Conversion Facility or decide to construct a smaller facility that would be compatible with the increased level of recycling.
19. For all the disposal options, it is possible to design, construct, and operate facilities that are capable of meeting permit requirements for all criteria and air toxic pollutant emissions.

20. Criteria pollutant emissions are expected to be higher for the Conversion Technologies than the Waste Export Disposal Option.
21. Volatile organic compound emissions from landfills are estimated to be higher than the Conversion Technologies.
22. Air toxic emissions are estimated to be significantly higher for the Waste Export Disposal Option than the Conversion Technologies due to fugitive landfill gas that is unavoidable even for the most optimally operated landfills.
23. Based on the assumptions used in the net emission analysis, the Waste Export Disposal Option is calculated to produce lower greenhouse gas emissions than the Conversion Technologies.
24. A Conversion Facility would require a similar infrastructure support system of transfer stations and transfer fleet as would be required for the Waste Export Disposal Option.
25. The construction of a Conversion Facility is a capital-intensive project that can be expected to range in cost from $460 million to $610 million in 2007 dollars, depending upon the type of Conversion Technology. Because large Conversion Facilities have not been constructed in the United States in more than 10 years, there is limited reliable cost information for these types of facilities that is current.
26. The construction and equipping of an intermodal facility for the Waste Export Disposal Option is expected to cost approximately $15 million to $20 million in 2007 dollars.
27. The operating and maintenance expenses of a Conversion Facility are estimated to range from approximately $29 to $47 per ton in 2007 dollars, depending upon the type of Conversion Technology.
28. The operating and maintenance expenses of the Waste Export Disposal Option are estimated to range from $45 to $50 per ton in 2007 dollars.
29. The Conversion Facilities are estimated to be capable of generating between 500 kWh to 550 kWh of electricity per ton of waste processed. Based upon the projected price of electricity, the Conversion Facilities are calculated to be able to generate between $29 million to $32 million in electricity revenues in 2016.
30. While the Waste Export Disposal Option is estimated to be capable of generating an increasing quantity of landfill gas that can be used to generate electricity each year from 2016 to 2036, it is unclear whether the County will directly benefit financially from the generation of electricity through the combustion of landfill gas.
31. The County will incur significant costs in the planning and implementation of any of the disposal alternatives. We estimate that the legal, engineering, and County staff costs to site and permit a Conversion Facility could range, at a minimum, from $2.1 million to $3.2 million in 2007 dollars. We estimate the same costs to site and permit an intermodal facility could range, at a minimum, from $800,000 to $1.8 million in 2007 dollars.

32. After considering the annual operating and maintenance costs, the annual debt service payments on the capital cost, and the annual revenues from the sale of electricity for each of the disposal options, we have calculated the estimated net present value cost of disposal of the four disposal options over the study period as shown in Table 16-1.

Table 16-1
Summary Comparative Cost Analysis

Disposal Option	Total Net Present Value Cost (2016 – 2035)	Average Net Present Value Cost Per Ton (2016 – 2035)
Mass Burn	$1.12 to $1.55 Billion	$42 to $58
RDF	$1.57 to $1.97 Billion	$59 to $74
Advanced Thermal Recycling	$1.44 to $1.88 Billion	$54 to $70
Waste Export	$1.14 to $1.26 Billion	$43 to $47

This analysis does not include consideration of the following potential additional sources of revenue for the three Conversion Technologies:

a. Sale of recovered ferrous metal

b. Sale of recovered non-ferrous metal

c. Sale of other recovered materials from advanced thermal recycling.

33. Based on the very preliminary planning estimates presented in the comparative cost analysis, the estimated net value of disposal for the four options over the study period are close enough that it would be difficult to eliminate any of the disposal options at this time based solely on cost.

34. A detailed life-cycle cost analysis over the normal 50-year expected life of the Conversion Facilities, coupled with a thorough evaluation of project risks, would be needed to support a decision-making process for disposal options.

Appendix A
OVERVIEW OF COUNTY'S CURRENT RECYCLING PROGRAM

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Programs in Place

King County has numerous programs in place to divert and recycle specific materials from the waste stream. County programs serve the residents of the unincorporated areas of the County as well as 37 of the 39 cities, excluding Seattle and Milton. These programs include:

- **Residential Curbside Recycling.** Curbside recycling service typically is provided at no additional charge by private collection companies along with their fee-based municipal solid waste (MSW) collection services. Many municipalities within the County contract for recycling collection as part of their MSW collection contracts, while others are served by the provider specified by the state-regulated MSW hauling certification system. Unincorporated areas are each served by the provider specified by the state-regulated MSW hauling certification system. The basic recyclable materials accepted in curbside programs include: newspaper, mixed paper, cardboard, glass bottles and jars, aluminum and tin cans, and PETE and HDPE bottles. The County publishes a curbside recycling guide as part of its public education efforts. The guide is available on the County's website at:

  www.metrokc.gov/dnrp/swd/garbage-recycling/documents/Curbside_recycling_guide.pdf

- **Multifamily Recycling.** Multifamily recycling service is typically provided at no additional charge by private collection companies along with their fee-based MSW collection service. According to a 2005 telephone survey,[1] 90 percent of multifamily residents indicated that they have recycling services available at their complex. The basic recyclable materials accepted in curbside programs include: newspaper, mixed paper, cardboard, glass bottles and jars, aluminum and tin cans, and PETE and HDPE bottles. Residents are encouraged to inquire with their property manager if their complex lacks recycling services, since residents cannot "sign up" for recycling services on their own.

- **Commercial Recycling.** Businesses in the County that choose to recycle may subscribe for recycling services from private haulers. There are no regulations that require businesses to recycle. A few cities provide city-contracted recycling services, bundled with their MSW collection services, to businesses within their

[1] Source: "Residential Waste Reduction and Recycling Survey 2005: Survey of King County Households," prepared by Informa Research Services, April 2005.

communities. Businesses may choose to use the city service at no additional charge or use a private recycler or hauler. Businesses sometimes choose to recycle only those materials that they generate in quantities large enough (i.e., cardboard or office paper) to reduce their garbage volume and, consequently, lower their garbage collection bill. Several cities provide technical assistance and other services to encourage businesses to recycle. The County's website provides extensive information and assistance to businesses regarding recycling.

- **Drop-Box Recycling at the Transfer Stations.** The County has recycling drop-boxes located at seven transfer stations:

  - Bow Lake
  - Cedar Falls
  - Enumclaw
  - Houghton
  - Renton
  - Skyhomish
  - Vashon Island
  - 1st NE (currently closed for renovation)

  The drop-boxes are for residential and business use. The items accepted for free include: aluminum cans, cardboard, glass bottles and jars, mixed waste paper, newspaper, plastic bottles (#1 and #2), and tin cans. Some sites also accept textiles (clothing, linens, shoes, etc.) for recycling.

  A few transfer stations also accept appliances, clean wood, and yard waste for a fee.

- **Recycling Collection Events.** The County, along with the suburban cities, holds recycling collection events for items that may not be collected through regular collection services. Materials typically collected at these events include: tires, wood, scrap metal, appliances, televisions, computers and other electronic goods, and reusable household goods. The events serve residents throughout King County, outside the City of Seattle. Residential collection events are usually held during the spring and fall on Saturdays from 9 a.m. to 3 p.m. Business recycling collection events are usually held in summer and fall from 11 a.m. to 4 p.m. Both residential and business recycling collection events are usually held at a school parking lot or a transit system park-and-ride lot. Locations, materials and hours of operation may changes from year to year.

- **Construction Recycling.** The County promotes recycling at construction/ deconstruction job sites and encourages contractors to consider keeping construction, demolition and land-clearing (CDL) debris separate from garbage. There are many options within the County for recycling clean wood, metals, concrete, asphalt, and natural vegetation. The County's website provides a great deal of information for CDL generators, including a Construction Recycling Directory.

- **Hazardous Waste Management.** The Local Hazardous Waste Management Program in King County offers two options for residents to properly dispose of household hazardous waste (HHW):

- The Wastemobile - a mobile collection service that travels throughout the County from approximately March through October and provides a convenient disposal option for residents.
- Fixed Site Drop-Off Service - three permanent collection facilities, open year-round: one at the Factoria Transfer Station in Bellevue, one located at Seattle's South Transfer Station, and another facility location in North Seattle (which operates by appointment only).

The County encourages residents and businesses to divert as much waste from disposal as possible. Its website provides recycling information and alternative disposal options for nearly 30 different types of materials, including certain more difficult-to-recycle materials such as appliances, pallets, propane tanks, and ink jet cartridges. Specific programs also are in place to target specific "problem" materials such as:

- **Electronics.** Since October 1, 2005, the County no longer accepts computers (including laptops) or televisions in the garbage or at its solid waste disposal facilities. The County's website offers proper disposal/recycling options for these materials for both residents and businesses. The website also promotes the Take it Back Network, a "partnership between government agencies, retailers, repair shops, charitable organizations and recyclers that provides consumers with options for recycling certain wastes – and their hazardous components – in a safe and cost effective manner."
- **Fluorescent lamps.** Also banned from disposal at County solid waste disposal facilities in October 1, 2005 were fluorescent bulbs and tubes. Residents may bring these lights to an HHW facility at no charge or to a "Take It Back Network" member that accepts fluorescent tubes and bulbs. Businesses must meet state and local requirements for the proper disposal of these lights, which are designated as universal waste. The County provides a great deal of information on its website, including a list of fluorescent lamp recyclers.
- **Residential and commercial food waste.** Currently, about 60 percent of all single-family garbage customers in King County, outside of Seattle, are able to divert food waste and soiled paper with their yard waste set out for curbside collection. Commercial generators are encouraged to find a hauler that provides composting service for food waste as well as proper disposal service for commercially generated fats, oil, and grease.

Types and Quantities of Material Recycled

Table A-1 lists the quantities of recyclable material reported by the County to have been collected in King County (excluding the cities of Seattle and Milton) from 2000 through 2004. The quantities include residential (curbside and drop-off) tons as well as commercial tons.

Table A-1
Historical Quantities (in Tons) of Recyclable Materials
Collected and Processed in King County

	2000	2001	2002	2003	2004	Percent of Total (2004)
Aluminum Cans	6,257	3,029	1,896	4,463	3,534	0.52%
Tin Cans	12,534	1,574	1,504	2,296	2,857	0.42%
OCC	105,164	102,431	100,293	140,460	130,760	19.18%
High Grade Paper	14,521	17,934	13,072	16,234	18,043	2.65%
Mixed Paper	89,372	54,442	62,751	79,036	82,842	12.15%
Newspaper	71,917	26,910	49,914	91,676	81,268	11.92%
HDPE	1,079	666	1,446	2,076	1,292	0.19%
PETE	994	512	1,217	1,643	1,999	0.29%
LDPE	3,052	4,324	5,701	7,224	3,881	0.57%
Other Plastic	2,026	1,520	764	1,845	2,988	0.44%
Container Glass	17,757	19,590	19,039	29,476	24,503	3.59%
Food Waste	20,753	13,221	25,330	20,144	32,900	4.83%
Yard Waste	229,267	114,102	163,529	183,054	222,701	32.67%
Ferrous Metals	42,828	45,606	51,219	53,545	53,979	7.92%
Nonferrous Metals	8,876	10,944	14,225	11,044	16,733	2.45%
Mixed Tin, Alum., Plastic, Glass (from King County transfer stations drop-off sites)	1,425	1,521	1,468	983	1,325	0.19%
Totals:	627,822	418,326	513,368	645,199	681,605	

OCC = old corrugated cardboard; HDPE = high density polyethylene; PETE = polyethylene terephthalate; LDPE = low density polyethylene

Source: King County Solid Waste Division. Quantities exclude the Cities of Seattle and Milton.

Data from 2005 were not available at the time of the preparation of this report. However, the County estimates the overall recycling rate in King County for 2005 was approximately 43.8 percent.[2] The overall quantity of materials recycled per capita is estimated to be 3.07 pounds per person per day, based on the 2004 estimate of 681,605 tons of material recycled and a population estimate of 1,214,900.[3]

When the quantity of material that was recycled in the 2000 to 2004 time period is combined with the total quantity of waste that was disposed of at the Cedar Hills

[2] Source: "Solid Waste Transfer and Waste Export System Plan," September 2006. This recycling rate is a combined residential and non-residential rate.
[3] Source: "2004 Solid Waste Division Annual Report," King County Department of Natural Resources and Parks.

Regional Landfill, it is possible to develop an estimate of the total amount of waste that was generated and what percentage of that waste was recycled each year, as presented in Table A-2.

Table A-2
Estimated Total Waste Generation and Recycling Rates
(Thousands of Tons)

	2000	2001	2002	2003	2004
Tons of Waste Disposed of at Cedar Hills Landfill (1)	974	936	939	965	991
Tons of Recycled Material (2)	628	418	513	645	682
Total Waste Generated	1,602	1,354	1,452	1,610	1,673
Estimated Recycling Rate (%) (3)	39.2	31.0	35.3	40.1	40.7

(1) Source: County staff.
(2) Source: Table 6-1.
(3) Equal to "Tons of Recycled Material" divided by "Total Waste Generated."

The County's recycling rate continues to increase each year and remains above the national average of 32 percent.[4]

[4] Source: "Municipal Solid Waste in the United States: 2005 Facts and Figures," U.S. Environmental Protection Agency, 2006. http://www.epa.gov/msw/pubs/ex-sum05.pdf

Appendix B
BACKGROUND INFORMATION ON SPOKANE WTE FACILITY

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BACKGROUND INFORMATION ON SPOKANE WTE FACILITY

The Spokane Regional Waste-to-Energy Facility is the only such facility operating today in Washington State and under the same general regulations that would apply to a potential King County waste-to-energy (WTE) facility. We believe it is valuable for the County to consider many of the lessons learned and developments realized at the Spokane facility.

The Spokane Regional Solid Waste System (the "Spokane System") was established between Spokane County and the City of Spokane, Washington in 1988. Since then, 12 regional cities and towns as well as Fairchild Air Force Base have joined the Spokane System. The Spokane System's mass burn WTE facility began operations in September 1991. Wheelabrator Spokane, Inc. operates the facility, under contract to the Spokane System.

The following discussion focuses specifically on the recycling and residue ash management practices employed by the Spokane System.

Recycling Practices

In 2005, the Spokane WTE facility processed 277,196 tons of waste and recycled approximately 3.69 percent of the material delivered to the Spokane System.

Table B-1 shows the quantities of materials recovered from the Spokane WTE facility, in tons and as a percentage of the total tons of waste processed.

Table B-1
Quantities of Materials Recovered from the Spokane WTE Facility (in Tons)
2001–2005

Year	Ferrous Metals Recovered from the Ash	White Goods Recovered from the Receiving Floor	Total Tons Recovered	MSW Tons Processed at WTE Facility	Percent Recovered
2005	8,491	1,751	10,242	277,196	3.69%
2004	8,955	1,066	10,021	279,310	3.59%
2003	10,416	1,098	11,514	266,004	4.33%
2002	12,394	1,034	13,428	274,506	4.89%
2001	10,337	971	11,308	268,390	4.21%

The recovered materials from the facility are brokered through local metals recyclers. The Spokane System reports that it has not had any difficulty in marketing the ferrous metals recovered from the ash. In 2006, approximately $15.00 per ton was received from the sale of recovered ferrous metals. The revenue is split 50/50 between the Spokane System and Wheelabrator Spokane, Inc., the operator of the facility.

The appliances (white goods) are diverted prior to incineration and marketed separately to a scrap metal processor. Revenue amounts from the sale of the Spokane System's white goods were not made available. However, current market pricing (national average) for white goods is $54 per ton.[1]

Relationships between Recycling and Waste Combustion at Spokane

In addition to the on-site recycling of recovered materials at the Spokane WTE facility, off-site recycling (curbside, drop-off, commercial) in Spokane and nearby communities has increased at a steady rate since the Spokane WTE facility went on-line in 1991. Table B-2 shows the percent of the Spokane System's generated waste that was recycled beginning in 1990.

Table B-2
Spokane Regional Solid Waste System
Recycling Rates 1990–2005

Year	Quantities Recycled (Tons)	Total Waste Generated (Tons)	Percent Recycled
1990	123,660	441,595	28%
1991	148,178	474,178	31%
1992	142,733	451,135	32%
1993	204,663	522,590	39%
1994	211,086	530,058	40%
1995	209,066	503,425	42%
1996	202,068	499,603	40%
1997	197,069	494,561	40%
1998	225,170	521,580	43%
1999	220,735	529,238	42%
2000	213,833	532,684	40%
2001	211,364	512,731	41%
2002	188,509	524,530	36%
2003	244,240	553,964	44%
2004	248,489	562,335	44%
2005	253,213	592,519	43%

[1] Source: Secondary Materials Pricing on WasteNews.com.

Spokane is an example of compatibility between recycling and WTE. The Spokane System's website reports that recycling generally increases the efficiency of the WTE plant.

For example, the removal of metals and glass:

- increases the Btu value per ton of remaining garbage by approximately 10 percent;
- reduces abrasion in the furnace; and
- reduces the weight of the ash.

In addition, removing yard waste from disposal increases the efficiency of the plant. Because fresh leaves and grass have a high moisture content, which reduces Btu values, the Spokane System promotes composting as a higher and better use for yard waste.

The Spokane System also promotes the recycling of paper even though removing paper from the garbage does lower the Btu value. The loss is only 1 to 2 percent of the Btu value and is offset by the benefits gained from recycling.

Spokane hopes to increase its recycling rate in the future with plans to expand the recycling of construction, demolition and land-clearing (CDL) debris.

Residue Ash Management

Since the facility began commercial operation in November 1991, the residue produced by the facility from the combustion of municipal solid waste (MSW) has been managed as Special Incinerator Ash pursuant to Chapter 70.138 RCW and WAC 173-306.

Current Residue Management

The Spokane WTE facility has two Babcock & Wilcox furnace-boiler units with Von Roll grates, each rated at 400 TPD, a Bailey distributed control system, a single 26-MW Turbodyne turbine-generator unit, and six 250-hp element air-cooled condensers. The air emissions control system for each unit consists of the following: Thermal DeNOx System converted to a Urea to Ammonia (U2A) gas injection system, spray dryer/absorber, powdered activated carbon injection, pulse jet baghouse with Gore-Tex bags at a 4:1 air-to-cloth ratio.

The residue system consists of the following elements. Bottom ash is discharged from each furnace-boiler unit's ram expeller onto a single flat pan vibrating conveyor. The flat pan conveyor spreads out the slugs of material to a single-layer stream. At the end of the flat pan conveyor, but prior to discharging onto the belt conveyor, a bar can be placed diagonally to divert the bottom ash into a container. Typically, a large belt conveyor transports the bottom ash and treated fly ash to a vibrating grizzly separator designed to separate 10-inch plus items to the metal processing area. The underflow material is dropped onto another vibrating pan conveyor. Prior to dropping into the chute, the bottom ash is passed under a rotating magnet to extract smaller ferrous metal.

Fly ash residue from the economizers, two spray dryer/absorbers, and 12 baghouse modules is conveyed via enclosed drag chain conveyors into one of two redundant transfer conveyors. The transfer conveyors move the fly ash into one of two surge bins. Each surge bin conveys the fly ash into a pug mill via a screw conveyor. Depending on the level in the surge bin, the screw conveyor and pug mill with stainless steel paddles have single- and double-speed controls. Appropriate quantities of water and phosphoric acid are added to control dust and treat the fly ash via the WES-PHix process. The pug mill discharges the treated fly ash onto the belt conveyor transporting the bottom ash. Both the bottom ash vibrating pan conveyor and the fly ash drag conveyors were extended to accommodate a third unit, thereby allowing continuous operation during construction of a third unit. The vibrating pan conveyor transports the combined residue to a chute that discharges into a waiting intermodal container. Generally, the intermodal containers each hold 25 to 30 tons and 8 to 10 containers are filled in a 24-hour period. All containers are loaded within a building and the access doors are closed during the loading to minimize fugitive dust emissions. The containers are custom designed for the application: 40-cubic-yard capacity, Teflon-lined, top-hinged, double-sealed end door, high-sided, and watertight fully loaded.

Bottom ash, fly ash/absorber residue, and combined residue are sampled each quarter by collecting two eight-hour composite samples of each waste stream on seven consecutive days. Each of these composite samples (42 each quarter) is analyzed for arsenic, barium, cadmium, lead, mercury, selenium, chromium, copper, nickel, zinc, and silver by an independent testing laboratory. Once per year, a quarterly composite sample is analyzed for dioxins and dibenzofurans. The results of the quarterly testing are submitted to the Washington State Department of Ecology (DOE). The Spokane System has tested 42 residue samples from the facility each quarter for the past 15 years.

The Spokane System is required to provide a landfill site and has a contract with Regional Disposal Company (RDC) until 2016 to provide for the transportation and disposal of facility residue, certain bypass, and non-processible waste at the Roosevelt Regional Landfill. This contract is in effect until 2011 with the option to extend it for five additional years. RDC owns and operates the Roosevelt Regional Landfill, which is located approximately 250 miles southwest of Spokane County in Klickitat County, Washington.

The Roosevelt Regional Landfill has been permitted for the acceptance and disposal of the facility's residue in compliance with state regulations. Excess MSW and residue from the facility is currently being disposed at the Roosevelt Regional Landfill. A special permit was issued in compliance with the provisions of the state's Special Incinerator Ash Residue Act (RCW 70.138). Permit conditions included construction of a residue monofill, maximum daily receipt of 280 tons, and maximum yearly quantities of 102,200 tons.

The containers are trucked to the Burlington Northern Yardley Intermodal Facility, loaded onto trains, and sent by rail to the Roosevelt Regional Landfill. RDC has provided uninterrupted service to the Spokane WTE facility. The facility has not had to curtail the receipt of solid waste due to a lack of residue service. When RDC experiences problems with rail service due to an uncontrollable derailment and/or increased freight demands, separate truck transport is implemented to maintain quality service.

Residue Testing Results

Review of the test data from the facility on combined residue samples collected over the past eight calendar quarters indicated that only two metals, cadmium and lead, are commonly detected by the Toxicity Characteristic Leaching Procedure (TCLP) test at levels requiring additional statistical evaluation. Other metals, including barium, mercury, and selenium, were occasionally detected at or near the method detection limits; however, these levels were typically one to two orders of magnitude below the maximum allowable limits, so a statistical analysis of these levels was not required.

The testing found detectable levels of four of the PAHs (polycyclic aromatic hydrocarbons) of concern for designation, at concentrations ranging from 25 to 43 ug/kg. Summing the known concentrations of these four compounds, in accordance with WAC 173-303-100 (6)(c), the total concentration was 126 ug/kg, or approximately 1/100,000th of the Persistent Dangerous Waste Table designation threshold of 1 percent. Therefore, pursuant to WAC 173-303-100 (6)(a), the residue was not designated as a persistent dangerous waste.

Future Plans for Residue Management

In accordance with WAC 173-306-500(4), and in consultation with DOE, the Spokane System has performed various tests and analyses over the past year to determine whether the residue is in fact Special Incinerator Ash, or if it can be managed as a Solid Waste. Based on these analyses the Spokane System determined that the residue from the facility is a Solid Waste. In December 2006, the Spokane System submitted extensive residue testing data to DOE for review, and on March 20, 2007, DOE concurred that the facility residue is a Solid Waste.

Because the residue produced by the facility is not Special Incinerator Ash, the Spokane System intends to manage it as a Solid Waste. Specific proposed activities include the following:

1. Co-dispose of the residue with other solid waste at the Roosevelt Regional Landfill, rather than in the separate monofill;
2. Discontinue separate lab testing of fly ash and bottom ash and reduce the testing frequency of the combined residue;
3. Pursue recycling opportunities for the bottom ash, fly ash, and combined residue; and

4. Discontinue other management activities which were only required because the combined residue was unclassified and managed as Special Incinerator Ash.

The future enhancements of the facility's residue processing system may be able to extract nonferrous metals and further process material for reuse. The Spokane System is exploring the use of the combined residue as an alternative daily cover for a MSW landfill and as a component in a remanufactured and marketable material. The Spokane Regional Health District would also monitor reuse of the residue from the facility.

The City of Spokane initially acquired the Malloy Prairie Landfill site in west Spokane County for a future residue monofill. Long-haul disposal options were developed as alternatives to developing the Malloy Prairie site. An environmental siting analysis was completed before site acquisition, but applications for permits have not been filed. The Spokane System could re-evaluate the development of the Malloy Prairie site for use as a residue landfill. This would eliminate the need for shipping the residue around 250 miles to Klickitat County, and would reduce the problems associated with the availability of rail cars.

Appendix C
PRINCIPAL ASSUMPTIONS FOR POWER PRICE FORECAST

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Appendix C
PRINCIPAL ASSUMPTIONS FOR POWER PRICE FORECAST

This appendix describes the principal study assumptions that were used for the Power Price Forecast.

Study Period

Price forecasts were developed using the structural simulation model MarketPower™, from January 2007 through December 2026. Prices from 2026 to 2036 were extrapolated using the results through 2026.

Time Periods

On-peak hours are defined as the period from 6:00 am to 10:00 pm, Monday through Saturday. All other hours are designated as off-peak.

Inflation

Inflation is assumed to be 2.4 percent per year, based on the October 2006 Blue Chip Economic Indicators report.

Load and Resource Balance

The load/resource balance is derived from the most current information from utility filings, proprietary databases, and R. W. Beck's own market research and market intelligence. Planned utility retirements and additions are included in the model, where deemed by R. W. Beck as appropriate. Planned resources that are under construction, have been approved by regional commissions, or have been awarded transmission interconnection are included in the database as named units.

Table C-1 presents the Peak Load and associated growth rates each year thereafter.

Table C-1
2007 Peak Load (MW) and Annual Growth Rates

Year	Peak Demand and Growth
2007	26,340
2008	1.3%
2009	2.5%
2010	1.5%
2011	1.2%
2012	1.5%
2013	1.3%
2014	1.5%
2015	1.4%
2016	1.4%
2017	1.4%
2018	1.3%
2019-2036	1.4%

Generic Resource Additions

New generic generation units are added to each of the market areas to maintain the given region's specified reserve margin. The study uses standardized assumptions for the cost of fossil-fueled resources that likely will be constructed to serve baseload, cycling and peaking power needs. Table C-2 summarizes the assumptions used in the assessment for generic gas-fired combined-cycle generators, generic gas-fired simple-cycle generators and generic supercritical pulverized coal-fired generators, respectively. Table C-2 depicts projections of regional average values without regard to site-specific and unit-specific issues that may cause significant deviations from the projected values. The values presented in Table C-2 should not be used to evaluate specific projects.

Table C-2
Generic Generator Assumptions

	Combustion Turbine - F Class	Western Washington Year 2009 Combined Cycle	Western Washington Year 2010 Combined Cycle	Western Washington Year 2011 Combined Cycle	Western Washington Year 2012 Combined Cycle	Western Washington Year 2013 Combined Cycle
Capacity (MW)	168	550	560	570	580	590
Installed Capital Cost (2006 $ per kW)	660	1,030	1,023	1,015	1,008	1,000
Debt/Equity Ratio	70/30	70/30	70/30	70/30	70/30	70/30
Interest Rate	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%
After Tax Return on Equity	13.0%	13.0%	13.0%	13.0%	13.0%	13.0%
Financing Period (years)	20	20	20	20	20	20
First Year of Operation	2008	2009	2010	2011	2012	2013
Fixed O&M (2006 $ per kW-year)	7.50	19.50	19.50	19.50	19.50	19.50
Forced Outage Rate	1.0%	2.0%	2.0%	2.0%	2.0%	2.0%
Heat Rate (Btu per kWh)	10,300	7,040	7,003	6,965	6,928	6,890
Maintenance Rate	3.0%	5.0%	5.0%	5.0%	5.0%	5.0%
NOX Emissions Rate (lb per Mmbtu)	0.01	0.01	0.01	0.01	0.01	0.01
SO2 Emissions Rate (lb per Mmbtu)	0.0006	0.0006	0.0006	0.0006	0.0006	0.0006
Variable O&M (2006 $ per MWh)	13.24	3.50	3.38	3.25	3.13	3.00

	Western Washington Year 2014 Combined Cycle	Western Washington Year 2015 Combined Cycle	Western Washington Year 2016 Combined Cycle	Western Washington Year 2017 Combined Cycle	Western Washington Year 2018 Onward Combined Cycle	Eastern Washington Super-Critical Pulverized Coal - PRB
Capacity (MW)	650	710	771	831	891	800
Installed Capital Cost (2006 $ per kW)	966	932	898	864	830	2,230
Debt/Equity Ratio	70/30	70/30	70/30	70/30	70/30	70/30
Interest Rate	7.5%	7.5%	7.5%	7.5%	7.5%	7.5%
After Tax Return on Equity	13.0%	13.0%	13.0%	13.0%	13.0%	13.0%
Financing Period (years)	20	20	20	20	20	30
First Year of Operation	2014	2015	2016	2017	2018	2012
Fixed O&M (2006 $ per kW-year)	19.50	19.50	19.50	19.50	19.50	42.00
Forced Outage Rate	2.0%	2.0%	2.0%	2.0%	2.0%	4.0%
Heat Rate (Btu per kWh)	6,808	6,726	6,644	6,562	6,480	9,240
Maintenance Rate	5.0%	5.0%	5.0%	5.0%	5.0%	9.0%
NOX Emissions Rate (lb per Mmbtu)	0.01	0.01	0.01	0.01	0.01	0.07
SO2 Emissions Rate (lb per Mmbtu)	0.0006	0.0006	0.0006	0.0006	0.0006	0.1
Variable O&M (2006 $ per MWh)	3.00	3.00	3.00	3.00	3.00	1.80

Other Resource Assumptions

Fixed and variable operation and maintenance (O&M) costs and unit heat rates for existing generating units are based on historical data. Forced and scheduled resource outages are based primarily on National Energy Regulatory Commission (NERC) historical averages reported in its Generating Availability Data System (GADS) publications. The majority of units were modeled to be dispatched economically, meaning such units were dispatched only when they were the next least expensive unit needed to meet the next increment of load. However, for reasons such as reliability and operating restrictions, some units are considered “must-run.” The model dispatches these units regardless of economic conditions and, as such, they may produce energy even when regional prices indicate it is uneconomic for the units to run. Wind and hydroelectric dispatch is based on individual unit historical monthly energy and load patterns, where available. For units without publicly available information, generalized assumptions by resource type are used.

Fuel Price Forecasts

We used the Energy Information Administration's Annual Energy Outlook 2007 (AEO 2007) for the natural gas price forecast at Henry Hub (Louisiana). Henry Hub is the focus of financial market trading on the NYMEX owing to its proximity to pipelines that carry as much as 50 percent of U.S. natural gas supply, thus creating robust liquidity.

Regional delivered gas prices that are used to model power prices and dispatch of gas-fired generating units are developed from our proprietary Pipeline Demand Balance model. This model estimates basis differentials between Henry Hub and various supply basins and market hubs by allocating supply over specific pipeline paths to meet demand in specific markets and evaluating the resulting capacity utilization and/or excess supply available. Because the model allows both supply and demand to change over time, the model estimates dynamic basis differentials (changes in basis over time, between market locations). These basis differentials, when added to the Henry Hub price, represent a generally available market price of natural gas facing consumers within the region that changes over time according to the projected change in supply and demand in that region relative to other regions in the United States.

The end result is a set of natural gas prices that represent the price of gas delivered into a particular geographic market or zone. Use of zonal prices recognizes that all generators within a given regional market experience similar market conditions and can pay a similar price for natural gas. R. W. Beck's projections for natural gas pricing do not take into account specific circumstances that vary from project to project, such as specially negotiated contracts or transportation arrangements that allow them to reduce their gas costs relative to other generators in that same market; such information is largely non-public and therefore inaccessible.

Table C-3 provides the Base Case natural gas price forecast used in this study.

Table C-3
Base Case Natural Gas Price Forecast
(Nominal $ per MMBtu)

Year	Henry Hub	Pacific Northwest
2007	7.63	6.97
2008	7.75	7.07
2009	7.30	6.61
2010	7.12	6.42
2011	6.76	6.05
2012	6.72	6.00
2013	6.68	5.94
2014	6.88	6.13
2015	6.96	6.21
2016	7.27	6.50
2017	7.73	6.95
2018	7.79	7.00
2019	7.89	7.08
2020	8.21	7.39
2021	8.40	7.57
2022	8.81	7.97
2023	9.23	8.38
2024	9.71	8.84
2025	9.93	9.05
2026	10.21	9.32
2027	10.50	9.60
2028	10.81	9.89
2029	11.11	10.18
2030	11.43	10.49
2031	11.76	10.80
2032	12.09	11.12
2033	12.44	11.46
2034	12.80	11.80
2035	13.16	12.15
2036	13.54	12.52

We also used AEO 2007 to develop regional delivered coal price forecasts. The price forecasts for coal supply basins and transportation costs were developed and combined to produce delivered coal prices to all coal-fired generators. The world oil prices used in the forecast are based on those used in R. W. Beck's natural gas price forecast. Regional petroleum product prices were developed using econometric techniques applied to historical world oil price and petroleum product price data.

Emissions Allowance Price Projections

R. W. Beck has developed a proprietary emissions allowance price forecast. The forecast is developed by simulating the operation of the U.S. power generating grid over the next 20 years. The emissions from each power plant are calculated and aggregated by the relevant emissions markets. The Clean Air Interstate Rule (CAIR) and other emissions regulations are modeled and the emissions prices are determined by the implementation of specific emission control technologies on individual plants. The process is iterated until stable emissions clearing prices are reached.

The emissions clearing prices incorporate the effects of future generation expansion, generation technology, emission control technologies and their incremental cost, and emissions regulations. Cost functions for capital, fixed and variable costs are developed for each emission control technology. We developed the emission control cost estimates.

Market Areas and Transmission

The transmission system is a critical factor in electric energy price volatility and electric market access. Limitations of the transmission system can have dramatic impacts on the electric energy marketplace and the profitability of individual generation units. The vast majority of the transmission system developed in the United States was put in place prior to 1992 and deregulation of the wholesale power business. The original design intent for most transmission investment was centered on the concept of constructing lines for reliability and to move power from a local utility's own generation to its own load centers. The existing transmission system is generally limited in its capability to handle substantial power transfer from control area to control area. Correspondingly, as new generation is built a key issue that must be examined is whether the output of the new plant can be transmitted to its intended market.

The zonal simulation used for this assessment computes energy and capacity prices through the modeling of market areas interconnected through a simplified representation of the electric transmission system. Loads and resources are segregated into market areas, which are then interconnected though defined transmission links and interfaces (which may apply to multiple links) to depict a maximum power flow that can occur between market areas. When properly applied, this simplified representation of the market topology is an industry-accepted technique for modeling market prices. However, the technique is only an approximation of the actual operation of the electric transmission network.

For this assessment, R. W. Beck's transmission experts have established transfer limits between modeled market areas based on system design constraints, published data and reports, and analyses of flows within and between market regions. Estimates for any applicable transmission wheeling costs and transmission losses are based on historical information. Figure C-1 depicts the Western Electricity Coordinating Council (WECC) modeled market areas and transmission links between them.

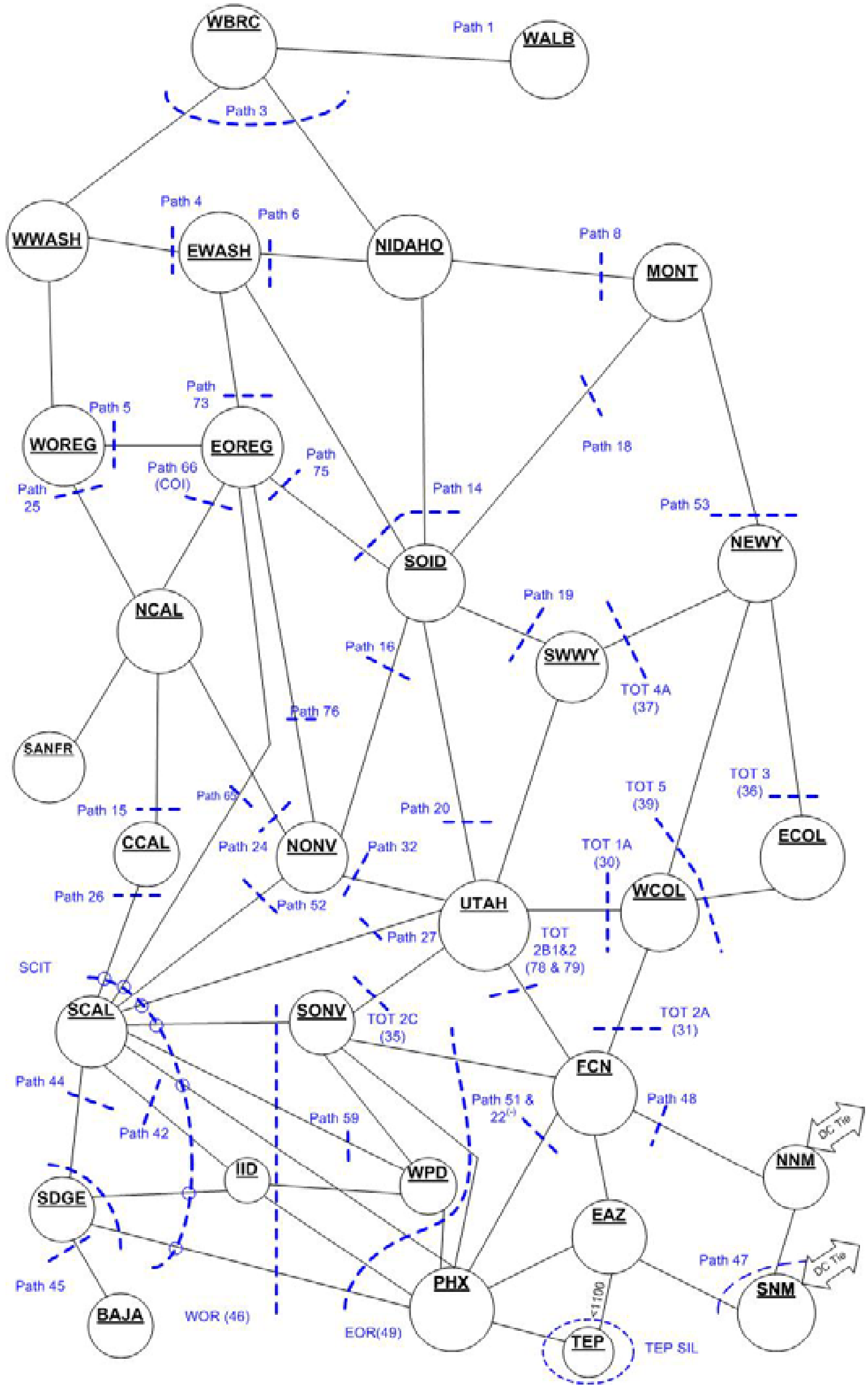

Figure C-1
WECC Market Areas