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An Environmental and Economic Assessment of Future Municipal Solid Waste Disposal: A case study of select high growth regions of Virginia.

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AN ENVIRONMENTAL AND ECONOMIC ASSESSMENT OF FUTURE MUNICIPAL SOLID WASTE DISPOSAL: A CASE STUDY OF SELECT HIGH GROWTH REGIONS ON VIRGINIA

A Thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Environmental Studies at Virginia Commonwealth University.

by

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Abstract

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This research analyzed environmental and economic factors associated with municipal solid waste (MSW) management of select high growth Planning District Commissions (PDCs) of Virginia. Current MSW management scenarios were compared to future hypothetical scenarios utilizing a regional landfill or waste-to-energy (WTE) combustion facility. Life-cycle inventory and full cost accounting methods of the Municipal Solid Waste Decision Support Tool, developed by the Environmental Protection Agency (EPA), were utilized to estimate annualized environmental emissions and economic costs. Model results and analysis indicate that a regional landfill would be the least cost intensive MSW management strategy in comparison to current management methods; however present the greatest environmental burden with respect to methane emissions. It was also inferred that a WTE facility would represent the least environmental burden with respect to energy offsets via MSW combustion while being the most cost intensive option. The study supports the anecdotal view that a regional-based approach to MSW management of high-growth PDCs would help reduce costs and potential environmental impacts.

Chapter 1. Introduction

1.1 Background

Since ancient times, humans have disposed of garbage away from living areas and have used various methods to avoid the unpleasant aspects of their rubbish heaps (Caponi 2008). Early in 20th century North America, most waste was incinerated, a method that prevailed well into the 1960s. In 1937, the first "sanitary landfill" was constructed and operated in Fresno, California, and by 1960; nearly 1,400 cities in the US were using sanitary landfills (Caponi 2008).

Solid waste predominantly consists of municipal solid waste (MSW), construction/demolition/debris (CDD), and industrial waste. MSW is more commonly known as trash or garbage and is the focus of this study. The collection and transportation of waste are the first steps in the management of MSW; accounting for 50% to 70% of a solid waste budget (Duffy 2006). Once MSW is collected it is commonly transported to waste transfer stations, materials recovery facilities (MRFs), landfills, or waste-to-energy (WTE) incineration facilities.

Transfer stations are viable waste management options that consolidate waste for easier transport to disposal facilities. A transfer station is typically used when the distance from the waste collection area to the waste treatment facility is large (Bovea et al., 2006). The utilization of transfer stations has traditionally minimized the economic costs of transport, since it is cheaper to transport large amounts of waste over long distances in large loads than in small ones (Tchobanoglous et al., 1993).

Landfilling continues to be the predominant MSW disposal method in the US. A 2007 U.S. study conducted by the Environmental Protection Agency (EPA) shows that nearly 80% of MSW that is not recycled, recovered, or composted from generated MSW is discarded in landfills, while the remaining amount of MSW is combusted with energy recovery (EPA 2008b). MSW landfill site selection is generally based on environmental impact assessments, economic feasibility, engineering design, and cost comparison (Charnpartheep et al., 1997). Other issues related to the availability of land, public acceptance, and increasing amounts of waste generation complicate the landfill site selection process. Additionally, the "not in my backyard" (NIMBY) phenomena has placed tremendous pressure on decision makers involved in the siting process (Chang et al., 2007). Due to the social complexity of siting waste management and disposal facilities, this study solely focuses on relevant economic and environmental impacts.

An alternative to landfilling is combustion via WTE facilities, which reduce waste volumes, produce heat, and generate electricity. The advent of modern WTE facilities prevailed in the US during the 1970s and early 1980s due in part to high oil prices, tax mechanisms, and stricter landfill regulations. However, during the early 1990s, the construction of large regional landfills and stable energy prices resulted in a substantial increase in long-term costs; nearly halting WTE growth (Hauser 2008).

MSW management and disposal continue to be areas of concern in relation to social, environmental, and economic issues. The balance of economic growth against the need to preserve valuable solid waste capacity poses a real dilemma for public officials (Rogoff 2006). Regions with high projected population growth will likely be accompanied by an increase in MSW disposal demands, therefore placing pressure on localities to site and manage new MSW management and disposal facilities.

The Commonwealth of Virginia currently has approximately 57 active MSW landfills, 35 waste transfer stations, and 3 mass-burn WTE incineration facilities. All of these facilities are managed across 21 Planning District Commissions (PDCs) as defined by the Virginia Association of Planning District Commissions. Specifically, this study attempts to evaluate the environmental releases and economic costs of MSW management options for select high growth Virginia PDCs using a life-cycle inventory approach.

Environmental and economic variables are analyzed by using the Municipal Solid Waste Decision Support Tool (MSW-DST) model developed by the EPA National Risk Management Research Laboratory and Research Triangle Institute (RTI) (Thorneleo et al. 2007). The MSW-DST model is based upon full cost accounting and life-cycle inventory methods to quantify MSW management and disposal costs and environmental emissions. Additional details with respect to the model and its relevance to this study are explained in the subsequent “Research Methods & Data” section. The following section frames the research problem of MSW management within the context of Virginia PDCs.

1.2 Research Problem

The current solid waste management report released by the Virginia Department of Environmental Quality (VDEQ) indicates that the remaining permitted MSW landfill capacity is 17.7 years, which is estimated based on the available capacity and the expected life of permitted facilities based on current disposal rates (VDEQ 2008). However; these projections do not account for population increases, changes in waste generation or disposal rates, or the closing of older MSW disposal units pursuant to statute (VDEQ 2008). Continued population growth would suggest that VDEQs estimate of remaining permitted landfill capacity is a conservative figure. Therefore, PDCs in Virginia with relatively high projected population growth that lack sufficient MSW disposal options will be the focal point of this study.

The Virginia Waste Management Board (VAWMB) incorporates a waste management hierarchy into the management of local and regional solid waste planning units (SWPUs) located within each PDC. This hierarchy according to the Virginia Administrative Code (VAC) is, listed in descending order and includes: planning, source reduction, reuse, reclamation, resource recovery, incineration, and landfilling (VGA 1993). This study limits its focus to the latter part of the waste management hierarchy to include; waste transfer stations, landfills, and WTE facilities.

Environmental Impacts

Transfer stations serve as centrally located processing units that condense and redistribute waste to long-distance disposal facilities. Transfer stations pose environmental problems due to fugitive dust and storm water quality resulting from leachate runoff from stored waste (EPA 2008a). Additionally, energy consumption and diesel emissions resulting from long distance hauling between transfer stations and disposal facilities are factored into the MSW-DST model for analysis.

MSW landfills potentially pose human health and environmental risks due to the formation of toxic leachate and landfill gas (LFG) emissions. In the past, health risks concerning MSW landfills centered on the potential for groundwater contamination, but better siting and facility engineering have minimized potential problems. Recently, air emissions from MSW landfills have been found to negatively affect human health and the environment (Jones 1994). MSW landfills emit LFG that is comprised of non-methane hydrocarbons (NMOCs), carbon dioxide (CO_2), and methane (CH_4) that is formed via anaerobic decomposition of organic waste. Themelis et al. (2006) calculated that an uncapped landfill can produce approximately 50 Nm^3 of methane per ton of typical MSW.

Anecdotal evidence indicates that the incineration of MSW via WTE facilities possesses its own set of environmental impacts ranging from air emissions to ash disposal. The general public voices the most concern about dioxin emissions from WTE facilities; however, the average emissions from 95 WTE facilities in the U.S. are much lower than EPA standard values (Lauber 2006). WTE incinerator ash is tested for toxicity before it is disposed of in a MSW landfill or reutilized. Air emissions originating from the preceding MSW facilities are taken into consideration when analyzing environmental impacts.

Economic Costs

Cost differences among landfills, WTE facilities, and waste transfer stations are an important factor in implementing each alternative and have direct (contractual) and indirect (socio-economic) implications for waste management policy making at the local and state level. Landfills are unique among industrial or construction operations in having relatively high upfront capital costs and relatively low unit operating costs (Duffy 2005). In comparison, WTE facilities usually have higher costs; however, are likely to be less costly over the long-term (Hauser 2008). The economic feasibility of a WTE facility depends on the volumes of waste generated and its management costs (NFESC 2008). Lastly, communities find the cost of upgrading or constructing new MSW disposal facilities to be prohibitively high; therefore transfer stations become a relatively inexpensive alternative (EPA 2008a). However the environmental burden is then placed on the receiving disposal facility.

1.3 Research Objectives

This study seeks to address questions concerning which MSW disposal option presents the greatest environmental impacts and which management option may impose the largest economic costs in response to high levels of projected population growth. Specifically, the key objectives of this study are:

1. **Assess the economic costs and environmental impacts of MSW management and disposal options given future population growth and increased need for waste disposal.** Such a task will call for identifying high population growth regions, especially for PDCs that may either currently lack sufficient MSW disposal options and/or operating facilities that are nearing their lifetime capacities.
2. **Compare and contrast MSW disposal options across select PDCs.** Future hypothetical MSW disposal options will be compared to the current baseline MSW management and disposal scenarios of each PDC. This study will specifically attempt to determine which MSW disposal option will emit the least amount of greenhouse gases (GHGs) and select criteria air pollutants as defined

by the EPA. Additionally, the differences in respective capital, operating, and closure costs of each option will be compared over their useful lifetimes.

The over-arching research goal is to recommend which MSW management or disposal methods will best suite each PDC based on economic costs and environmental releases with respect to projected MSW disposal demands.

Various studies have analyzed the environmental impacts of landfills concerning methane gas emissions and toxic leachate contamination of groundwater resources. Air emissions and ash disposal have typically been the focus of studies with respect to WTE facilities. Fewer studies have actually compared the impacts of both; however an adequate number of studies do exist. There is inadequate information on the environmental and economic implications of waste management for Virginia and this study aims at providing such information.

1.4 Expected Results and Policy Implications

Since WTE facilities are typically highly capital intensive, in terms of startup efforts, it is expected that the disposal cost (per unit ton of MSW) will be greater than the annualized cost of alternative MSW management methods. Review of literature indicates that landfills will carry the highest environmental impacts due to current and long-term post-closure fugitive methane emissions. Post-closure costs and environmental impacts will also likely be higher for landfills than WTE facilities. Finally, PDCs relying on waste transfer stations will likely carry the least disposal cost; however the management costs will be higher due to collection and long-haul transportation costs.

Results of this analysis attempts to assist in the development of a practical and integrated MSW management plans that would effectively provide information on environmental impacts, given cost-effective regulatory compliance. The analysis of both environmental impacts and economic costs may help land-use planners better understand the trade-offs among these two variables when developing strategic population growth plans. Policy implications may include tax incentives, fee restructuring, or reorganization of MSW management and disposal practices within PDCs to include larger regionalized areas to better serve Virginia localities due to economies of scale. Furthermore, the results and conclusions of this study could supplement future academic research regarding the use of life-cycle inventory methods to study MSW management and disposal.

The next chapter of this thesis project presents a literature review that focuses on previous comparative MSW disposal studies, Life Cycle Assessment (LCA) studies, and Virginia's current MSW disposal issues. The third chapter outlines proposed research questions and methods as well as relevant data. The fourth chapter contains results and data analysis pertaining to economic costs and environmental impacts among future MSW management options. The final chapter will propose conclusions as well as recommendations with regards to future planning and policy making efforts. Suggestions of future research efforts will also be discussed.

Chapter 2. Literature Review

2.1 Economic and Environmental Impacts of MSW Disposal

Various comparative studies have documented the environmental impacts and economic implications of MSW landfills versus WTE facilities. The question of whether to “burn or bury” MSW was the focus of researchers, Dijkgraaf and Vollebergh (2004), who evaluated the social costs between WTE facilities and methane capturing landfills in Netherlands. Results from their study indicated that WTE facilities carried a much higher net private and gross environmental cost compared to landfills only when energy savings and material recovery were analyzed. Data used in this study was native to the Netherlands; however results and findings may also be reflective of MSW management in the U.S.

Jones (1994) performed a risk-based approach to compare from both WTE facilities and landfills using dispersion modeling. Emissions data showed that WTE facilities emitted lower concentrations of CO_2, NMOC, and dioxins when compared to landfills, while WTE facilities emitted greater concentrations of nitrogen oxides (NOx). This study incorporated emissions from landfill control devices in addition to fugitive emissions, while regulators only typically study fugitive emissions.

Simonsen’s (1992) study cited that a jurisdictions ability to implement successful recycling, reuse, or reduction programs impacts the amount of waste in need of disposal; therefore gauging the need and size of WTE facilities. In a later study, Simonsen (1994) suggested that the sale of electricity, steam, or recovered ferrous metal is never sufficient to cover the total costs of a WTE facility and the only major benefit is reduction of waste volume. The author hypothesized that output (scale factor), labor and capital inputs, the quality of the operation, factor prices, pollution control devices used, technology used, and the types of revenue-generating devices used will influence the cost of a WTE facility. Simonsen (1994) concluded that the lower the net cost of a WTE facility or the higher the cost of disposal at a MSW landfill; the more likely WTE facilities will be economical.

Incineration of waste via WTE facilities has generally thought to produce fewer externalities when compared to conventional landfilling (Miranda 1997). However, Dijkgraaf and Vollebergh (2004) stated that WTE facilities contribute to externalities, such as emissions to air and chemical waste residue contained in ash. Their study also suggested that the relative performance of WTE facilities depends not only on its emissions profile, but also on the differing technological options for landfilling and all of their associated private and environmental costs.

DeAngelo (2004) compared the hypothetical utilization of a single WTE facility compared to siting two WTE facilities used in conjunction with two nearby marine MSW transfer stations. The author used Geographical Information System (GIS) methods to site potential WTE facilities in the Bronx and Brooklyn within New York City (NYC) to replace several existing transfer stations. Results indicated that the operation one WTE facility would save approximately 12 million truck transport miles per year, while operating two facilities would eliminate all transfer stations and avert nearly 24 million truck miles. Such a MSW management scenario may not be applicable to any of the areas in Virginia due an abundance of economically inexpensive land and a relatively lower population base.

Moy et al. (2008) as also studied the NYC area but compared the human health risks of two realistic scenarios which included a WTE facility option as well as the long-haul transport of MSW to an out-of-state landfill. A risk assessment methodology compared inhalation exposures and concluded that landfills presented higher individual cancer and non-cancer risks when compared to WTE facilities by a factor of 5. As previously noted, the study area of NYC differs significantly from any region in Virginia; however the authors cited supporting results from similar studies outside of NYC area.

Chang et al. (1997) attempted to systemically connect hypothetical transfer stations to existing landfills and WTE facilities that were already in place across metropolitan regions in Taiwan. An optimization model was applied to an economic construct that evaluated transportation, construction, operating, and recycling costs of waste. A discounted cost analysis of three scenarios concluded that an integrated regionalization approach relying on recycling, WTE, and limited use of landfills was appropriate to obtain large cost savings. However, the populations in this study top 2.5 million in a 2000 km^2 region generating over 6,500 tons for waste per day. Therefore, the same conclusions may not be feasible for regions in Virginia where projected populations are well below the estimate cited by the study.

2.2 A Life Cycle Assessment Approach to MSW Management

Life cycle assessment (LCA) is a technique for assessing the environmental aspects and potential impacts associated with a product (or service), by compiling an inventory of relevant inputs and outputs of the products system; evaluating the potential environmental impacts associated with those inputs and outputs; and interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study (ISO 1997). While many LCA studies have typically considered the life-cycle of products or services, there have been a number of LCA studies that have focused on the process of waste disposal. LCA has been proven to be a valuable tool to document the environmental considerations and has been successfully utilized in the field of solid waste management (Liamsanguan 2008). The following is a review of recent LCA-based studies that have analyzed environmental impacts of MSW management and disposal options.

Ozeler et al. (2007) evaluated global warming, acidification, eutrophication, and human toxicity of MSW management scenarios in Ankara, Turkey. LCA methodology contained in the IWM-1 model quantified impacts of collection and transportation, source reduction, MRFs, transfer stations, WTE facilities, anaerobic digestion, and landfilling. It was found that source reduction, collection, transport, and landfilling scenarios resulted in the minimal energy requirements, while scenarios that additionally contained MRFs and WTE facilities followed due to energy production. The highest human toxicity impacts were representative of the scenario which contained incineration as an option. The emissions requirements for WTE facilities in Turkey are unknown, which could negatively impact human toxicity factors.

Bovea et al., (2007) analyzed the environmental impacts of transportation and operation of a transfer station from the collection point of MSW to the subsequent transportation to a MRF. A comparison was made between 8 towns in Spain, some of which used transfer stations while others transported waste directly to MRFs. An aggregation of 4 different Life Cycle Impact Assessment (LCIA) methods concluded that the use of transfer stations reduce environmental impacts compared to direct hauling to a MRF. The preceding study mirrors current MSW management scenarios in localities within Virginia where transfer stations are used to long distance haul MSW to regional landfills.

Liamsanguan et al. (2008) utilized LCA methodology in order to compare the global warming potential (GWP) of alternative solid waste management scenarios in Phuket, Thailand. A baseline waste management scenario included a 250-ton/day incinerator and a landfill compared to alternative scenarios that additionally included 30% source separation recycling and anaerobic recycling. The study concluded that the baseline scenario was the least favorable, with landfills contributing 1,385 lb kg CO_2 eq. to the GWP; while the adding 30% recycling and anaerobic digestion is the most favorable option which produced 915 lb CO_2 eq. The landfill analyzed in this study lacked landfill gas emission controls in contrast to the fact that similar landfills located in the U.S. would require these controls. Therefore, the predicted GWP potential for the observed landfill in Thailand is likely higher than a modern landfill managed in Virginia.

Life Cycle Inventory (LCI) is a method used within the LCA process that has been utilized by models that predict environmental impacts of MSW disposal scenarios.

Shmelev et al. (2006) integrated LCI analysis, multi-criteria optimization, and GIS methods in order to estimate environmental and economic impacts of varying MSW management systems focusing on public health and biodiversity. The study area of Gloucestershire, England, principally relied on landfilling and consisted of a population of 574,000 with annual MSW generation figures between 617 to 952 lbs of MSW per person. The study analyzed approaches that utilized recycling, landfilling, and incineration with energy recovery. Generalized results indicated that an increase in MSW system management costs by a factor of 1.82 reduced environmental damage by a factor of 2.99.

Chen et al. (2008) used LCI methodology to provide GHG emission figures that represented various proposed MSW management scenarios in Taipei City, Taiwan. The GWP of CO_2, ammonia (NH_4), and nitrous oxide (N_2O) where analyzed with respect to emissions associated with collection, transportation, MRFs, WTE facilities, composting, landfilling, and swine feeding. This study concluded that waste minimization via recycling coupled with incineration of household MSW presents the greatest reduction in GHG emissions compared to other scenarios. As with this study, Taipei City largely differs from Virginia regions in population size and density, 2.63 million people and 9,700 people per square kilometer respectively. The 3,900 ton per day operating capacity of the WTE facilities in the precceding study will likely be more economically feasible due to economies of scale as compared to a reduced supply of MSW in Virginia.

In a U.S. based study, Thorneleo et al. (2007) utilized MSW-DST software to model ten different hypothetical waste management strategies of medium-sized communities. The MSW-DST model quantifies environmental impacts using LCI methodology and calculates economic costs using a full cost accounting approach. Life-cycle costs, energy consumption, climate change, acidification, eutrophication, ozone, human health, and ecological toxicity variables were compared across waste management scenarios that included transfer stations, landfills, and WTE facilities. Results indicated that costs were highest for the scenario that included a WTE facility, while net carbon dioxide emissions were the most favorable for WTE facilities; partly due to negative offsets of energy conservation and metals recovery. The model mentioned above will be used in this project to analyze economic costs and environmental impacts of MSW management in Virginia since it has been successfully developed and tested within the U.S. The following examples illustrate MSW management and disposal problems that Virginia has encountered over the past two decades which serve as the rationale for this thesis project.

2.3 Recent History of MSW Management in Virginia

In June of 1992, Loudoun County Va., officials abruptly learned that there was no more capacity for trash in the county landfill, which was estimated to be adequate for another year. The Board of County Supervisors suggested that the county pay to have residents' trash hauled to Fairfax or Prince William County or to a dump in another state, which could cost as much as $6 million a year (The Washington Post 1992). The article cited the planned closing of the Lorton landfill in Fairfax County as placing pressure on several localities. Other Virginia landfills, similar to the Lorton landfill, have undergone closure per House Bill 1205 (HB 1205) legislation; requiring unlined landfills to cease operations by scheduled time-frames (VGA 2005). There are still a remaining number of landfills in Virginia that fall under the HB 1205 legislation and thus pose similar challenges for county localities as to the situation presented in the previous article.

In 1994, a U.S. Supreme Court ruling in the case of *C & A Carbone, Inc. v. Town of Clarkstown* declared flow control laws unconstitutional on the basis of the “dormant” Commerce Clause. Media reports (Washington Post 1996) identified the construction of a landfill near Fredericksburg Va., by USA Waste Services Inc. as an example of the latest in an aggressive campaign by companies to take advantage of population growth in the Washington, D.C. suburbs. Subsequently, a Washington Post (1998) news article concluded that stricter environmental regulations and the prohibition of flow control laws led to the construction and operation of many privately owed and/or operated regional landfills. These landfills were effectively able to offer lower tipping fees based on economies of scale.

Blair et al. (2005) provides supporting evidence to this claim when the authors analyzed the structural impacts on Ohio’s landfill industry with respect to federal and state regulations. The researchers hypothesized that environmental regulations result in fewer but larger landfills (larger market shares) with higher tipping fees compared to areas with less strict regulations. A circular city empirical model tested the preceding hypotheses based on location, landfill capacity, waste quantities, remaining capacities, county average tipping fees, county demographics, physical characteristics, and highway density. The results indicated that both regulatory and geophysical factors influence industry structure, while highway density helps determine siting, market share, and tipping fees. The closing of older landfills in response to stricter environmental regulations may more likely result in the adoption of waste transfer stations or regionalized efforts signaled by the development of regional landfills.

The Virginia based Lynchburg News & Advance (Feb. 2008) reported that by the summer of 2008 the cities of Lynchburg and Bedford and the counties of Nelson, Campbell, and Appomattox in Virginia will form a regional waste authority to be named, “Region 2000 Services Authority.” A subsequent article (Lynchburg News & Advance June 2008) noted that due to regionalization efforts, Campbell County will potentially save at least $700,000 per year in long term costs by halting the transfer of MSW to a distant landfill in Amelia County. Also, the newly formed authority has been considering future regional options in response to expected landfill closures; which include a new regional landfill, transfer stations, or a WTE facility.

In another example of regionalization, Warren County Va. has been negotiating with Page County to utilize their ‘Battle Creek’ MSW landfill which would save a projected $250,000 in annual transportation costs as well as reduce emissions, instead of shipping waste to Richmond (Daily News Record 2008). Such reports highlight the growing need for Virginia localities to explore new MSW management options in response to increasing MSW disposal demands and the future closure of existing landfills. Furthermore, this select literature also illustrates the reoccurring economic and environmental issues associated with MSW management, as well as current problems that face Virginia’s localities. This study aims to provide environmental and economical information that will be useful to regional planning authorities undergoing future population growth and landfill closures.

Chapter 3. Research Questions and Methods

3.1 Research Question: Region Selection

This section presents the question of how regions in Virginia were selected in this study for subsequent analysis of economic cost and environmental burdens of future MSW disposal options. A set of criteria based on projected population growth and permitted MSW disposal capacity was utilized to appropriately select PDCs that were investigated. Rationale for the following research question and methods employed to satisfy this question are described below.

3.1.1 Which Virginia PDCs represent high growth regions and currently have minimal permitted MSW disposal capacity?

Rationale: The Virginia General Assembly created the statutory framework for the creation of the PDCs in 1968 and later adopted the Regional Cooperation Act which clearly articulates that PDCs were created to provide a forum for state and local government to address issues of a regional nature (VDHCD 2009). PDCs were selected as areas of comparison since literature identifies MSW management and disposal as regional problem. Therefore, it could be inferred that effective MSW management and disposal planning is critical in regions that will experience high projected population growth and increasing MSW disposal demands. Furthermore, localities that currently lack permitted MSW disposal capacity due to landfill closures pursuant to HB1205 legislation; requiring unlined landfills to cease operations by scheduled time-frames, place addition pressures on localities to find other economical outlets for MSW disposal. Thus, it was determined that high population growth PDCs with minimal permitted MSW disposal capacity would be candidate regions for economic and environmental analysis concerning future MSW management planning. The following describes the methods utilized in selecting candidate PDCs for analysis.

3.2 Research Methods and Data: Region Selection

The current and projected population of each PDC was developed using data retrieved from the Weldon Cooper Center for Public Services and the US Census Bureau. PDCs were ranked according to "percent population change" from years 2010 to 2020 summarized in table 3.1. The top five ranked PDCs were selected for further analysis of remaining permitted MSW disposal capacity. Projected permitted landfill capacities and estimated lifetime capacities were summarized using data obtained from VDEQ's *2007 Solid Waste Management Report.* Data reflecting MSW landfill capacities and estimated lifetimes are found in Appendix A, while summarized data is presented in table 3.2. The Rappahannock-Rapidan Regional Commission and Thomas Jefferson Planning District Commission were selected for analysis due to limited accumulative MSW disposal capacities. Each PDC was then further analyzed on a county/city locality level in order to capture the current MSW generation rates and MSW management schemes. The next section establishes the research question, rationale, and testable hypotheses used to analyze the economic costs and environmental releases related to MSW management within the selected PDCs.

Table 3.1 Summary of Virginia PDCs Population Projections (2010-2020)

PDC	Population 2010	Population 2020	% Change	Population Change
George Washington Regional Commission	345,022	443,412	28.52	98,390
Rappahannock-Rapidan	176,584	216,460	22.58	39,876
Northern Shenandoah Valley	225,501	264,115	17.12	38,614
Northern Virginia	2,192,533	2,545,883	16.12	353,350
Thomas Jefferson	234,606	268,261	14.35	33,655
Richmond Regional	994,425	1,119,227	12.55	124,802
Middle Peninsula	94,630	105,411	11.39	10,781
Central Shenandoah	281,272	304,448	8.24	23,176
Crater	180,353	195,133	8.20	14,780
Hampton Roads	1,662,480	1,786,437	7.46	123,957
Piedmont	243,276	258,139	6.11	14,863
Accomack-Northampton	54,235	57,117	5.31	2,882
Northern Neck	51,721	54,300	4.99	2,579
Region 2000	101,455	106,481	4.95	5,026
New River Valley	175,336	183,208	4.49	7,872
Roanoke Valley-Alleghany	267,634	274,564	2.59	6,930
West Piedmont	248,072	251,941	1.56	3,869
Mount Rogers	189,461	191,742	1.20	2,281
Cumberland Plateau	114,700	115,309	0.53	609
LENOWISCO	91,506	91,376	-0.14	-130
Southside	85,538	84,605	-1.09	-933

Source: Weldon Cooper Center for Public Services and the US Census Bureau

Table 3.2 Summary of MSW Landfill Capacities for Candidate PDCs

PDC	Remaining Permitted Capacity (yd^3)	Remaining Permitted Capacity (tons)	Remaining Life (yrs)
Northern Shenandoah Valley	45,283,704	22,641,852	116
Northern Virginia	31,291,570	15,645,785	78
George Washington Regional Commission	29,858,474	14,929,237	40
Rappahannock-Rapidan	2,011,832	1,005,916	18
Thomas Jefferson	255,000	127,500	6

Source: VDEQ *2007 Solid Waste Management Report*

3.3 Research Question: Economic and Environmental Impacts

This section presents the question concerning the economic costs and environmental releases resulting from MSW management within PDCs as a function of future population growth. A rationale and hypotheses will be stated to support the research question at hand.

3.3.1 What are the economic costs and environmental impacts associated with MSW management and disposal processes of selected high growth PDCs?

Rationale: Economic costs and environmental releases were selected as variables of analysis since they represent important factors related to the siting of MSW management and disposal facilities. Although other factors such as social and political pressures are equally important in managing MSW; these factors were not taken into account and are considered beyond the scope of this study. Economic costs associated with collection, transportation, transfer stations, WTE facilities, and landfills were each analyzed in response to the volume of MSW that was estimated to be generated within selected PDCs as a function of population growth. Environmental burdens concerning air emissions, water releases, and energy consumption were assumed to vary across each MSW management and disposal option. Thus, the aim of this study is to relate economic costs and environmental impacts on per ton basis regarding MSW disposal across high population growth PDCs.

Furthermore this study seeks to suggest which MSW disposal option presents the greatest environmental impacts and which option may impose the largest economic costs in response to high projected population growth. This study will specifically attempt to estimate the environmental air emissions related to total particulate matter (PM), NO_x, sulfur oxides (SO_x), carbon monoxide (CO), CO_2 and CH_4. These air pollutants were selected for analysis since they represent a mix of GHGs and criteria air pollutants as defined by EPA. Resulting capital, operating, and closure costs will be aggregated for each option over their useful lifetimes and compared to environmental impacts. Therefore, testable hypotheses for the research question stated above are summarized below:

Hypotheses:

H_o^1: *There is no difference in terms of environmental and economic impacts across current MSW management options for select high-growth PDCs compared to future MSW management options consisting of a regional landfill or WTE combustion facility in response to expected surge in population in these PDC's.*

H_1^1: *There is a difference in economic costs between current MSW management options within select high-growth PDCs compared to future MSW management options utilizing a regional landfill or WTE combustion facility in response to high population growth.*

It is the intent of this study to assess whether the Null or Alternate Hypotheses will be rejected and identify related policy implications. The section below describes the MSW-DST model and outline the methodology and data used to estimate economic costs and environmental impacts.

3.4 Research Methods and Data: MSW-DST Model Description

The MSW-DST model was developed for the EPA and was designed to estimate costs and environmental releases related to MSW collection, transfer stations, transportation, composting facilities, materials recovery facilities, WTE incineration facilities, and landfills. This study only utilized model processes concerned with MSW collection, transfer stations, transportation, WTE facilities, and landfills as they relate to MSW management scenarios currently practiced by PDC localities of interest. The MSW-DST also functions as an optimizer tool to configure possible integrated MSW management alternatives based on user restraints; however optimization is beyond the scope of this study and will not be exercised within the model.

Selection of the MSW-DST model was influenced by the ease of its availability and ability to capture MSW management processes relevant to each locality as well-depicted by Winkler et al (2007). Additionally, the development of the model included the active participation of over 80 parties of differing interests. The methodology, process models, and documentation went through extensive review including that of stakeholders, a series of external peer-reviews, in addition to peer, quality assurance, and US EPA administrative review (Thorneloe 2007).

The MSW-DST model utilizes a life-cycle inventory (LCI) method to quantify environmental emissions and full cost accounting (FCA) to estimate costs. LCI is an analytical tool used to compile and quantify environmental flows over the entire life-cycle of a process (Camobreco 1999). FCA methods capture past and future net annualized economic costs. Relevant model input parameters were gathered from localities and MSW facilities via surveys and interviews. Site specific information and estimates were used to provide input estimates to the EPA and in cases where such data was not available; the MSW-DST model was used to select peer-reviewed default model parameters.

LCI is a component of the Life Cycle Assessment (LCA) process as recognized by the International Organization for Standardization (ISO) 14040 Standards. LCA is defined as a systematic set of procedures for compiling and examining inputs and outputs of material and energy and the associated environmental impacts directly attributable to the functioning of a product or service system throughout its life cycle (ISO 1995). The MSW-DST model was utilized in this study to calculate LCI values of energy consumption and atmospheric emissions generated by collection, transfer station, transportation, WTE facility, and landfill model processes.

The FCA method used in this model was limited to the costs incurred by the public sector; therefore commercial and institutional generated MSW was excluded from this study. Cost accounting was assumed to begin when MSW is collected via drop-off MSW convenience centers and ends when MSW is ultimately disposed of in a landfill. The cost of each model process was annualized and given in terms of cost per unit ton of MSW managed. All model process equations and methods were adapted from RTI (2000) documentation.

3.4.1 MSW-DST Common Model Processes and General Assumptions

The common model process contains variables that are used across all processes (ie collection, transfer stations, landfills, etc.) used in the overall model. The composition, compaction densities, and physical properties of residential MSW were assumed to remain constant among all PDC localities which are located in Appendix B. Energy consumption and generation were based on the electrical energy split of Virginia, projected electricity prices, and projected fuel prices estimated by the Energy Information Administration (EIA) which are found in Appendix C.

The model accounts for emissions related to the pre-combustion phase of energy production. Pre-combustion emissions, as they relates to the model, are emissions released during the production of fuel and electricity consumed during the respective model process. Pre-combustion energy is defined by the model as the amount of energy that was consumed to generate fuel of electricity for consumption within the model. Both combustion emissions and energy are measured by the model when fuel or energy sources are consumed via combustion.

Any emission or energy offsets that occur within the model are assumed to be related to the energy recovery via methane gas from landfills and combustion of MSW by way of WTE facilities. Generated energy from these sources is assumed to displace pollutants and energy that would have otherwise been emitted and consumed during conventional energy usage with respect to the regional energy grid. The five MSW-DST model processes used in this study are explained below to include equations used and inherent modeling assumptions.

3.4.1.1 MSW Collection Model Process

The collection process of the MSW-DST model calculates the cost and LCI values pertaining to the initial collection of MSW from one or more surrounding localities. MSW was assumed to be collected from residential drop-off MSW convenience centers where it would be taken directly to a transfer station, landfill, or WTE facility. Collected MSW was reflective of the amount of MSW generated within each locality as referenced in tables 3.3 and 3.4, which is based on *2006 Annual Recycling Rate Report* figures to exclude MSW that was recycled. MSW composition (Appendix B), average collection radius (Appendix D), and type of vehicle used to transport MSW were variables used to calculate cost and LCI values within the model. The collection process was assumed to occur via roadway and carried out by light duty garbage collection vehicles. All input data described in the following sections are found in Appendix D. Figure 3.1 is a graphical representation of the collection model process.

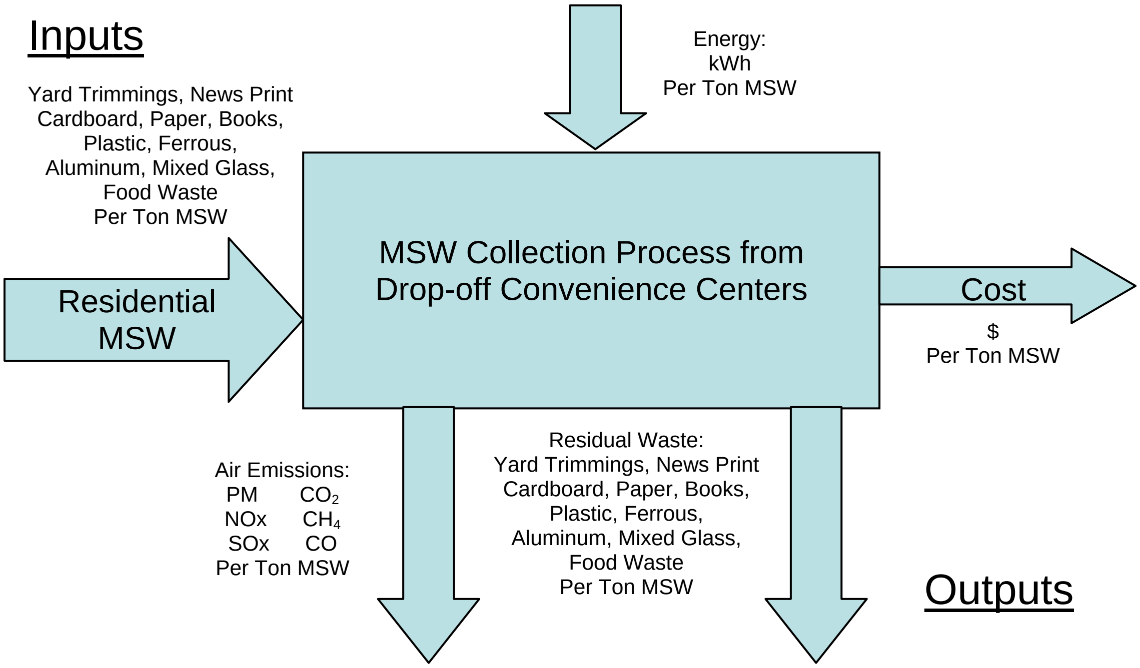

Figure 3.1 MSW-DST Collection Model Process

a) Costs Methods

Diesel fuel costs (Appendix C) and average collection distances (Appendix D) were defined and estimated for each locality. The total annual collection costs were calculated by multiplying the total average collection distances traveled annually within each locality by the cost per mile traveled per ton of MSW collected based on fuel consumption. Fuel consumption was reflective of model calculations based on vehicle type, vehicle maintenance, licensing, taxes, vehicle weight capacity (Appendix D), MSW density (Appendix B), fuel cost (Appendix C), and fuel efficiency on the vehicle (Appendix D).

b) LCI Methods

LCI values derived from the collection model process were related to fuel consumption of the collection vehicle and compaction density of the MSW being collected. Collection based LCI values are dependent on quantity of diesel fuel consumed by the vehicle as well as electricity consumed in the production of the diesel fuel. Annual air emissions included PM, NO_x, SO_x, CO, and CO_2 which were calculated by multiplying the annual quantity of diesel fuel consumed by the pollutants emitted per gallon of fuel combusted based on default model data. Water and solid waste releases were assumed to be insignificant.

3.4.1.2 MSW Transfer Station Model Process

The transfer station model process calculated economic costs and LCI figures related to energy consumption and air emissions. The annual MSW generation volume of each locality was used determine the type and size of the transfer station facility that would need to be constructed. Transfer stations were assumed to manage mixed residential MSW and house a one-level loading bay with a tipping floor. MSW is loaded into a hopper from the tipping floor where it is fed into a compactor. After compaction the MSW is placed into a trailer for subsequent transport. The following describes the methods and equations used to estimate the costs of a transfer station. Figure 3.2 represents the transfer station model process.

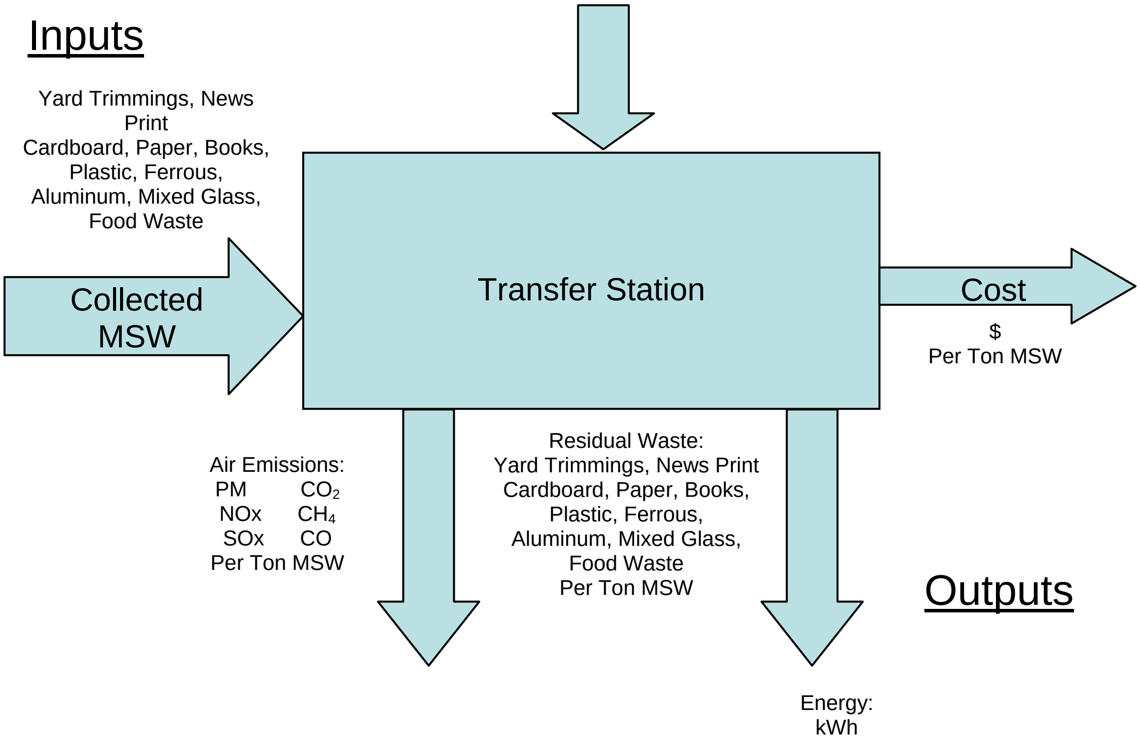

Figure 3.2 MSW-DST Transfer Station Model Process

a) Costs Methods

Annualized capital and operating costs were calculated per ton of MSW processed. The capital cost of a transfer station was estimated based on the anticipated volume of MSW to be processed. Areas for the tipping floor, collection vehicle unloading area, loading bay, and office areas were calculated and summed to estimate the total transfer station area. The construction costs were determined by multiplying estimated cost rates by each respective constructed area. These costs in addition to engineering costs and land acquisition costs were summed and annualized over the expected life of the transfer station to represent the annual capital cost (FAC_AC).

Annual equipment costs (EQ_AC) included the purchase and installation costs related to the rolling stock and compactors of a transfer station. The rolling stock and compactor costs were calculated by multiplying unit cost, installation cost, and a capital recovery factor (CRF) of each unit and summing them together. Operating costs (OP_AC) were then calculated as a summation of annual labor and management costs, equipment and facility energy costs, and equipment and facility maintenance costs. FAC_AC, EQ_AC, and OP_AC were then summed and divided by the working days to estimate the cost factor per ton of MSW processed. Respective equations and data inputs are located in Appendix E.

b) LCI Methods

LCI values were calculated with respect to energy consumption and environmental releases in which LCI parameters were allocated to each component of the MSW stream being processed. LCI values for combustion and pre-combustion energy consumption were based on fuels related to electricity for equipment, lighting, and heating transfer stations.

Emissions were represented by the compactor and building energy usage multiplied by the estimated amount of pollutant emitted per kWh of energy used. Emissions from rolling stock operations were also calculated via diesel fuel combustion. These variables were summed to estimate the total emissions originating from the transfer station to include; PM, NO_x, SO_x, CO, CO_2, and CH_4. Respective equations and data are located in Appendix E.

3.4.1.3 MSW Transportation Model Process

The transportation portion of the MSW-DST model calculates the cost and LCI values pertaining to the transportation of MSW between various MSW management and disposal facilities represented in each model scenario. MSW composition, distance traveled, and type of vehicle used to transport MSW were variables that were used in the model process to calculate cost and LCI values. All long-haul transportation was assumed to be via roadway and carried out by diesel tractor-trailers. All equations and data described in the following sections are found in Appendix F.

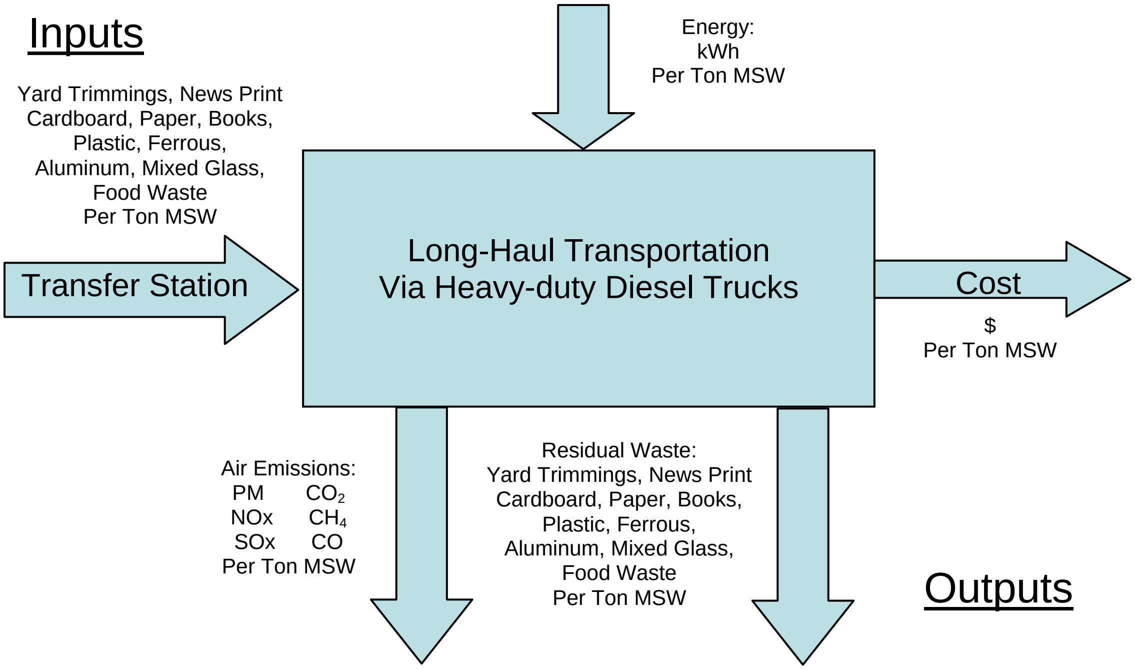

Figure 3.3 MSW-DST Transportation Model Process

a) Costs Methods

Transportation costs were calculated per ton of MSW managed in units of dollars per mile based on vehicle weight capacity, MSW density, and distances traveled between MSW process facilities. The total annual cost was calculated by multiplying the total estimated distance traveled annually within each locality by the cost per mile traveled based on fuel cost and fuel efficiency of the vehicle.

b) LCI Methods

LCI values derived from the transportation model process were related to fuel consumption of the transportation vehicle and compaction density of the MSW being transported. Transportation based LCI values are dependent on quantity of diesel fuel consumed by the vehicle as well as electricity consumed in the production of fuels. Annual air emissions included PM, NO_x, SO_x, CO, and CO_2 (non-biomass) which were calculated by multiplying the annual quantity of diesel fuel consumed by the default value of emissions per gallon of fuel combusted. Water and solid waste releases were assumed to be insignificant.

3.4.1.4 WTE Combustion Facility Model Process

The WTE combustion model process uses both default design parameters and current industry best estimates to calculate economic cost and LCI values. Hypothetical facilities modeled in this study were assumed to be designed as mass burn facilities and meet current EPA emission standards. Resulting ash from incineration and recovered ferrous metal was not taken into account within this study due to insufficient data but is recognized as an important contributing environmental and cost factor. Any electricity that is generated from the incineration process is assumed to be used by both direct use and redistributed to the local energy grid which represents an offset. All equations and data described in the following sections are found in Appendix G. Figure 3.4 is a visual of the WTE facility model process.

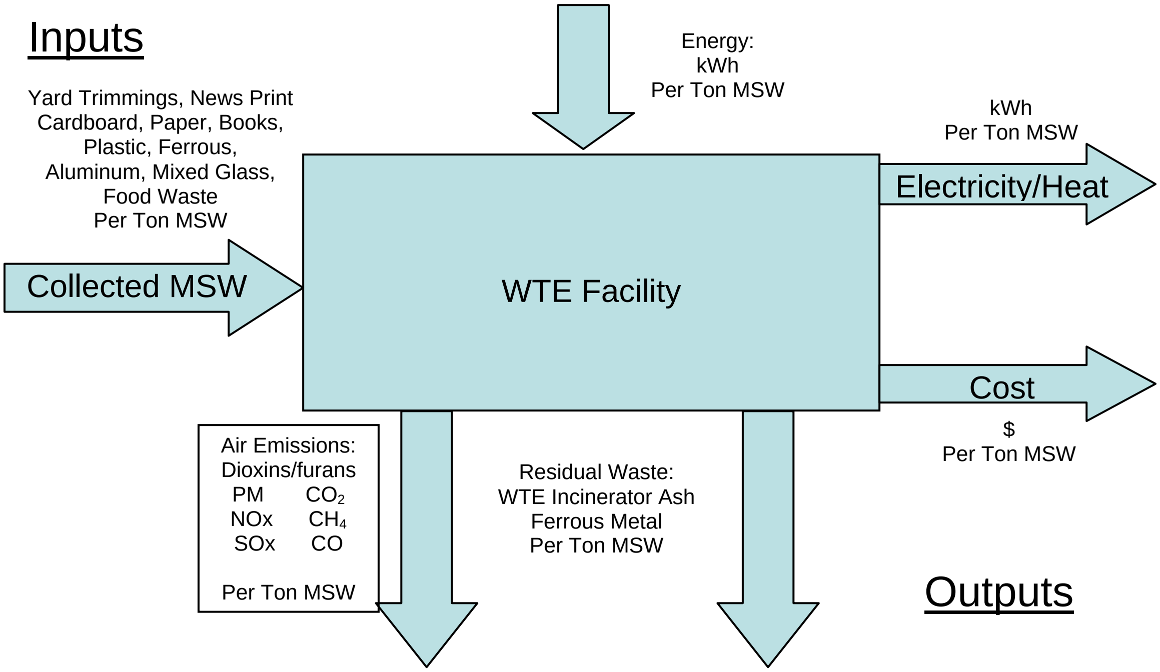

Figure 3.4 MSW-DST WTE Facility Model Process

a) Costs Methods

The model utilizes linear cost functions derived from the regression of four varying facility sizes; therefore the facility's capacity is proportional to the volume of MSW generated (RTI 2000). Revenue realized from energy recovery is dependent on the British Thermal Unit (BTU) value of MSW entering the facility. This study only analyzed WTE facility capital and O&M costs; however it should be pointed out the waste residue disposal costs is a contributing cost factor. Due to data limitations; ash residue disposal costs were not considered in this study.

Capital cost is comprised of the cost of combustors, ash handling system, turbine, and air pollution control and monitoring devices. The capital cost was calculated based on a unit cost measured in $/BTU/yr. The annual cost was expressed using a capital recovery factor that is dependent upon a book lifetime and discount rate (RTI 2000). Operation and maintenance (O&M) costs include labor, overhead, taxes, administration, insurance, indirect costs, auxiliary fuel cost, electricity cost, and maintenance. The O&M cost function depends upon the rate at which MSW enters the plant, the capacity factor, and the cost of ash disposal (RTI 2000). Input values concerning cost were based on industry averages collected during this study. Revenue from ferrous metal recovery is noted but is outside the scope of this study.

b) LCI Methods

LCI values associated with WTE incineration include energy consumption and environmental releases related to the combustion process. Energy that is generated and recovered for use was recognized as an energy gain pertaining to calculated LCI values. It was assumed that electricity generated by WTE facilities will displace portions of electricity produced from conventional fuels that would otherwise be consumed. Energy offsets were determined using the current electrical energy generation split relative to Virginia (Appendix C).

Net air emissions from the WTE facility were identified in this model as post-treatment emissions minus the displaced emissions that would have otherwise been produced by a conventional electricity generating facility. Default emission factors related to non-metal emission factors were used in this study to reflect current regulatory EPA emission standards.

3.4.1.5 MSW Landfill Model Process

Landfills represent the final process of the MSW management process. Traditional Resource Conservation and Recovery Act (RCRA) Subtitle D "dry-tomb" landfills were assumed and modeled according to regulatory specification related to liner specifications, landfill gas collection systems, and leachate collection systems. A 20-year time period was used in the model analysis to represent the active decomposition lifetime of MSW in a Subtitle D landfill. All equations and data described in the following sections are found in Appendix H. The landfill model process is represented in figure 3.5

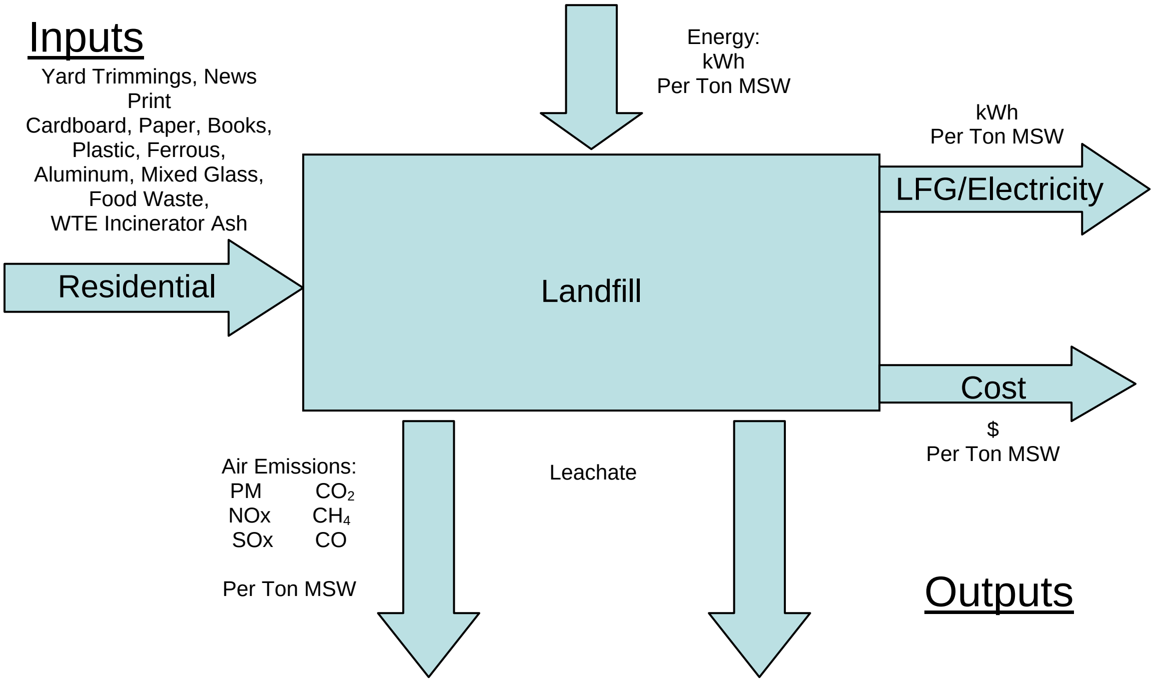

Figure 3.5 MSW-DST Landfill Model Process

a) Costs Methods

The costs related to landfills were divided into four main categories to include; initial construction, cell construction, operations, and closure. The calculated costs of future hypothetical landfills were based on the size of the landfill dependent on the amount of MSW generated within the PDC for disposal. Daily MSW flow and landfill lifetime were variables used in the model to estimate landfill size to reflect landfill cost.

Initial estimated construction costs include; land acquisition, site fencing, building and structures, platform scales, site utilities installation, site access roads, monitoring wells, initial landscaping, leachate storage facility, site suitability study, and licensing. The total cost of each variable was amortized over the operating period of the facility and normalized to the annual volume of MSW received (RTI 2000).

Individual landfill cell construction costs included in model were related to site clearing and excavation, berm construction, liner installation, leachate control materials, and pre-operational costs. The total cell construction cost is amortized over the operating period of the landfill and normalized to the annual volume of MSW received (RTI 2000). Hypothetical landfills were assumed to have five cells constructed over 20 years.

O&M costs of a landfill include labor, equipment procurement, leachate treatment, daily cover overhead, taxes, administration, insurance, indirect costs, auxiliary fuel cost, utilities, and maintenance (RTI 2000). The annual O&M costs are dependent upon the volume of MSW that enters the landfill. All costs associated with O&M were assumed to be annual and reoccurring.

Finally, landfill closure costs used in the model pertain to the installation of the final landfill gas extraction system, final cover, and perpetual maintenance. The total closure cost was amortized over the operating period of the facility and normalized to the annual volume of waste received (RTI 2000). A 30-year time period was used as a post closure care period, which is relevant to RCRA Subtitle D regulations. Any revenue realized from landfill gas generation sold to an end user was not taken into account during this study.

b) LCI Methods

LCI values were calculated to represent net energy consumption and environmental releases pertaining to construction, operation, closure, and post-closure activities associated with the landfill model process. Air emissions were identified as originating from landfill equipment use and the decomposition MSW. If energy was produced via landfill gas recovery systems; energy gain was denoted in the LCI inventory and assumed to displace a similar amount of electricity produced from conventional fuels (RTI 2000).

Water releases were considered post-treatment releases of leachate from publically owned treatment works (POTWs), however these releases were not taken into consideration since results cannot be directly compared to other process models where water pollutants are insufficient. The next section describes the model scenarios of each PDC locality with respect to the model processes explained above.

3.5 Research Methods and Data: MSW-DST Model Scenarios

Baseline model scenarios were first created to represent the current MSW management and disposal practices relevant to the functioning of each PDC locality.

Population and MSW generation data were obtained from the Weldon Cooper Center for Public Services database and the *2006 Annual Recycling Rate Report* published by VDEQ respectively. Per capita MSW generation rates were calculated by dividing the total tonnage of MSW generated within each PDC locality by the current predicted population. Calculated MSW generation rates were multiplied by the projected population estimates of each PDC locality to estimate the annual MSW generated within each locality for years 2010 and 2020. Projected MSW generation volumes were subsequently used as model input data. Estimations from this report exclude MSW that was recycled, therefore only MSW that is anticipated for disposal was evaluated. The following is a summary of PDC locality descriptions pertaining to projected populations and MSW generation figures as well as a description of current MSW management practices.

3.5.1 Rappahannock-Rapidan Regional Commission

The Rappahannock-Rapidan Regional Commission (RRRC) represents an area of Virginia of that is comprised of 5 counties (Culpeper, Rappahannock, Fauquier, Madison, Orange), each of which is recognized by the VDEQ as a separate SWPU. The RRRC has the second largest projected population growth rate among all PDCs within Virginia (see table 3.1). This area was chosen since it represents a high-growth PDC consisting of independently operating SWPUs.

Table 3.3 summarizes the data inputs used in the MSW-DST model concerning projected population growth and MSW generation for localities within the RRRC. Projected MSW volumes were calculated by multiplying the MSW generation rates by the projected population. MSW generations rates were calculated by dividing each localities estimated tonnage of MSW generated during 2007 as reported per VDEQ by the provisional population of that locality. It was assumed that the MSW generation rated would remain static during the future which accounts for linearity among generated volumes of MSW as a function of population growth. MSW generation figures exclude MSW that was recycled or recovered.

Figure 3.6 represents the location of the current MSW management units to include drop-off convenience centers where MSW collection is initiated and transfer stations where MSW is consolidated then transported to regional landfills outside of the PDC. The following localities will be cumulatively analyzed and referred to as the RRRC baseline scenario.

Table 3.3 RRRC Population and MSW Generation Projections

County/City	**2007 Provisional Population**[1]	**2007 Residential MSW (tons)**[2]	**2010 Projected Population**[1]	**2010 Residential MSW (tons)**	**2020 Projected Population**[1]	**2020 Residential MSW (tons)**
Culpeper	45,505	28,058	48,074	29,642	61,255	37,769
Rappahannock	7,193	6,313	7,593	6,664	8,242	7,234
Fauquier	65,319	50,781	72,685	56,507	89,318	69,438
Madison	13,828	7,036	14,105	7,177	15,624	7,950
Orange	32,364	17,017	34,127	17,944	42,021	22,095
Total	164,210	109,205	176,584	117,934	216,460	144,486

1 Weldon Cooper Center for Public Services
2 VDEQ 2006 Virginia Annual Recycling Rate Report

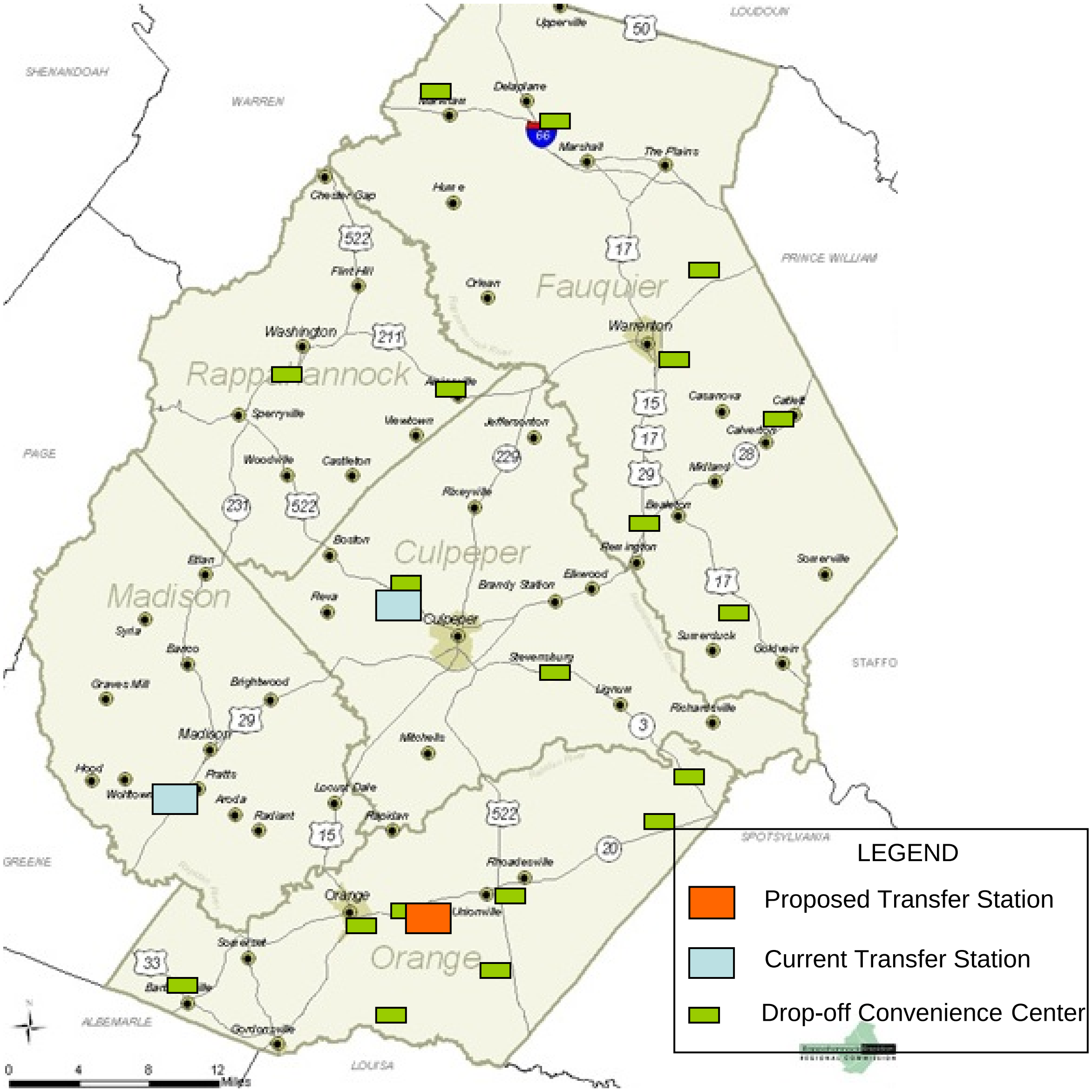

Figure 3.6 RRRC Baseline MSW Management Scenario

Culpeper County and Rappahannock County

Culpeper County has the largest projected population increase from 2010 to 2020 within the RRRC. Two convenience centers are located within the county, which serve as drop-off locations for county residents. MSW is transported from these convenience centers to the Culpeper County transfer station where the MSW is then sent to the Old Dominion landfill in Henrico County; located approximately 100 miles from the site. Culpeper County also receives MSW from a single convenience center that is located in Rappahannock County since the county landfill located in Rappahannock closed in 2007. Both Culpeper and Rappahannock counties will be treated as a single unit during analysis since both counties are served by a single transfer station. A representation of the MSW management scenario is presented in Figure 3.7.

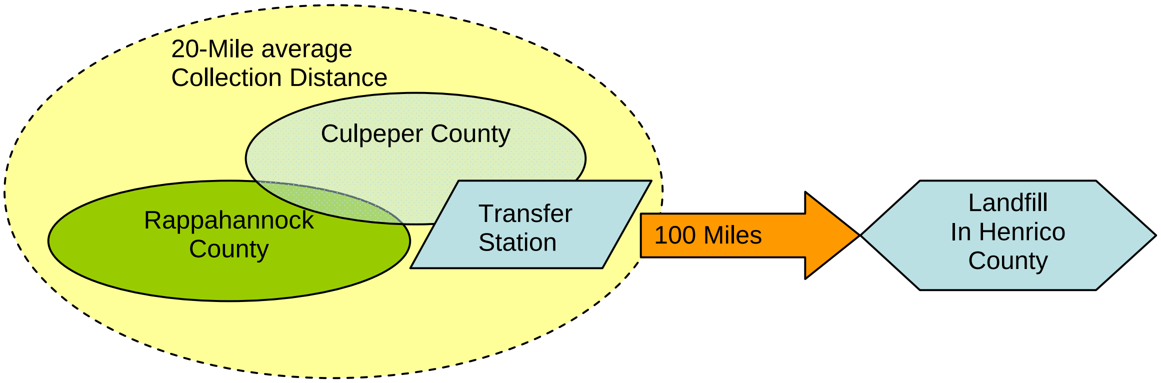

Figure 3.7 Culpeper County and Rappahannock County

Fauquier County

Fauquier County is located to the northeast of Culpeper and Rappahannock Counties. Fauquier is the largest populated county, however is second to Culpeper County in population density per square mile. Residents within Fauquier County currently transport waste to one of seven county operated MSW convenience centers which are located throughout the county. Residents may also contract with private haulers for curbside collection services which directly transfer MSW to the Corral Farm Landfill located in Fauquier County. A representation of the MSW management scenario is presented in Figure 3.8.

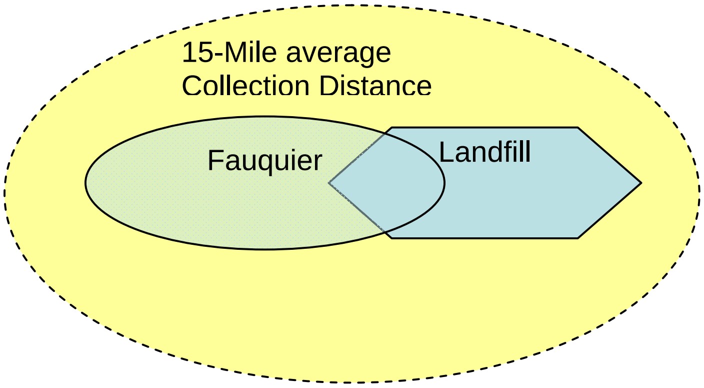

Figure 3.8 Fauquier County

Madison County

Madison County lies to the southwest of Culpeper County. Madison County is projected to have the second lowest population percentage growth from 2010 to 2020 within the RRRC. Residential MSW generated within the county is either directly transported to the county owned transfer station by residents or collected via private haulers. Funding for solid waste management is provided through general revenue funds. The transfer station is privately operated and serves as the only collection point within the county from which waste is then transported to the Maplewood Landfill located 90 miles away in Amelia County. A representation of the MSW management scenario is presented in Figure 3.9.

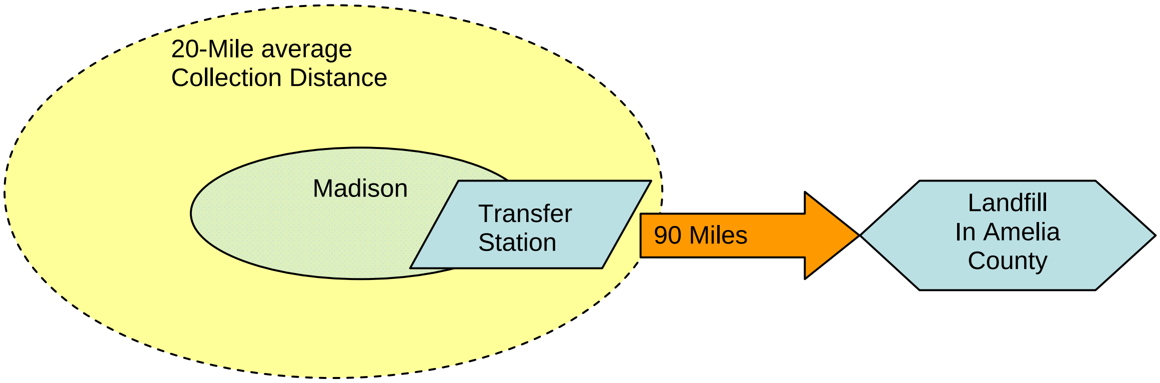

Figure 3.9 Madison County

Orange County

Orange County is located to the southeast of Culpeper County. Orange County ranks second in projected population growth from 2010 to 2020 among the other counties within the RRRC. Residential MSW generated within Orange County is either transported by residents to one of seven convenience centers or collected and transported to the county landfill by contracted private haulers. The Orange County Landfill is slatted for closure in 2012 due to environmental regulations pursuant to HB1205 legislation. For purposes of this study it was assumed that a transfer station would be used for future MSW management when the landfill undergoes closure. A representation of the MSW management scenario is presented in Figure 3.10.

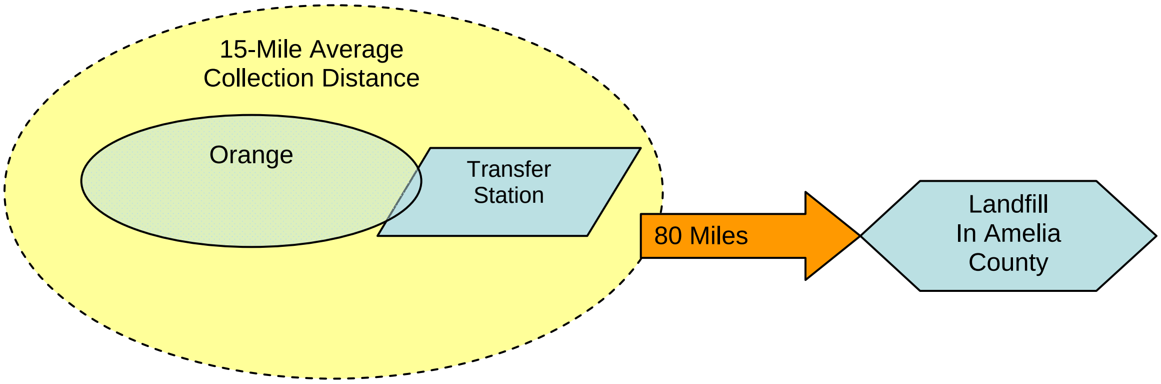

Figure 3.10 Orange County

Results from each locality were summed together within the RRRC to estimate the total costs and environmental emissions related to the PDC. Subsequent scenarios represent a hypothetical centrally located landfill and a WTE incineration facility that would serve the RRRC on a regional basis.

RRRC: Hypothetical Regional Landfill

A hypothetical regional landfill scenario was modeled with respect to the entire population of the TJPDC during years 2010 and 2020 as previously indicated. The size of the landfill was designed to meet the MSW disposal needs of the TJPDC related to the projected volume of MSW generated. This landfill was assumed to be centrally located within the TJPDC which is illustrated in figure 3.11.

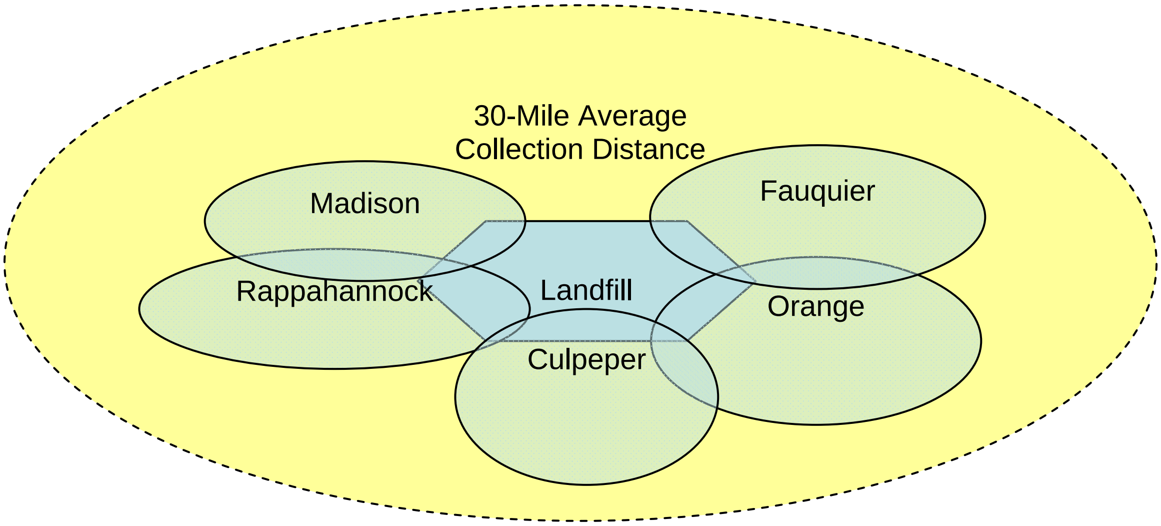

Figure 3.11 RRRC Regional Landfill Scenario

RRRC: Hypothetical Regional WTE Facility

A hypothetical WTE facility was created within a model scenario to serve the needs of the entire RRRC on a regional scale. A population of 216,460 was assumed to generate 144,768 tons of residential MSW during the year 2020. This tonnage figure was used to estimate the cost per ton of MSW by the facility assuming that all of the MSW generated less recycling would be treated by the WTE facility. This model process, equations, and data are summarized in section 3.4.1.3 and the model scenario is depicted in figure 3.12.

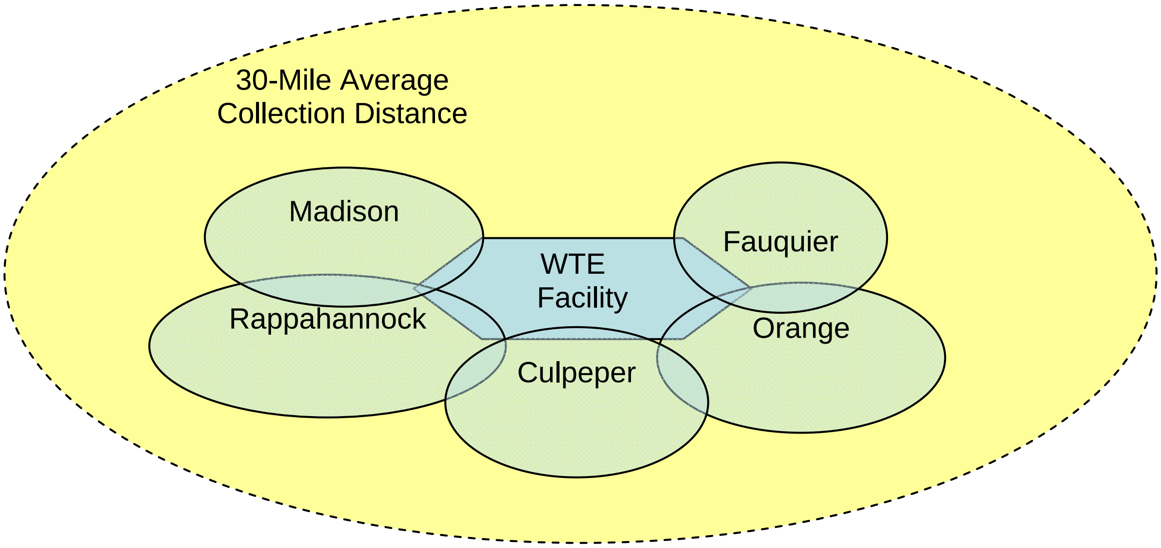

Figure 3.12 RRRC Regional WTE Facility Scenario

3.5.2 Thomas Jefferson Planning District Commission

The Thomas Jefferson Planning District Commission (TJPDC) consists of 5 counties (Albemarle, Fluvanna, Greene, Louisa, Nelson) and the City of Charlottesville. Route 29 and the I-64/250 corridors are major transportation routes found within the TJPDC. The TJPDC has the fifth largest projected population growth rates among all PDCs within Virginia (see table 3.1). This region was selected since it represents a high-growth PDC that relies solely on transfer stations for long-haul transportation of MSW to out-of-county landfill facilities. See table 3.4 for a summary of projected population and MSW generation figures for the TJPDC. The current MSW management scenario for the PDC is depicted in figure 3.13

Table 3.4 TJPDC Population and MSW Generation Projections

County/City	2007 Provisional Population[1]	2007 Residential MSW (tons)[2]	2010 Projected Population[1]	2010 Residential MSW (tons)	2020 Projected Population[1]	2020 Residential MSW (tons)
Albemarle	134,875	106,056	136,886	107,637	149,183	117,307
Charlottesville						
Fluvanna	26,057	4,849	28,971	5,391	37,433	6,966
Greene	17,714	9,759	19,269	10,616	23,088	12,720
Nelson	15,172	9,352	15,557	9,590	16,668	10,274
Louisa	31,177	15,745	33,923	17,132	41,889	21,155
Total	224,995	145,761	234,606	150,366	268,261	168,422

1 Weldon Cooper Center for Public Services

2 VDEQ 2006 Virginia Annual Recycling Rate Report

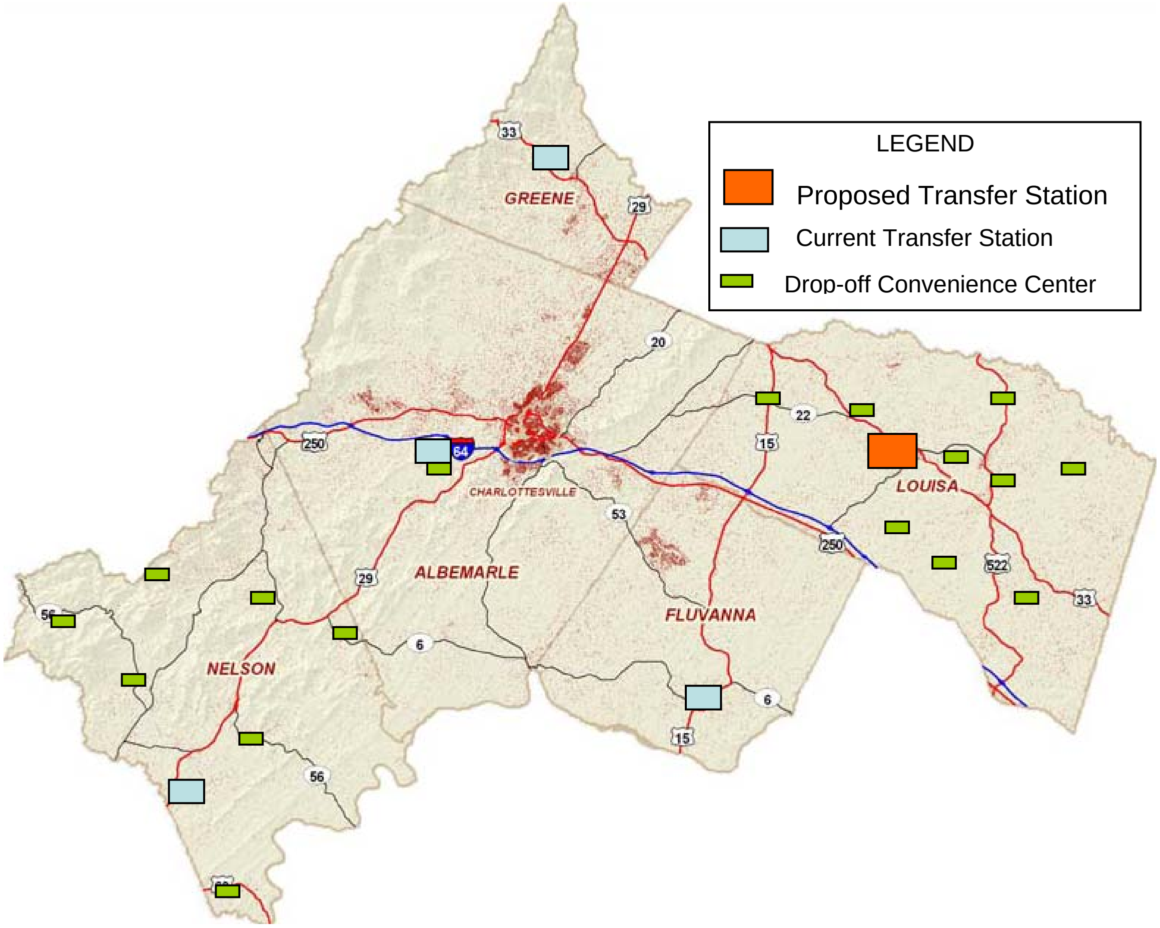

Figure 3.13 TJPDC Baseline MSW Management Scenario

Albemarle County & the City of Charlottesville

The City of Charlottesville is surrounded by Albemarle County which is centrally located within the TJPDC. The populations of these localities represent approximately half of entire population of the TJPDC. Charlottesville has slowly been declining in population due to an agreement made with Albemarle County that will halt the expansion of the city. Both localities rely on a single transfer station located in Albemarle County to transport MSW nearly 80 miles away to the Maplewood Landfill in Amelia County. A representation of the MSW management scenario is presented in Figure 3.14.

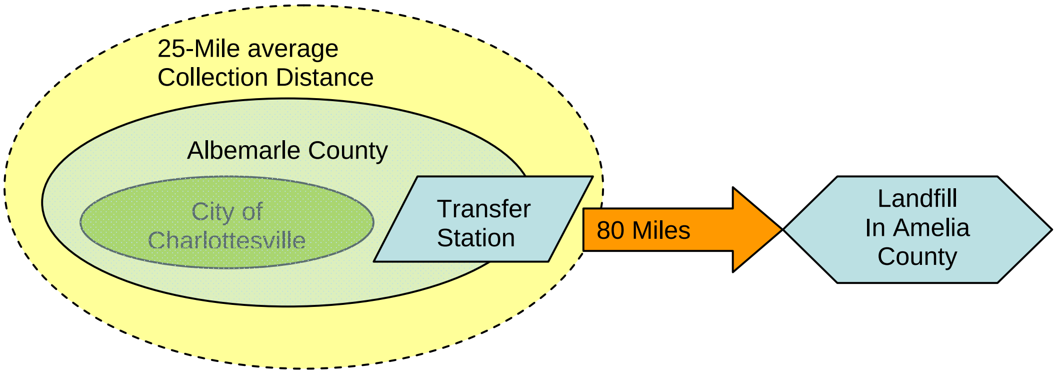

Figure 3.14 Albemarle County & the City of Charlottesville

Fluvanna County

Fluvanna County is one of the most rapidly growing counties in Virginia, predicted to grow by almost 30% between years 2010 and 2020. Fluvanna County lies to the southeast of Albemarle County and to the southwest of Louisa County. Fluvanna County's landfill closed in 2007 due to HB1205 legislation which was subsequently replaced by a privately owned and operated transfer station that serves the county. MSW is transported

60 miles to the Old Dominion Landfill in Henrico County. A representation of the MSW management scenario is presented in Figure 3.15.

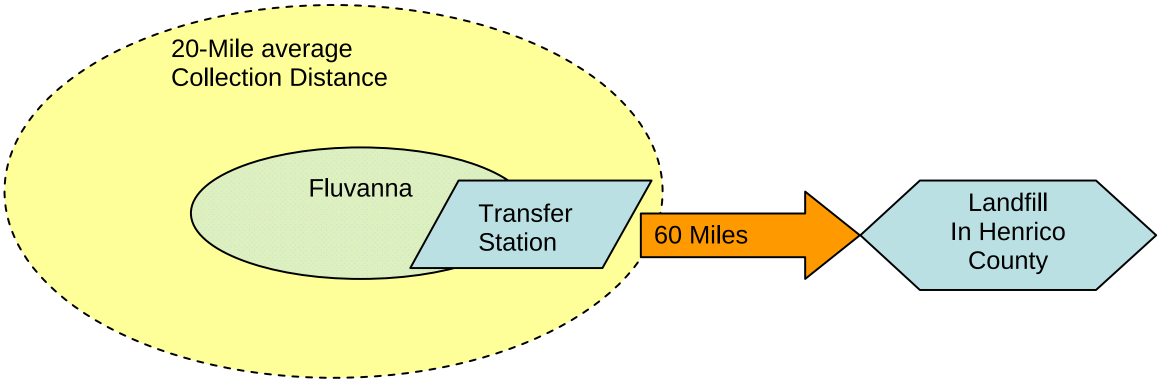

Figure 3.15 Fluvanna County

Greene County

Greene County boarders Albemarle County to the north and is another rapidly growing county with a 20% increase in population from 2010 to 2020. Waste is either collected by private hauling firms or taken by individuals to a single county owned transfer station. MSW is then transferred to the Maplewood Landfill located in Amelia County via contractual agreements with private haulers. A representation of the MSW management scenario is presented in Figure 3.16.

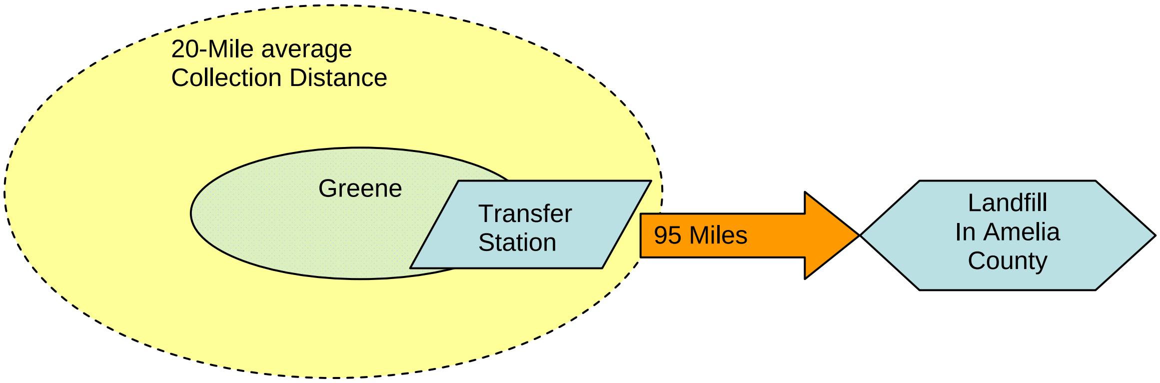

Figure 3.16 Greene County

Louisa County

Louisa County is the eastern most county of the TJPDC and currently operates nine convenience centers located throughout the county. MSW is directly transported from these convenience centers or private residence directly to the county landfill via private haulers. The Louisa County Sanitary Landfill is slated for closure during 2012 due to HB1205 legislation. It was assumed that a transfer station would be used for future MSW management when the landfill undergoes closure; therefore a transfer station model was used in this scenario for purposes of this study. A representation of the MSW management scenario is presented in Figure 3.17.

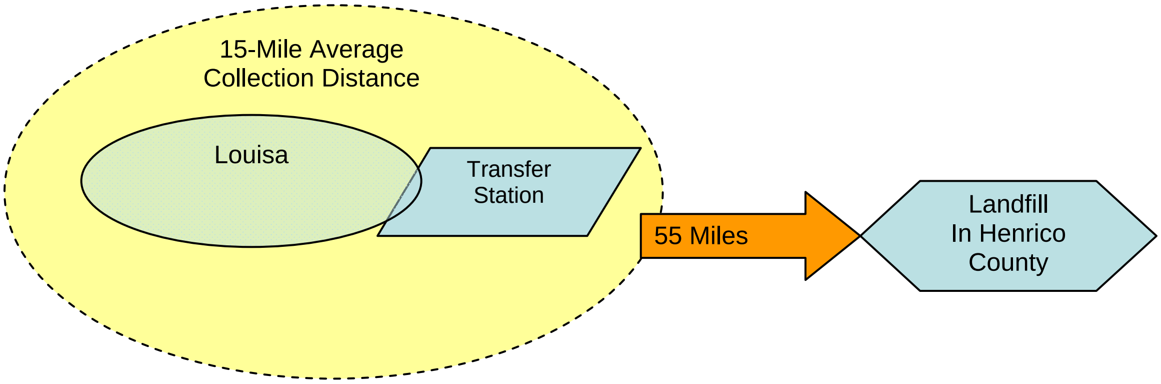

Figure 3.17 Louisa County

Nelson County

Nelson County is situated to the southwest of Albemarle and represents the slowest growing county in the TJPDC; however the northern half is growing at rate similar to Albemarle County (TJPDC 2004). Nelson County manages seven separate MSW convenience centers that serve as collection points for residents. The county currently utilizes a transfer station that transports MSW to the Maplewood Landfill located in Amelia County. A representation of the MSW management scenario is presented in Figure 3.18.

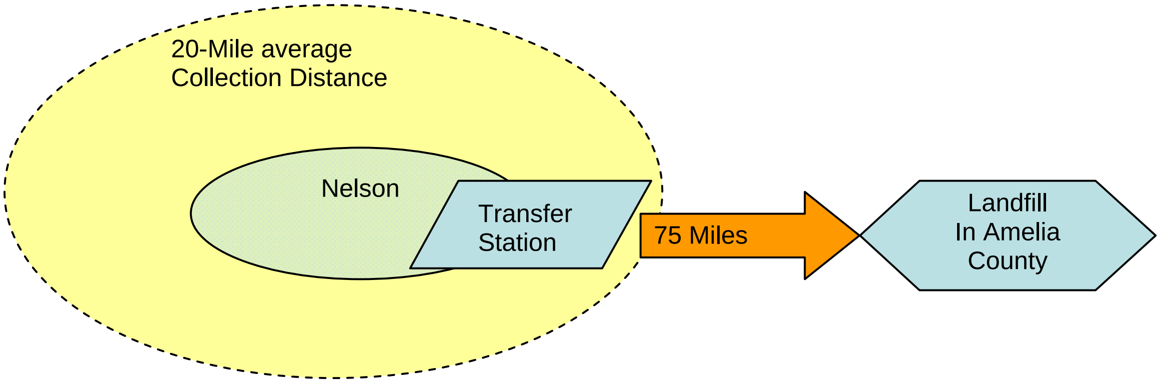

Figure 3.18 Nelson County

Results from each locality were summed together within the TJPDC to estimate the total costs and environmental emissions. Subsequent scenarios represent a hypothetical centrally located landfill and a WTE incineration facility that would serve the TJPDC on a regional basis.

3.5.2.6 TJPDC: Hypothetical Regional Landfill

A hypothetical regional landfill scenario was modeled with respect to the entire population of the TJPDC during years 2010 and 2020 as previously indicated. The size of the landfill was designed to meet the MSW disposal needs of the TJPDC related to the projected volume of MSW generated. This landfill was assumed to be centrally located within the TJPDC which is depicted in figure 3.19.

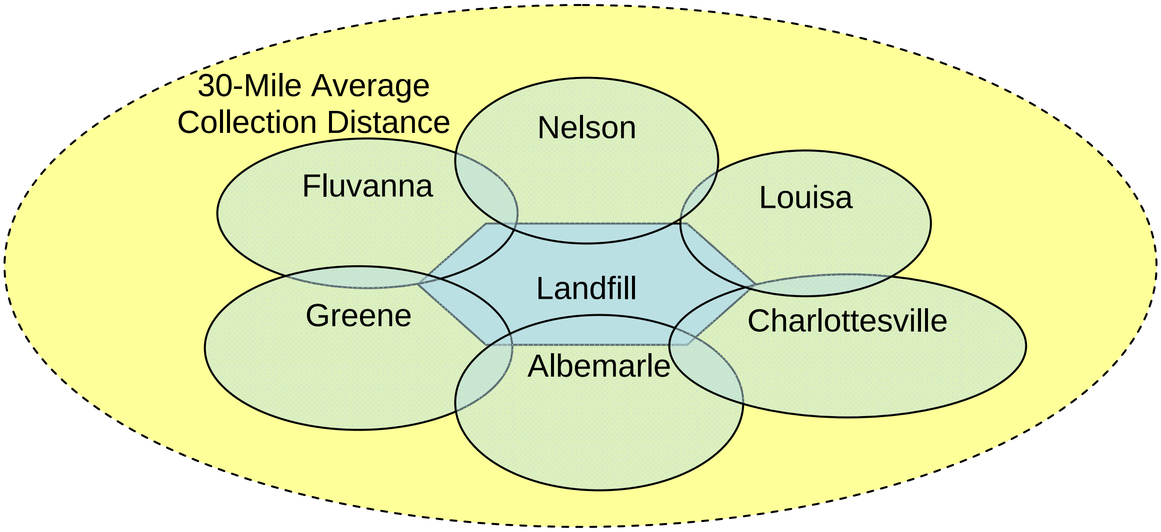

Figure 3.19 TJPDC Regional Landfill Scenario

3.5.2.7 TJPDC: Hypothetical Regional WTE Facility

A hypothetical WTE facility was created within a model scenario to serve the needs of the entire TJPDC on a regional scale. Projected populations were estimated to generate 150,366 and 168,363 tons of residential MSW during years 2010 and 2020 respectively. MSW generation figures were used to estimate the cost per ton of MSW by the facility assuming that all of the MSW generated less recycling would be treated by the WTE facility. This model process, equations, and data are summarized in section 3.4.1.3 and the model scenario is depicted in figure 3.20. The next chapter will summarize the outputs and analysis of PDC management scenarios.

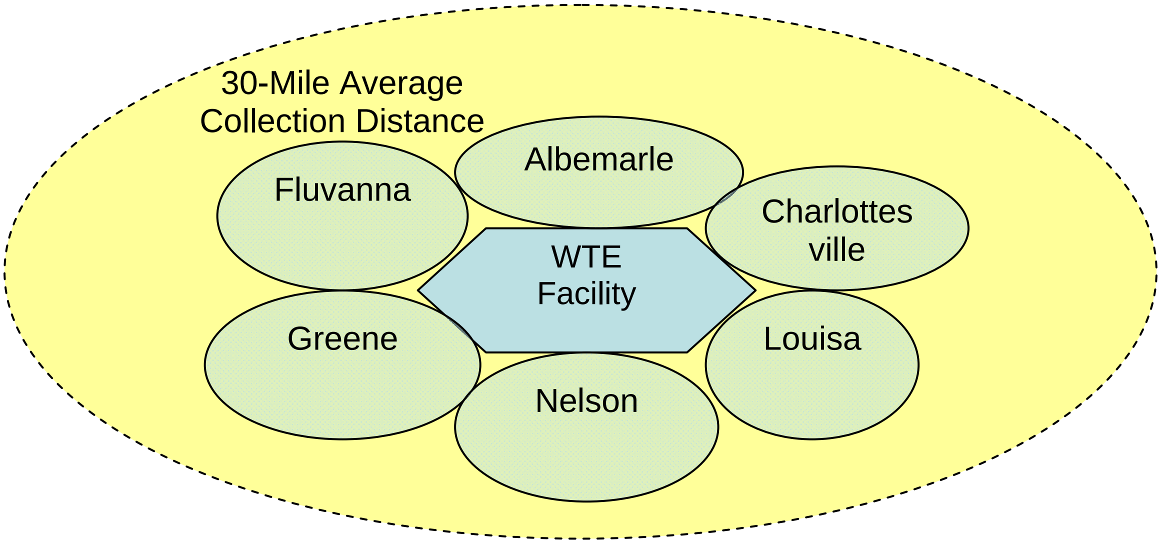

Figure 3.20 TJPDC Regional WTE Facility Scenario

Chapter 4. Results & Discussion

This chapter presents results of economic costs and environmental releases relevant to each MSW management option across select PDCs of Virginia. A baseline scenario reflective of the current MSW management practice of each PDC was compared to hypothetical MSW management scenarios of both a regional landfill as well as a regional WTE incineration facility. The annual costs, environmental releases, and energy consumption of each MSW management practice were calculated and compared across each MSW scenario on a per ton basis of MSW disposed relevant to population increase.

Annual costs were comprised of capital costs and O&M costs relevant to each MSW management option in addition to closure costs that are unique to landfill operations. Air emission comparisons of all scenarios were made between total particulate matter (PM), nitrogen oxides (NO_x), sulfur oxides (SO_x), carbon monoxide (CO), and methane (CH_4). Dioxin and furan emissions from WTE facilities were calculated but life-cycle offsets were not taken into account and direct comparisons to other model processes were not made due to insufficient data; however worthy of additional future analysis. Air emissions also account for pre-combustion emissions as defined in Chapter 3. Landfill gas emissions were calculated over a 100-year period relevant to the tonnage of MSW that was disposed. These emissions where then expressed as a current value that can be compared to the instantaneous emissions of a WTE facility.

Total annual energy consumption of electrical and fuel consumption were calculated for the operations of each MSW management option. Any energy generated via

MSW combustion (WTE facility) or methane capture (landfill) was treated as an energy offset to the conventional energy generation portfolio of the region that would have otherwise been consumed as described in Chapter 3. The following section compares MSW management scenarios that are relevant to the RRRC followed by comparisons made within the TJPDC.

4.1 RRRC MSW Management Scenarios

The baseline configuration for the RRRC is representative of figures 3.7 – 3.10 located in Chapter 3. Each locality within the RRRC manages MSW independently with the exception of Rappahannock County and Culpeper County, which share the use of a transfer station for long-haul transportation of MSW. Madison County currently operates a transfer station, while Fauquier County and Orange County operate their own county landfill. Since Orange County's landfill will close in 2012 it was assumed that the county will utilize a transfer station for long-haul transportation of MSW. The estimated costs of each locality were aggregated to represent the total cost of MSW management for the entire PDC during years 2010 and 2020 based on projected population and MSW generation.

Alternative scenarios were analyzed to reflect hypothetical regional MSW management options consisting of both a landfill (figure 3.11) and WTE incineration facility (figure 3.12) to manage the MSW of the entire PDC. The scenario containing a regional landfill was assumed to be centrally located and utilize a gas collection system operating at 75% efficiency to recover useable LFG energy. The WTE scenario was assumed to be centrally located and designed to meet new facility air controls to satisfy regulatory limits set by EPA.

Each MSW management scenario consisted of a collection model process which was assumed to occur once MSW was collected from drop-off MSW convenience centers that were located within each locality. The use of transfer stations and the long-haul transportation process models were only used in the baseline scenario. Regional landfill and WTE scenarios were assumed to be supplemented solely by the collection model process therefore eliminating the need for transfer stations and long-haul transportation occurring within the PDC.

4.1.1 RRRC Costs

Figure 4.1 depicts the annual cost comparisons among the baseline, landfill, and WTE model scenarios across years 2010 and 2020. Figure 4.2 shows the allocation of costs for year 2010 within each scenario to account for collection, transfer stations, landfills, WTE facilities, and transportation.

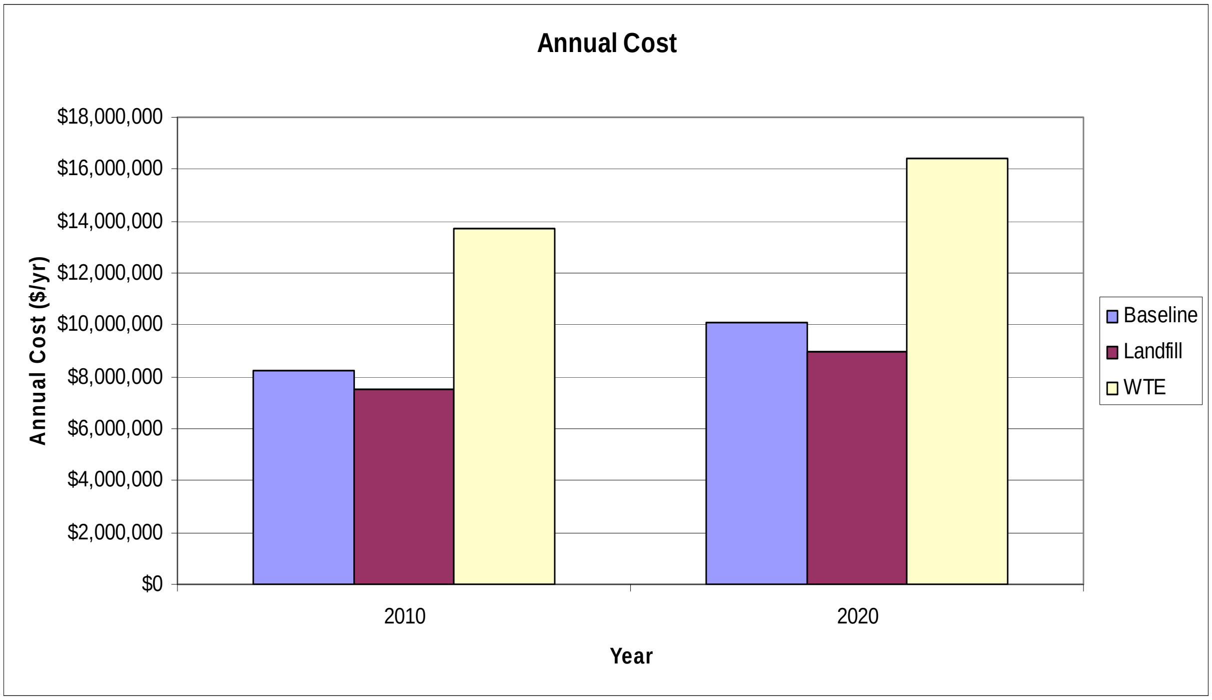

Figure 4.1 RRRC Annual Scenario Cost Comparisons

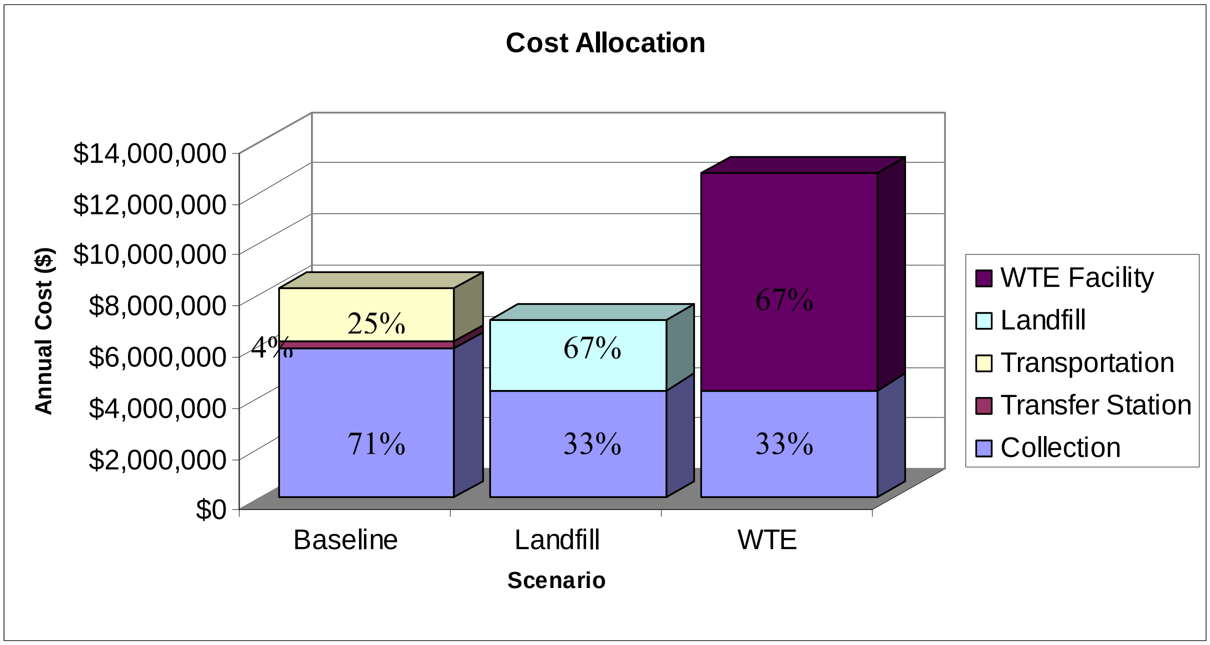

Figure 4.2 RRRC Annual Scenario Cost Allocation (2010)

Figure 4.1 shows that the regional WTE facility scenario calls for greatest economic cost; while the adoption of a regional landfill represents the lowest cost option among all model scenarios. Figure 4.2 represents cost allocation and further supports the claim that WTE facilities require a significant cost by representing around $8.5M in annual cost to make up 67% of the total annual MSW management scenario cost compared to a regional landfill at a cost of nearly $3M.

Both regional landfill and WTE scenarios do not differ in relation to annual collection cost and percentage of cost allocation since the area of collection between these two options is assumed to be the same. The collection costs of the baseline scenario represents 71% of the total cost at nearly $6M while a centrally located regional landfill and WTE scenarios both carry collection costs of just over $4M, making up 33% of the total annual scenario costs. Long-haul transportation costs associated with the baseline scenario total over $2M or 25% of annual costs; while the cumulative annual operational costs of transfer stations within the PDC represent nearly $300K or 4% of the total annual cost.

Table 4.1 contains the percent change with respect to annual costs that differ between each model scenario. Results indicate an 8.5% decrease in annual costs if a regional landfill was implemented when compared to the baseline scenario, while there would be a 67% increase in cost with the adoption of a regional WTE facility. Results also indicate that there would be a nearly 2.5% lower annualized cost if a regional landfill was constructed and 4.5% decrease if a WTE facility was utilized compared to baseline operations during 2020 when compared to 2010. This lower annualized cost may be related to the increased volume of MSW disposal, which may lower costs due to economies of scale.

Table 4.1 RRRC Scenarios: Annual Cost Comparisons

Year	Scenario Cost ($)			% change
	Baseline	Landfill	WTE	
2010	8,200,000	7,500,000	-	-8.5
	8,200,000	-	13,700,000	67.1
2020	10,100,000	9,000,000	-	-10.9
	10,100,000	-	16,400,000	62.4

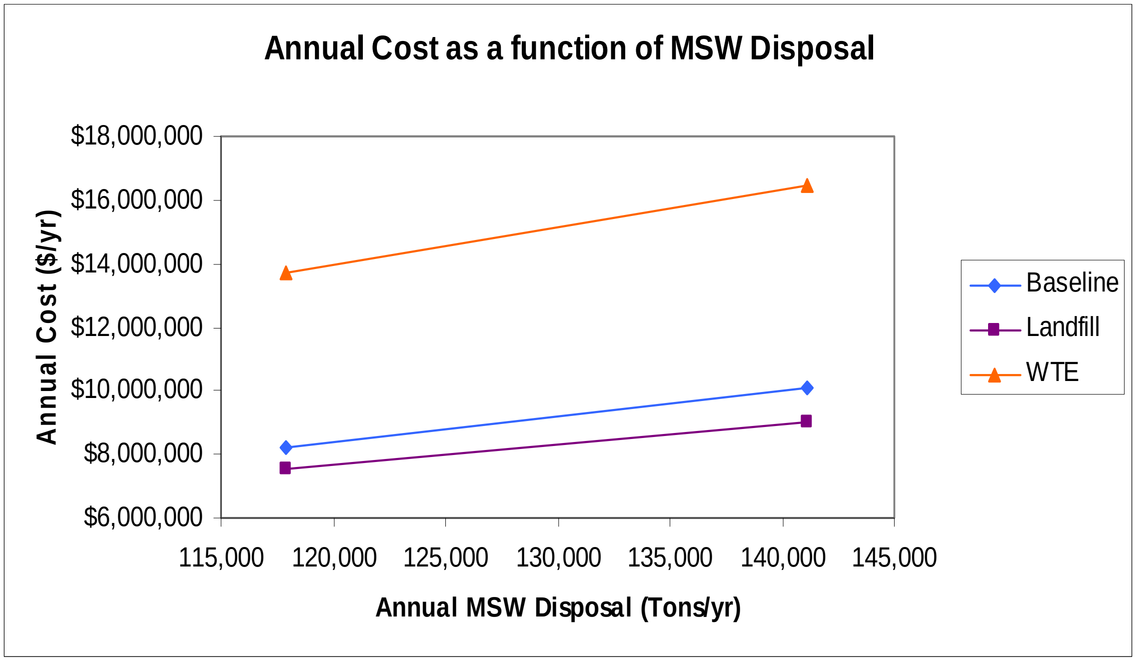

Figure 4.3 RRRC Annual Cost as a function of MSW Disposal

Figure 4.3 represents the linear relationship of annual MSW management scenario costs as a function of annual MSW disposal occurring between year 2010 and 2020. The relationship shows that as the annual tonnage of MSW increases, the related annual costs increase across each MSW management scenario. Linear equations indicate that the cost per ton of MSW disposal related to the baseline, regional landfill, and regional WTE facility are $80.54, $63.70, and $116.50 respectively.

4.1.2 RRRC Emissions

Annual air emissions consisting of total PM, NO_x, SO_x, CO, CO_2, and CH_4 were measured in lbs per year. Negative values indicate an offset of pre-combustion and combustion emissions related to the generation and consumption of conventional energy sources. The energy production of LFG from landfills and combustion energy from WTE facilities helps to offset conventional energy sources that would otherwise be consumed. Figure 4.4 and figure 4.5 are graphical representations of total PM, NO_x, SO_x, CO, and CH_4 air emissions from table 4.2 occurring during 2010 and 2020 respectively.

Table 4.2 RRRC Scenarios: Annual Air Emissions

Air Pollutant (lb/yr)	**Baseline**		**Landfill**		**WTE**	
	2010	**2020**	**2010**	**2020**	**2010**	**2020**
Total Particulate Matter	59,000	60,000	-17,000	-20,000	-165,000	-216,000
Nitrogen Oxides	433,000	531,000	42,000	40,000	-255,000	-304,000
Sulfur Oxides	132,000	162,000	-161,000	-192,000	-801,000	-964,000
Carbon Monoxide	850,000	1,043,000	185,000	222,000	13,000	28,000
Carbon Dioxide Biomass	30,000	37,000	92,000,000	111,000,000	157,000,000	187,000,000
Carbon Dioxide Fossil	24,000,000	29,000,000	-22,000,000	-27,000,000	-53,000,000	-67,000,000
Methane	20,000	24,000	2,100,000	2,500,000	-280,000	-340,000
Dioxins/Furans*	-	-	-	-	0.0051	0.0061

*Only calculated for WTE facility, offsets were not taken into account.

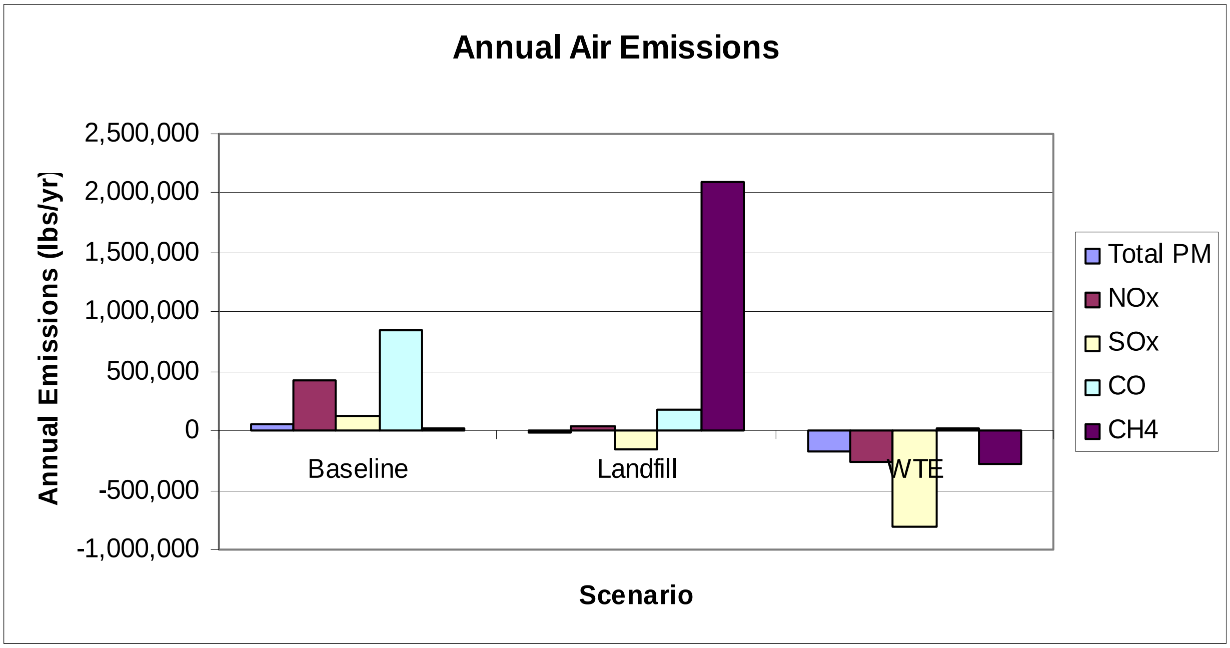

Figure 4.4 RRRC Annual Scenario Air Emissions (2010)

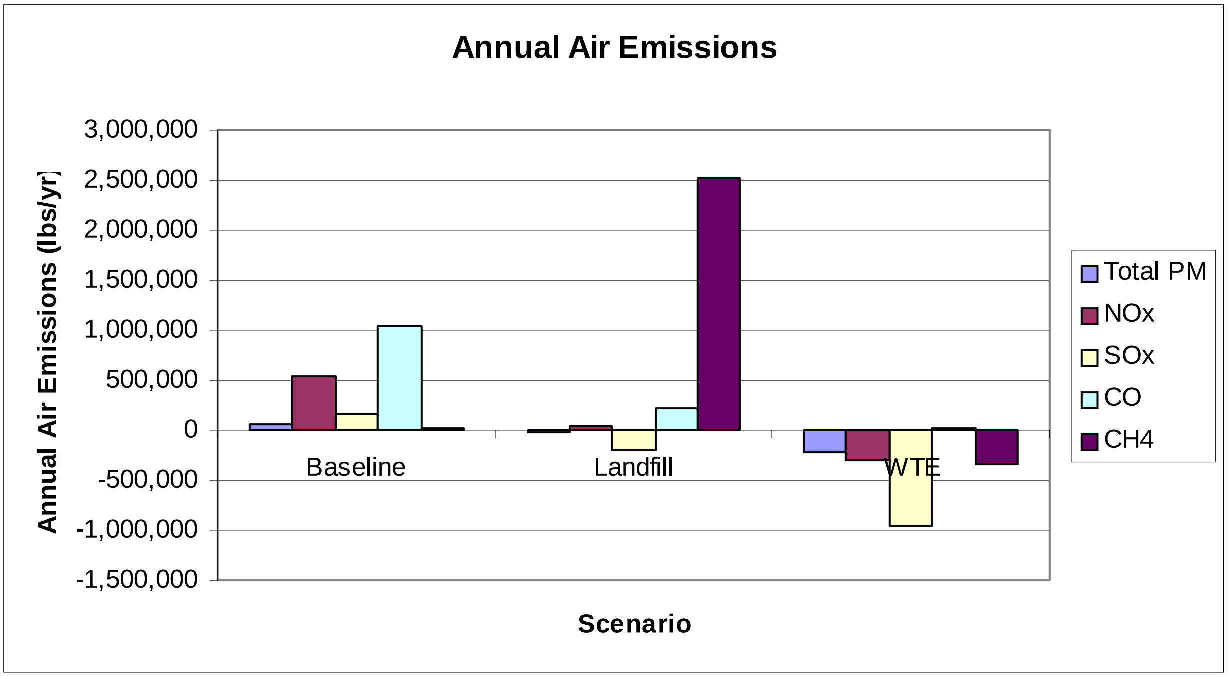

Figure 4.5 RRRC Annual Scenario Air Emissions (2020)

All air emissions occurring in the baseline are a result of fuel combustion related to collection and transportation vehicles as well as electrical energy that is consumed during transfer station and vehicle collection garage operations. CO and NO_x represent the greatest annual emissions in the baseline scenario, which are likely related transportation and collections processes. No emission offsets occur in the baseline scenario since energy is consumed and not generated during collection, transfer station, and transportation processes. WTE facilities have net emissions only for CO while the remaining pollutants are reflective of emission offsets related to the avoidance of emissions resulting for the pre-combustion and combustion process related to conventional energy production that would have otherwise been consumed.

Methane emissions are greatest among pollutants emitted by the regional landfill scenario, which can be attributed to the anaerobic decomposition of MSW buried in the landfill. Methane emissions are also the greatest in comparison to the baseline and WTE scenario. Total PM and SO_x emission offsets are representative of avoided emissions related to conventional energy production that would have otherwise been emitted if methane capture and utilization had not occurred.

Annual air emissions and offsets occurring during 2020 (figure 4.4) are greater in magnitude than emissions and offsets predicted to occur during 2010 (figure 4.5) since the amount of MSW being disposed of increases as a result of population increase assuming MSW generation rates remain constant. In summary, the baseline scenario carried the highest environmental burden with respect to net annual air emissions and the regional WTE facility scenario was representative of the minimal net annual air emissions due to the offset of air emissions related to energy production via combustion. However, WTE facilities emit amounts of furans and dioxins into the environment which were not directly compared to the baseline or landfill scenario and is worthy of additional future analysis.

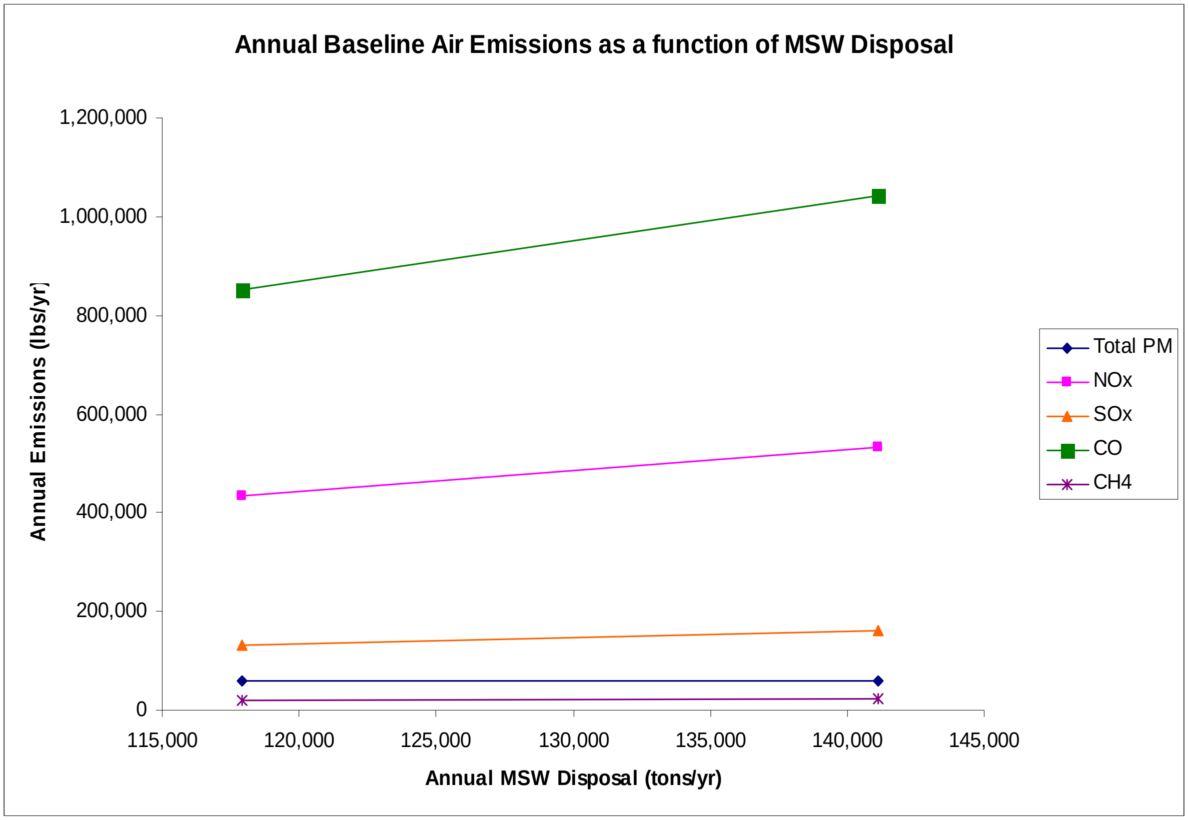

Figure 4.6 RRRC Annual Baseline Scenario: Air Emissions

Figure 4.6 represents the linear relationship between annual baseline emissions and annual MSW disposal volume for the year 2010 (figure 4.4) and year 2020 (figure 4.5). Linear relationships exist since the only change between input variables is an increase in MSW disposal related to a projected increase in total PDC population assuming MSW generation rates remain constant. Linear regressions of each emission show that CO (8.33 lbs / ton) represents the largest emissions per ton of MSW disposed within the baseline scenario of the RRRC. Table 4.3 presents the amount of each pollutant emitted per ton of MSW disposed.

Table 4.3 RRRC Baseline Air Emissions per Ton of MSW Disposed

Air Pollutant	Ratio (lbs/ton)
Total PM	0.04
NO_x	4.24
SO_x	1.30
CO	8.33
CH_4	0.20

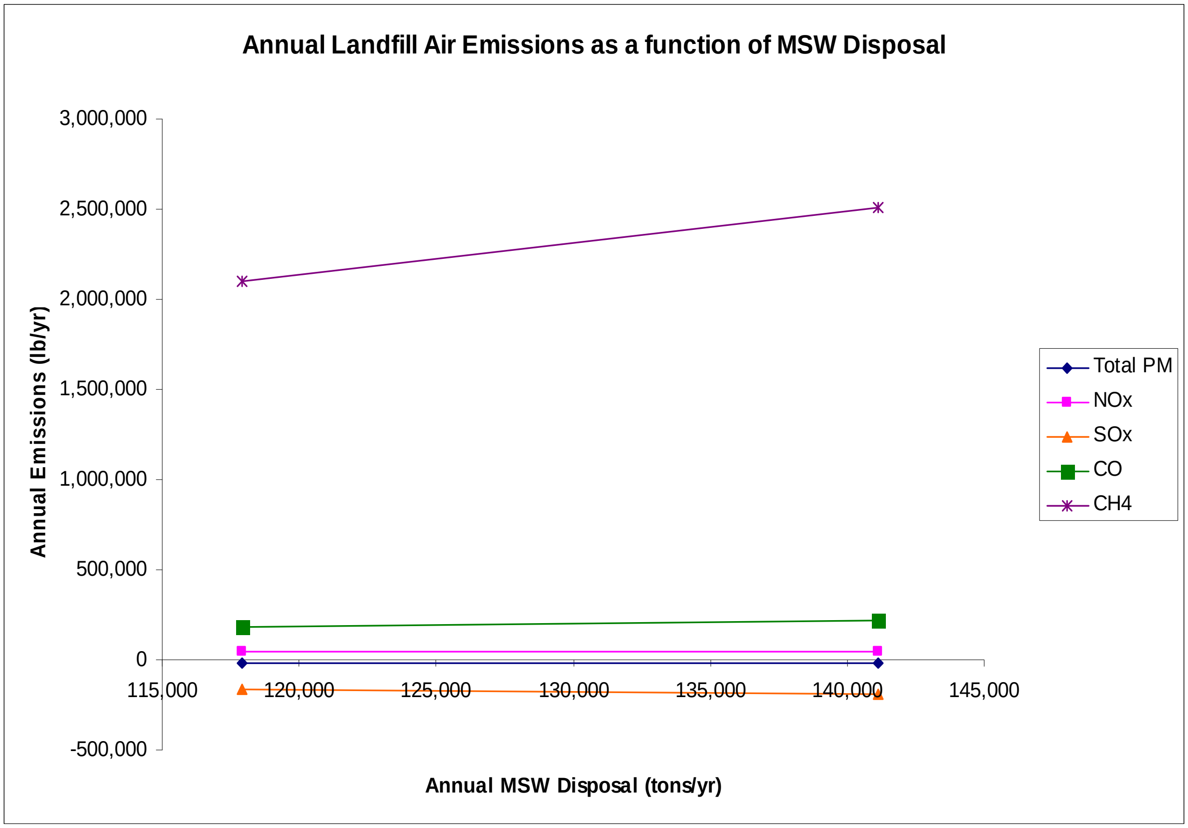

Figure 4.7 RRRC Annual Landfill Scenario: Air Emissions

Figure 4.7 represents the linear relationship between annual landfill emissions and annual MSW disposal volume for the year 2010 (figure 4.4) and year 2020 (figure 4.5). Linear relationships exist since the only change between input variables is an increase in MSW disposal related to a projected increase in total PDC population assuming MSW generation rates remain constant. Linear regressions of each emission show that CH_4 (17.80 lbs / ton) represents the largest emissions per ton of MSW disposed within the regional landfill scenario of the RRRC. Table 4.4 presents the amount of each pollutant emitted per ton of MSW disposed.

Table 4.4 RRRC Landfill Air Emission per Ton of MSW Disposed

Air Pollutant	Ratio (lbs/ton)
Total PM	-0.14
NO_x	0.35
SO_x	-1.36
CO	1.57
CH_4	17.80

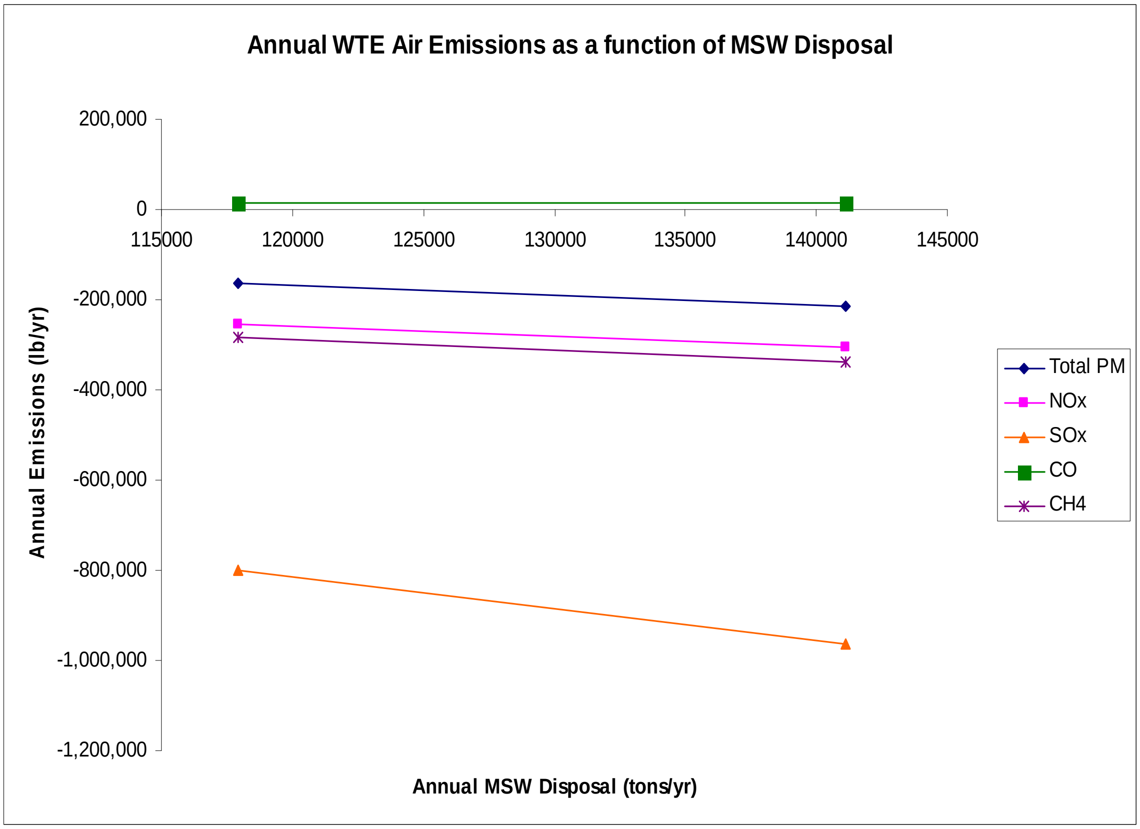

Figure 4.8 RRRC Annual WTE Facility Scenario: Air Emissions

Figure 4.8 depicts the linear relationship between annual WTE facility emissions and annual MSW disposal volume for the year 2010 (figure 4.4) and year 2020 (figure 4.5) assuming MSW disposal rates remain constant. As the tonnage of MSW disposed increases the total net emissions of total PM, NO_x, SO_x, and CH_4 decrease due to offsets; making SO_x (-7.04 lbs / ton) the largest offset. CO (0.11 lbs / ton) emissions represent the only net emission per ton of MSW disposed within the regional WTE facility scenario of the RRRC. Table 4.5 presents the amount of each pollutant emitted per ton of MSW disposed.

Table 4.5 RRRC WTE Facility Air Emission per Ton of MSW Disposed

Air Pollutant	Ratio (lbs/ton)
Total PM	-2.20
NO_x	-2.10
SO_x	-7.04
CO	0.11
CH_4	-2.40

4.1.3 RRRC Energy Consumption

Annual energy consumption was calculated by the model and measured in British Thermal Units (BTUs) millions or MBTUs. Table 4.6 contains the energy consumption representative of each model scenario during years 2010 and 2020. Negative values pertaining to regional landfill and WTE facility scenarios indicate an energy offset due to energy that is generated from methane and MSW combustion. This generated energy offsets conventional energy that would have been consumed via the regional energy grid. WTE facilities produce the greatest amount of annual energy measured at 611,000 MBTUs per year during 2010, followed by energy recovered from LFG in landfills measured at 47,000 MBTUs per year in 2010. The baseline scenario consumes energy at 812,000 MBTUs per year during 2010. Table 4.6 is graphically depicted in Figure 4.9.

Table 4.6 RRRC Scenarios: Annual Energy Consumption

Year	Energy Consumption (MBTU/yr)			% change
	Baseline	Landfill	WTE	
2010	812,000	-47,000	-	-105.8
	812,000	-	-611,000	-175.2
2020	997,000	-56,000	-	-105.6
	997,000	-	-732,000	-173.4

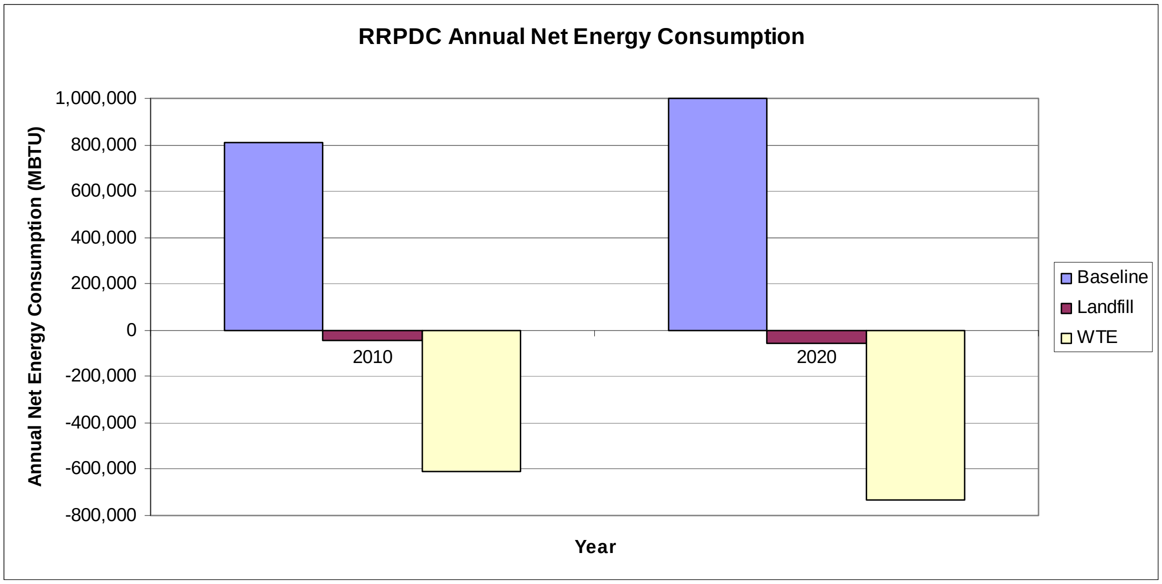

Figure 4.9 RRRC Annual Net Energy Comparisons

4.2 TJPDC MSW Management Scenarios

The baseline configuration for the TJPDC is representative of figures 3.14 – 3.18 located in Chapter 3. Each locality within the TJPDC manages MSW independently with the exception of Albemarle County and the City of Charlottesville, which share the use of a transfer station for long-haul transportation of MSW. Louisa County is the only locality with the TJPDC that relies on a local landfill; however this landfill is slated for closure in 2012 per VDEQ regulations. Therefore, it was assumed that the county will utilize a transfer station for long-haul transportation of MSW. Each locality's estimated costs were aggregated to represent the total cost of MSW management for the entire PDC.

Scenario results are based on projected population data and MSW generation rates for years 2010 and 2020. Alternative scenarios were analyzed to reflect hypothetical regional MSW management options consisting of both a landfill (figure 3.19) and WTE incineration facility (figure 3.20) to manage the MSW of the entire PDC. All assumptions and parameter were the same as those used in the RRRC landfill and WTE scenarios.

4.2.1 TJPDC Costs

Figure 4.10 depicts the annual cost comparisons among the baseline, landfill, and WTE model scenarios across years 2010 and 2020. Figure 4.11 shows the allocation of costs for year 2010 within each scenario to account for collection, transfer stations, landfills, WTE facilities, and transportation.

Figure 4.10 is similar the RRRC cost comparisons (Figure 1.1) in that the regional WTE facility scenario requires the greatest economic cost; while the adoption of a regional landfill represents the lowest cost option among all model scenarios. Figure 4.11 shows that WTE facilities require a significant cost by representing around $11.3M in annual cost to make up 67% of the total annual MSW management scenario cost compared to a regional landfill at a cost of nearly $3.6M. Both cost figures are greater than the RRRC cost estimates since more MSW is handled and disposed than by TJPDC.

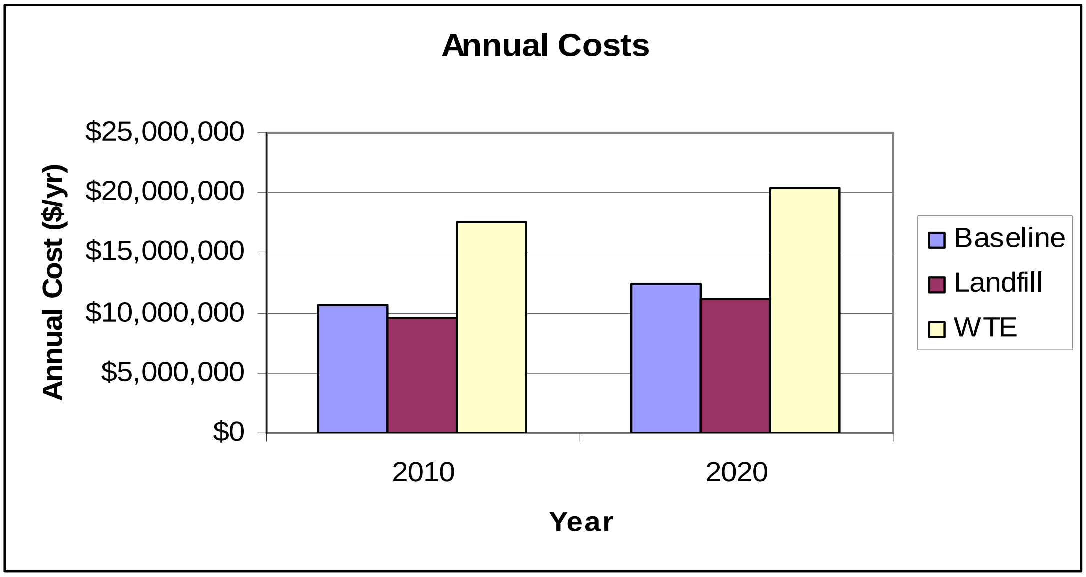

Figure 4.10 TJPDC Annual Scenario Cost Comparisons

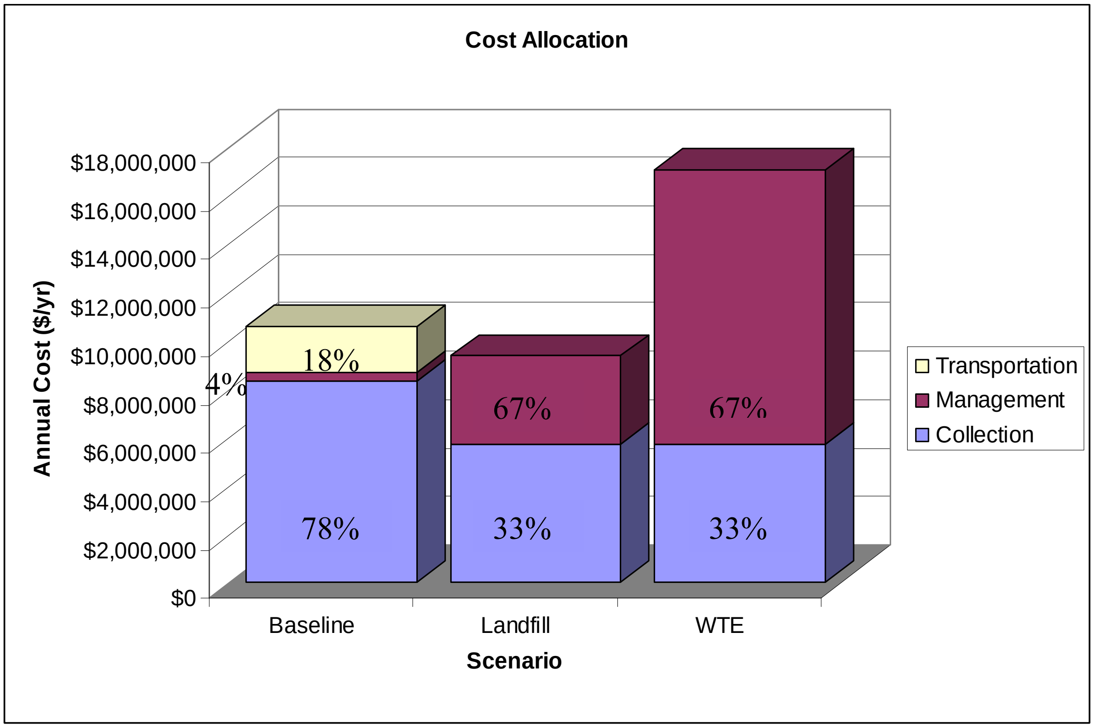

Figure 4.11 TJPDC Annual Scenario Cost Allocation (2010)

Both scenarios - regional landfill and WTE - do not differ in relation to annual collection cost and percentage of cost allocation since the area of collection between these two options is assumed to be the same. The collection costs of the baseline scenario represents 78% of the total cost at nearly $8M while a centrally located regional landfill and WTE scenarios both carry collection costs of just over $5.7M, making up 33% of the total annual scenario costs. Collection costs for the TJPDC is likely higher than the RRRC since the TJPDC covers a larger area and consists of more localities. Similar to the RRRC, the presence of a centrally located regional MSW disposal facility serving the entire PDC may reduce related collection costs. Long-haul transportation costs associated with the baseline scenario represent over $2M or 18% of annual costs; while the cumulative annual operational costs of transfer stations within the PDC represent nearly $360K or 4% of the total annual cost.

Table 4.7 contains the cost estimations across each MSW management scenario which representative of figure 4.10. Results indicate a 9.4% decrease in annual costs if a regional landfill was implemented when compared to the baseline scenario, while there would be a 66% increase in cost with the adoption of a regional WTE facility.

Table 4.7 TJPDC Scenarios: Annual Cost Comparisons

Year	**Scenario Cost ($)**			**% change**
	Baseline	**Landfill**	**WTE**	
2010	10,600,000	9,600,000	-	-9.4
	10,600,000	-	17,600,000	66
2020	12,500,000	11,200,000	-	-10.6
	12,500,000	-	20,300,000	62.9

Figure 4.12 represents the linear relationship of annual MSW management scenario costs as a function of annual MSW disposal occurring between year 2010 and 2020. The relationship shows that as the annual tonnage of MSW increases, the related annual costs increase per MSW management scenario. Linear equations indicate that the cost per ton of MSW disposal related to the baseline, regional landfill, and regional WTE facility are \$80.29, \$63.70, and \$116.50 respectively.

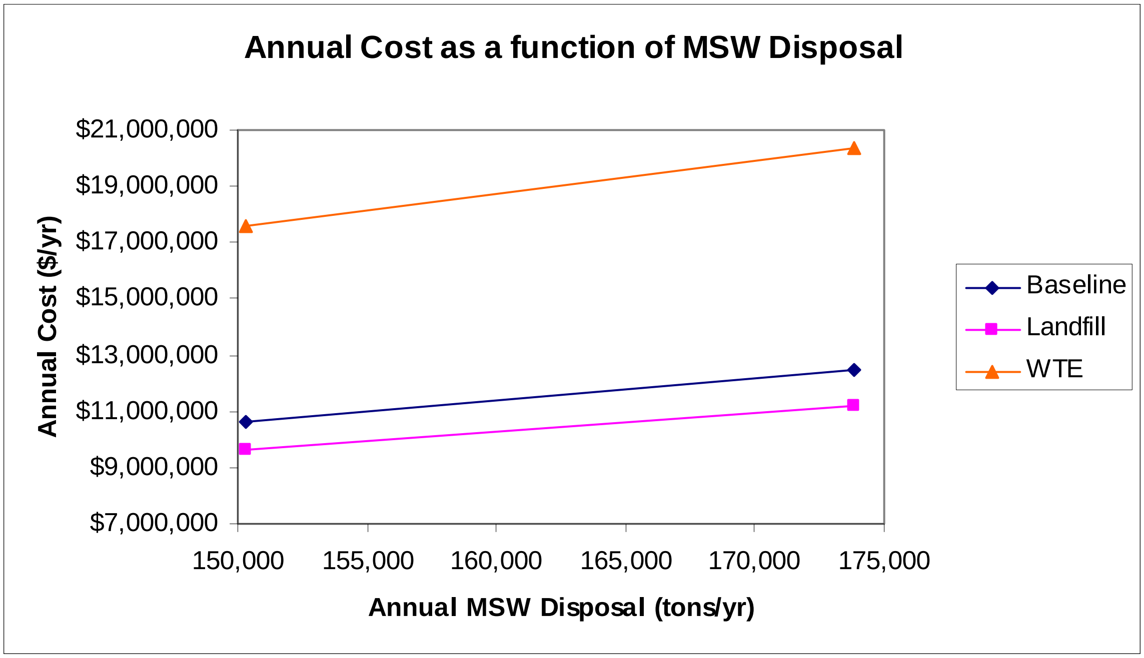

Figure 4.12 TJPDC Annual Cost as a function of MSW Disposal

4.2.2 TJPDC Emissions

Annual air emissions consisting of total PM, NO_x, SO_x, CO, CO_2, and CH_4 were measured in lbs per year. Negative values indicate an offset of pre-combustion and combustion emissions related to the generation and consumption of conventional energy sources. The energy production of LFG from landfills and combustion energy from WTE facilities helps to offset conventional energy sources that would otherwise be consumed. Figure 4.13 and figure 4.14 are graphical representations of total PM, NO_x, SO_x, CO, and CH_4 air emissions from table 4.8 occurring during 2010 and 2020 respectively.

Table 4.8 TJPDC Scenarios: Annual Air Emissions

Parameter (lbs/yr)	**Baseline**		**Landfill**		**WTE**	
	2010	**2020**	**2010**	**2020**	**2010**	**2020**
Total Particulate Matter	81,000	91,000	-18,000	-21,000	-211,000	-244,000
Nitrogen Oxides	600,000	672,000	58,000	68,000	-325,000	-376,000
Sulfur Oxides	189,000	211,000	-179,000	-207,000	-1,021,000	-1,180,000
Carbon Monoxide	1,231,000	1,381,000	213,000	247,000	16,000	19,000
Carbon Dioxide Biomass	54,000	61,000	107,000,000	124,000,000	200,000,000	231,000,000
Carbon Dioxide Fossil	32,000,000	36,000,000	-24,000,000	-28,000,000	-68,000,000	-78,000,000
Methane	28,000	31,000	2,400,000	2,800,000	-361,000	-418,000
Dioxins/Furans*	-	-	-	-	0.0075	0.0065

*Only calculated for WTE facility, offsets were not taken into account.

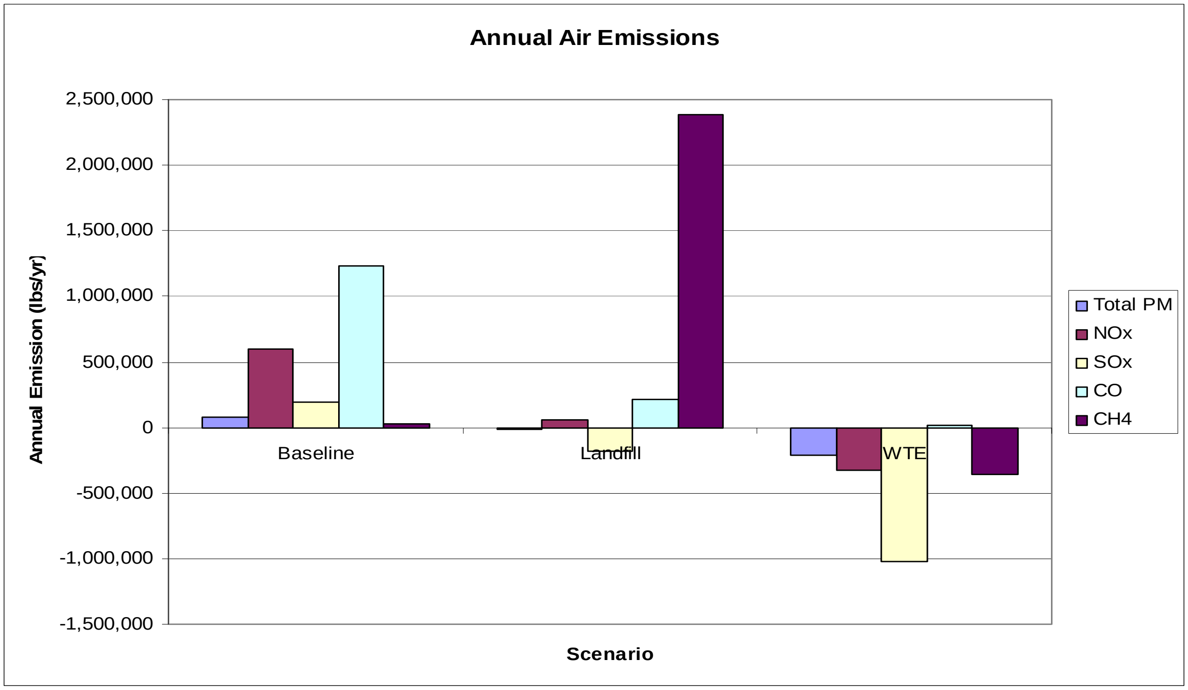

Figure 4.13 TJPDC Annual Scenario Air Emissions (2010)

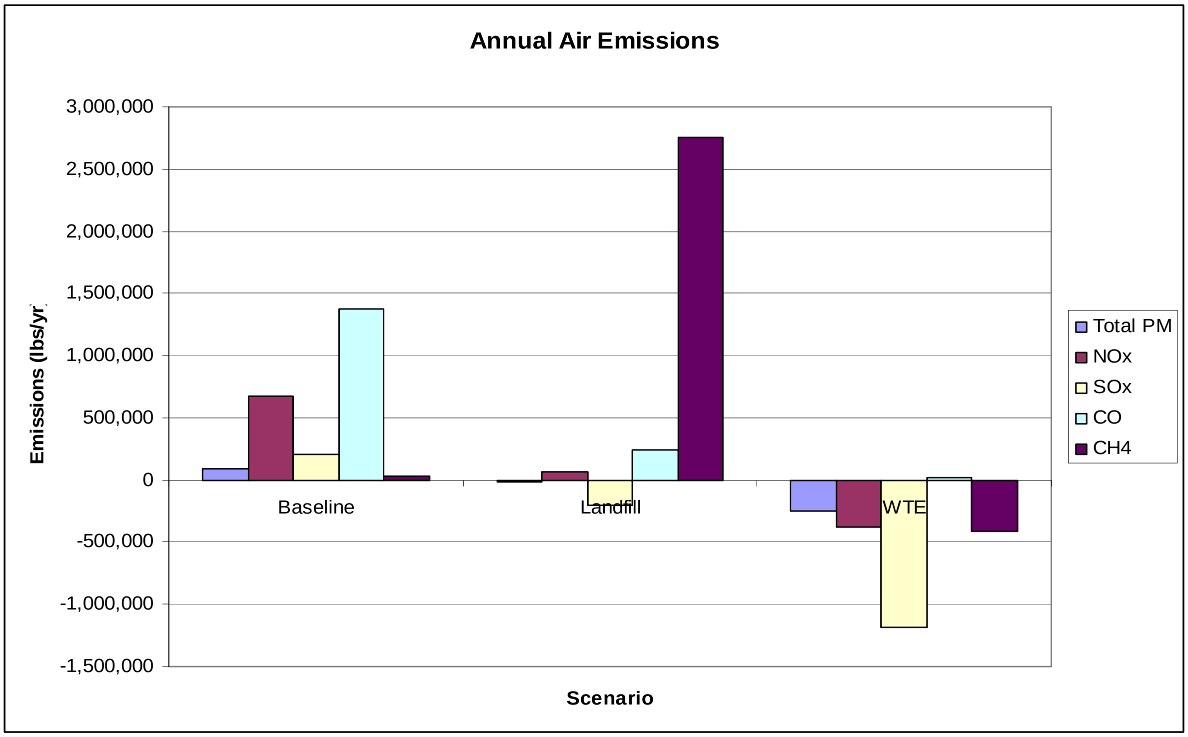

Figure 4.14 TJPDC Annual Scenario Air Emissions (2020)

CO and NO_x, again represent the greatest annual emissions in the baseline scenario, which are likely related transportation and collections processes. No emission offsets occur in the baseline scenario since energy is consumed and not generated during collection, transfer station, and transportation processes. Methane emissions are greatest among pollutants emitted by the regional landfill scenario, which can be attributed to the anaerobic decomposition of MSW buried in the landfill. Methane emissions are also the greatest in comparison to the baseline and WTE scenario. Total PM and SO_x emission offsets are representative of avoided emissions related to conventional energy production that would have otherwise been emitted if methane capture and utilization had not occurred. WTE facilities have net emissions only for CO while the remaining pollutants are reflective of emission offsets related to the avoidance of emissions resulting for the pre-combustion and combustion process related to conventional energy production that would have otherwise been consumed.

Annual air emissions and offsets occurring during 2020 (figure 4.14) are greater in magnitude than emissions and offsets predicted to occur during 2010 (figure 4.13) since the amount of MSW being disposed of increases as a result of population increase assuming MSW generation rates remain constant. In summary, the baseline scenario carried the highest environmental burden with respect to net annual air emissions and the regional WTE facility scenario was representative of the minimal net annual air emissions; however dioxins and furans were not taken into account.

Figure 4.15 highlights a linear relationship between baseline annual emissions and annual MSW disposal volume for the year 2010 (figure 4.13) and year 2020 (figure 4.14). Linear relationships exist since the only change between input variables is an increase in MSW disposal related to a projected increase in total PDC population assuming MSW generation rates remain constant. Linear regressions of each emission show that CO (6.40 lbs / ton) represents the largest emissions per ton of MSW disposed within the baseline scenario of the TJPDC. Table 4.9 presents the amount of each pollutant emitted per ton of MSW disposed.

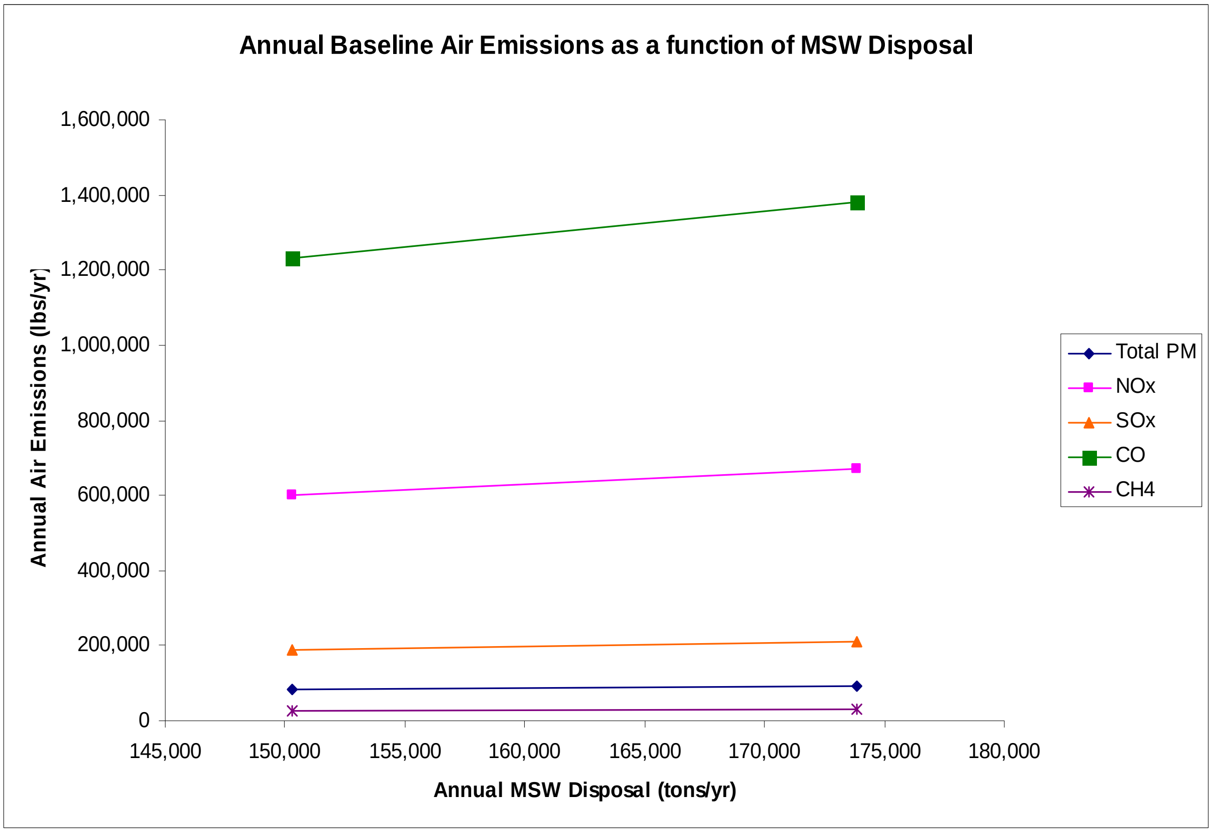

Figure 4.15 TJPDC Annual Baseline Scenario: Air Emissions

Table 4.9 TJPDC Baseline Air Emissions per Ton of MSW Disposed

Air Pollutant	Ratio (lbs/ton)
Total PM	0.04
NO_x	3.04
SO_x	0.97
CO	6.40
CH_4	0.15

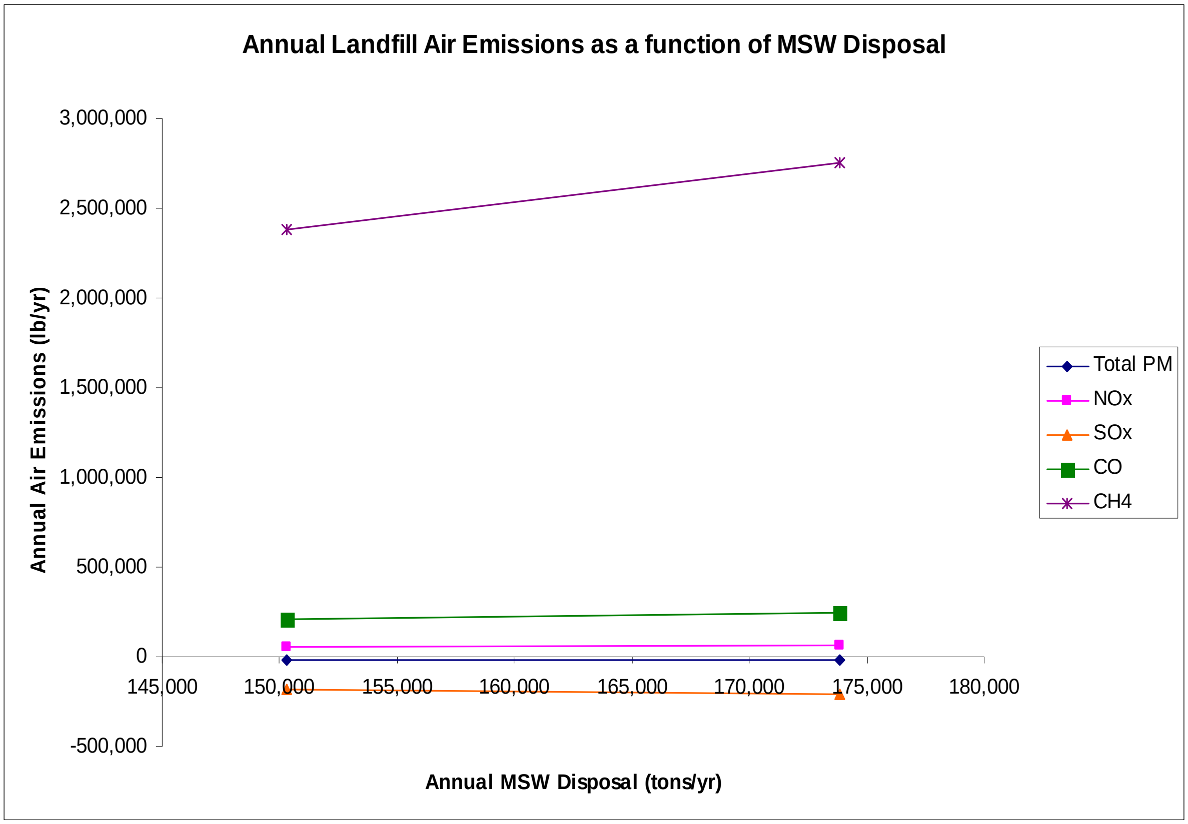

Figure 4.16 TJPDC Annual Landfill Scenario: Air Emissions

Figure 4.16 indicates that a linear relationship exists between annual landfill emissions and annual MSW disposal volume for the year 2010 (figure 4.13) and year 2020 (figure 4.14). Linear relationships exist since the only change between input variables is an increase in MSW disposal related to a projected increase in total PDC population assuming MSW generation rates remain constant. Linear regressions of each emission show that CH_4 represents the largest emissions per ton of MSW disposed (15.87 lbs / ton) within the regional landfill scenario of the TJPDC. Table 4.10 presents the amount of each pollutant emitted per ton of MSW disposed.

Table 4.10 TJPDC Landfill Air Emission per Ton of MSW Disposed

Air Pollutant	Ratio (lbs/ton)
Total PM	-0.12
NO_x	0.39
SO_x	-1.20
CO	1.42
CH_4	15.87

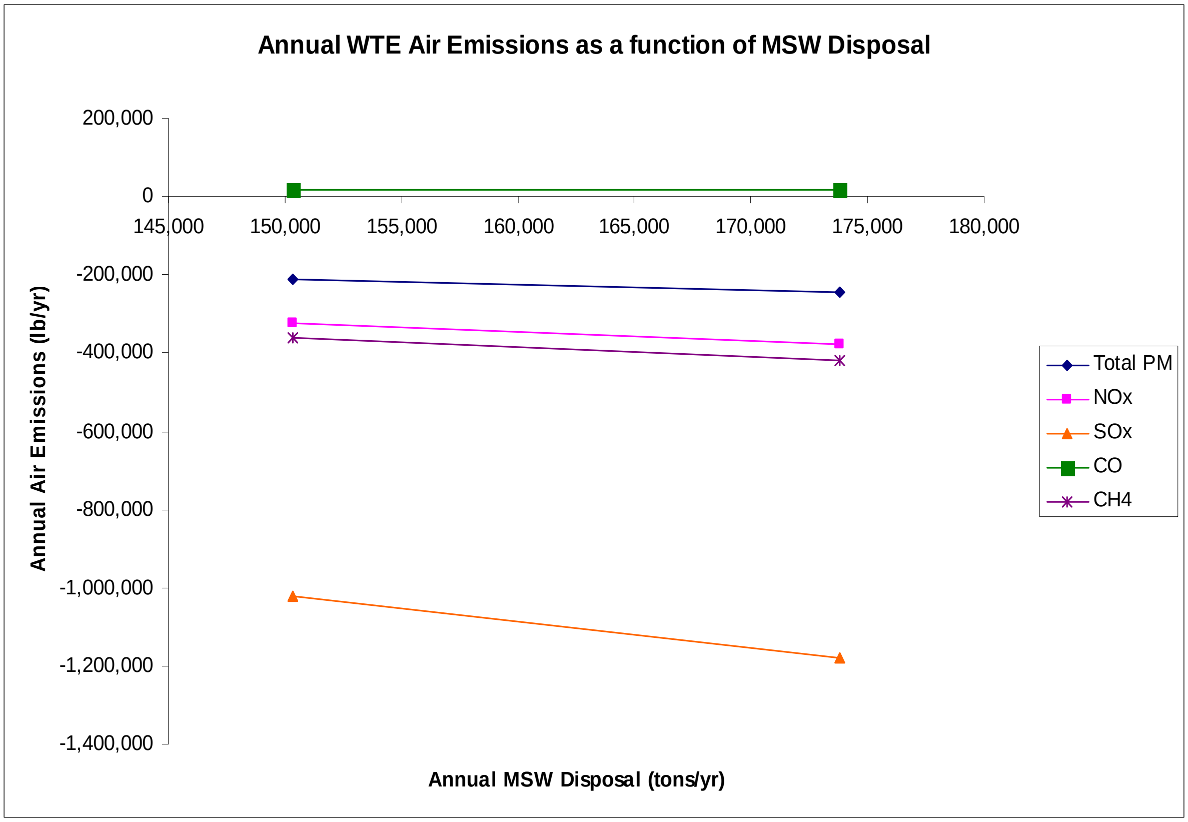

Figure 4.17 TJPDC Annual WTE Facility Scenario: Air Emissions

Figure 4.17 shows linearity between annual WTE facility emissions and annual MSW disposal volume for the year 2010 (figure 4.13) and year 2020 (figure 4.14) assuming MSW disposal rates remain constant. As the tonnage of MSW disposed increases the total net emissions of total PM, NO_x, SO_x, and CH_4 decrease due to offsets; making SO_x (-6.79 lbs / ton) the largest offset. CO (0.11 lbs / ton) emissions represent the only net emission per ton of MSW disposed within the regional WTE facility scenario of the TJPDC. Table 4.11 presents the amount of each pollutant emitted per ton of MSW disposed.

Table 4.11 TJPDC WTE Facility Air Emission per Ton of MSW Disposed

Air Pollutant	**Ratio (lbs/ton)**
Total PM	-1.40
NO_x	-2.16
SO_x	-6.79
CO	0.11
CH_4	-2.40

4.2.3 TJPDC Energy Consumption

Annual energy consumption was calculated by the model and measured in British Thermal Units (BTUs) presented in millions or MBTUs. Table 4.12 contains the energy consumption representative of each model scenario during years 2010 and 2020. Negative values pertaining to regional landfill and WTE facility scenarios indicate an energy offset due to energy that is generated from methane and MSW combustion. This generated energy offsets the consumption of conventional energy that would have been consumed via the regional energy grid. WTE facilities produce the greatest amount of annual energy measured at 779,000 MBTUs per year during 2010, while the baseline scenario consumes energy at 1,700,000 MBTUs per year during 2010. Table 4.12 is graphically depicted in Figure 4.18.

Table 4.12 TJPDC Scenarios: Annual Energy Consumption

Year	Energy Consumption (MBTU/yr)			% change
	Baseline	Landfill	WTE	
2010	1,700,000	-39,000	-	-102.3
	1,700,000	-	-779,000	-145.8
2020	2,000,000	-46,000	-	-102.3
	2,000,000	-	-901,000	-145.1

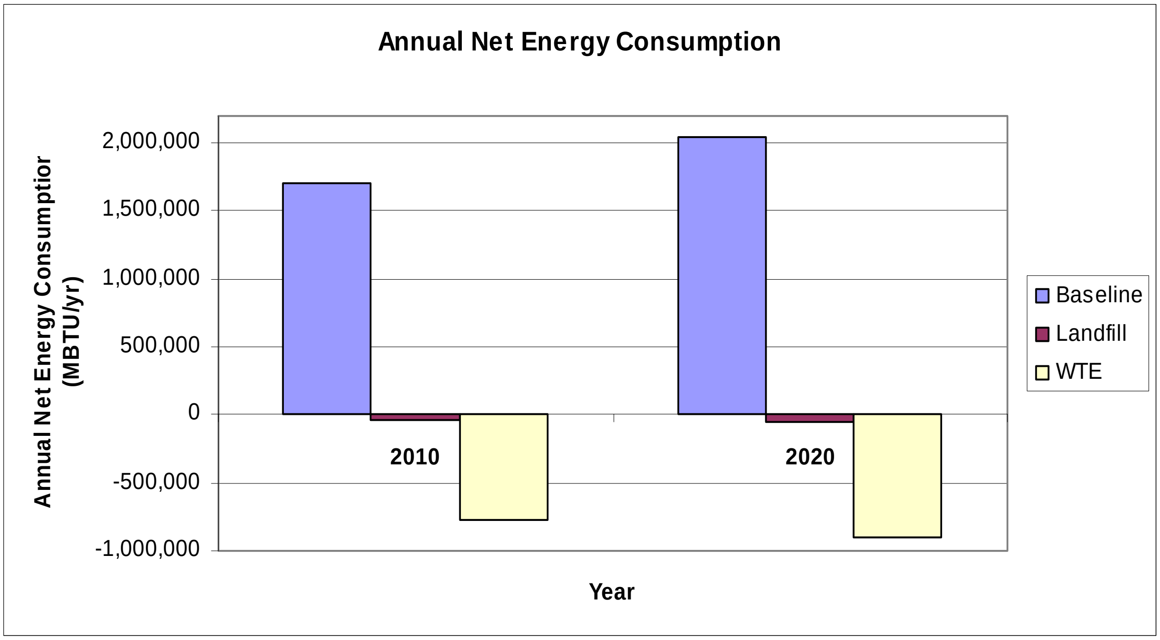

Figure 4.18 TJPDC Annual Net Energy Comparisons

4.3 Discussion

The following briefly discusses some of the over-arching conclusions that were noted earlier in this chapter. It should be that MSW generation rates between years 2010 and 2020 were not assumed to vary from year to year; therefore MSW generation due to population growth formed a linear relationship between all dependant variables. Energy and emission offsets were measured and compared at the life-cycle level since energy recovery was assumed to occur amongst landfills and WTE combustion facilities.

4.3.1 Costs

The regional landfill scenario represented the least annualized cost option for both RRRC and TJPDC planning districts when compared to the baseline scenario; which involved the use of transfer stations for long-haul transportation of MSW. In both PDC regions, collection costs accounted for over 70% of total annual costs pertaining to the baseline scenario which was a comparable higher cost than the regional landfill scenario. Higher collection costs associated with the baseline scenario are likely due to the fact that collection occurs separately amongst the county localities of differing collection area sizes that make up the PDC. The presence of a centrally located regional MSW disposal facility serving the entire PDC may reduce the number of collection vehicles, average distance traveled, and number of collection trips executed per day to reduce related collection costs.

The construction and operation of a WTE facility in both PDCs is about 67% more costly than the baseline scenario and 83% costlier than the use of a regional landfill. This is consistent with literature that deems WTE facilities a cost intensive MSW management option due to the high capital costs of construction and pollution control equipment.

However, if revenue from electricity generation and ferrous recovery is taken into account then the overall cost would likely decrease. Landfill gas revenue is also not accounted for in this study which may offset the annualized operating costs of the landfill.

4.3.2 Emissions and Energy Consumption

CO and NO_x represent the greatest air emissions per ton of MSW disposed per baseline analysis. These air emissions are common byproducts of fuel combustion that is likely related to the collection and transportation process models of the baseline scenario. Annual net CO and NO_x emissions are lower for the landfill and WTE facility scenarios when compared to the baseline since long-haul transportation from transfer stations is not assumed. Also, an offset of CO and NO_x emissions occur due to avoided emissions from a typical coal-fired power plant that would have otherwise been used to generate electricity. The electrical generation from MSW combustion from WTE facilities and methane recovery from landfills helps to offset these emissions.

The regional landfill scenario emits the largest amount of methane compared to the baseline and WTE facility scenarios. Landfill methane is also the greatest emitted pollutant amongst total PM, NO_x, SO_x, and CO when compared across all scenarios. Even though 75% of the generated methane is assumed to be recovered, model results indicate that over 2.5M lbs of methane will still be released into the environment due to decomposition of organic matter disposed of the landfill. Methane has been identified as a GHG and studies have suggested a relationship between methane emissions and the idea of global climate change.

The WTE facility scenario offsets every pollutant analyzed with the exception of CO. As noted earlier, these net annual emissions offsets are recognized as an avoidance of emissions associated with conventional energy production. Dioxins and furans account for air emissions from WTE; however a proper analysis was not made due to insufficient model data concerning other process models.

From a life cycle perspective, a WTE combustion facility is the least energy intensive MSW management scenario since electrical energy is generated to help offset the production of conventional energy sources. Landfills offset energy as well if it is assumed that methane gas is recovered for utilization of an energy source, either by direct heat or electrical generation. The baseline scenario was considered by the model to consume the most energy that is likely related to fuel usage from collection and transportation of MSW. The next chapter will summarize the main conclusions, identify the shortcomings of this study, provide extensions for future research, and recommend policy implications.

Chapter 5. Conclusions & Policy Implications

This section will articulate general conclusions with respect to the MSW-DST model outputs and analysis. Ideas for future studies and shortcomings of this research will then be noted. Lastly, policy implications and suggestions will be made with respect to academia, regulatory agencies, and land-use planning in Virginia.

4.1 Conclusions

Based on model results, the null hypothesis ($\mathbf{H_o^1}$) is rejected and alternate hypothesis ($\mathbf{H_1^1}$) is accepted. In other words, it could be stated that there are differences among environmental impacts and economic costs between current MSW management practices and future MSW management scenarios utilizing a regional landfill or WTE combustion facility in response to high population growth. Simulated model output analysis indicated that a regional WTE facility would require the greatest annual cost comparable to the other MSW disposal scenarios identified in this study. However, WTE facilities would release the least net air emissions due to displaced conventional energy production when analyzed on a life cycle basis. Such an analysis is amenable to future statistical assessment but is not the focus of this study

Modeling results also indicate that landfills emit the greatest amount of methane per year, while the use of transfer stations and long-haul transport of MSW within baseline scenarios carry the highest annual carbon monoxide emissions. Collection and transportation associated with transfer stations increase overall costs and also shift the environmental burdens of landfill disposal to the population surrounding landfills outside of the PDC. When taking energy recovery into account, a WTE facility is the least energy intensive option; while the baseline scenario is the most energy demanding.

Overall, this study inferred that a WTE facility would be the most cost intensive option while a regional landfill would reduce current and future costs. It could also be inferred that WTE have a minimal environmental impact when compared to a landfill on a life-cycle basis. Lastly, there seems to be disjunctive chaos amongst SWPUs and PDCs as two different organizational constructs; thus potentially hindering the planning for efficient MSW management in some instances within Virginia. Better synchronization may be needed to address the issue of MSW management on a regional "PDC-level" rather than a "SWPU-level" in which a single county or small group of localities acts to manage MSW. An organizational improvement may help combine resources and reduce costs at both county and regional levels with the RRRC and TJPDC planning districts.

4.2 Future Studies

This study and relevant conclusions have shortcomings related to method design and uncertainties. This assessment excludes long term land impacts associated with landfills, water releases from the tipping floors of transfer stations and WTE facilities, and other detrimental air emissions such as volatile organic compounds (VOCs). Additional variables and factors include analyses of; bioreactor landfills, recycling, and composting to develop a more integrated perspective of MSW management. Assumptions concerning recycling were held constant throughout the projected project model scenario time frames. An increase in respective locality recycling rates would likely have an impact on the volume of generated MSW that would need to be considered for disposal.

Future extensions of this study could use output data to perform ecological or a community-level human health risk assessment in order to construct potential dose-response relationships between estimated pollutant concentrations and potential health effects. A sensitivity analysis could be performed within the MSW-DST model to estimate the variation of outputs with respect to changes of input parameters and assumptions related to MSW generation rates, recycling rates, energy costs, and fuel costs. A comparison study could also be conducted using differing MSW life-cycle assessment models to analyze the PDCs relevant to this study in order for to cite differences in results and identify recurrent data gaps. Finally, social attitudinal assessment studies could be executed to capture the social concerns regarding landfills and WTE facility siting with respect to the NIMBY phenomena.

4.3 Policy Implications

- More academic research and funds could be allocated towards improving life cycle assessment methods as they relate to MSW management.
- County commissioners and land-use planners of high-growth localities should consider managing MSW on a regional PDC level to reduce costs and emissions associated with long-haul transportation and collection.
- The VDEQ utilize these findings to develop cost-benefit analyses and risk assessments to evaluate current and future regulatory controls to help level the playing-field amongst MSW disposal options.
- Virginia policy makers could offer tax breaks or other economic incentives with respect to MSW management options that recover energy for utilization.

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APPENDIX A

PDC Landfill Capacity and Life-time

PDC	Locality	Facility Name	Type	Remaining Permitted Capacity (yd^3)	Estimated remaining life (years)
George Washington Regional Commission	Caroline	-	-	-	-
	King George	King George Sanitary LF	LF	27,219,177	21
	Stafford	Rappahannock Regional SWM	LF	733,900	3.5
	Fredericksburg	BFI Fredericksburg Recyclery	MRF	-	-
	Spotsylvania	Spotsylvania - Livingston	LF	1,905,457	15.5
Rappahannock-Rapidan	Culpeper	Laurel Valley Center	TS	-	-
	Fauquier	Fauquier County SWMF	LF	1,495,238	13
	Madison	Madison County TS	TS	-	-
	Orange	Orange County LF	LF	516,594	5
	Rappahannock	-	-	-	-
Northern Shenandoah Valley	Frederick	Frederick County LF	LF	10,208,704	42
	Clarke	-	-	-	-
	Winchester City	-	-	-	-
	Page	Battle Creek LF	LF	2,075,000	40
	Shenandoah	Shenandoah County LF - Edinburg	LF	33,000,000	34
	Warren	Warren County Transfer Station	TS	-	-
Northern Virginia	Arlington	Arlington/Alexandria Covanta WTE	WTE	-	-
	Fairfax City	-	-	-	-
	Fairfax County	I-95 Covanta WTE	WTE	-	-
		I-66 Transfer Station	MRF	-	-
		Waste Management of VA - Merrifield	MRF	-	-
		Metalpro Incorporated	MRF	-	-
		Rainwater Landfill	MRF	-	-
	Loudoun	Loudoun County Sanitary LF	LF	22,578,921	60
		Waste Management of VA - Leesburg	MRF	-	-
		Waste Management of Virginia - Sterling	MRF	-	-
		Con Serv Industries	MRF	-	-
	Prince William	Prince William County Sanitary LF	LF	8,712,649	18
	Alexandria	-	-	-	-
	Falls Church	-	-	-	-
	Manassas City	Waste Management of Virginia	TS	-	-

	Manassas Park	-*	-	-	-
Thomas Jefferson	Albemarle	Ivy Materials Utilization Center	TS	-	-
	Charlottesville	-	-	-	-
	Fluvanna	-	-	-	-
	Greene	Greene County Transfer Station	TS	-	-
	Nelson	Nelson County LF Transfer Station	TS	-	-
	Louisa	Louisa County Sanitary LF	LF	255,000	6

APPENDIX B

Default Data

MSW Component	Density in Refuse Collection Vehicle (lb/yd^3)	Residential Composition % mass	Heating Value (BTU/lb)	Ash Content (dry basis) (weight fraction)	Water Content (%)	LAB DATA - Component CH4 Yield, Dry (L CH$_4$/kg)	k-value
Yard Trimmings, Leaves	550	5.60%	2,601	0.06	0.6	30.6	0.03
Yard Trimmings, Grass	550	9.30%	2,601	0.06	0.6	136	0.09
Yard Trimmings, Branches	550	3.70%	6,640	0.06	0.6	62.6	0.03
News Print	550	6.70%	7,541	0.02	0.06	74.3	0.03
Corrugated Cardboard	550	2.10%	6,895	0.05	0.05	152.3	0.03
Office Paper	550	1.30%	6,313	0.06	0.06	217.3	0.03
Phone Books	550	0.20%	6,248	0.06	0.06	74.3	0.03
Books	550	0.90%	6,248	0.06	0.06	217.3	0.03
Magazines	550	1.70%	5,386	0.23	0.06	84.4	0.03
3rd Class Mail	550	2.20%	6,076	0.06	0.06	150.85	0.03
HDPE - Translucent	550	0.40%	18,687	0.00	0.02	0	0.03
HDPE - Pigmented	550	0.50%	18,687	0.00	0.02	0	0.03
PET	550	0.40%	18,687	0.00	0.02	0	0.03
Ferrous Cans	550	1.50%	301	0.97	0.03	0	0.03
Aluminum Cans	550	0.90%	0	0.97	0.02	0	0.03
Mixed Glass	550	6.50%	84	0.99	0.02	0	0.03
Paper - Non-recyclable	550	17.10%	6,464	0.06	0.06	103.67	0.03
Food Waste	550	4.90%	1,797	0.05	0.7	300.7	0.09
Plastic - Non-Recyclable	550	9.90%	14,101	0.10	0.02	0	0.03
Misc. (CNNN)	550	7.50%	3,669	0.06	0.2	0	0.03
Ferrous - Non-recyclable	550	3.20%	0	0.97	0.03	0	0.03
Al - Non-recyclable	550	0.50%	0	0.97	0.02	0	0.03
Glass - Non-recyclable	550	0.70%	0	0.99	0.02	0	0.03
Misc. (NNNN)	550	12.30%	0	1.00	0.2	0	0.03

APPENDIX C

Energy Input Data

Virginia Electrical Composition

Fuel Type	Input (%)*
Coal	47
Natural Gas	10
Residual Oil	1
Distillate Oil	0
Nuclear	38
Hydro	2
Wood	0
Other	2

*Source: EIA State Renewable Electricity Profiles (2006)
Note: CY2006 values are assumed during years 2010-2029.

Energy Economic Parameters

Parameter	Input	Units
US Average (2010-2019)		
Electricity Price*	0.09	$/kwh
Electricity Cost*	0.09	$/kwh
Diesel Cost**	2.48	$/gal
Gasoline Cost**	2.33	$/gal
US Average (2020-2029)		
Electricity Price (sale)*	0.09	$/kwh
Electricity Cost (purchase)*	0.09	$/kwh
Diesel Cost**	2.55	$/gal
Gasoline Cost**	2.37	$/gal

*Source: EIA Report No.: DOE/EIA-0383 (2008) Table 8
**Source: EIA Report No.: DOE/EIA-0383 (2008) Table 12

National Grid Generation Efficiencies and Heating Values

Fuel Type	Default National Unit Efficiency	Default National Heating Value (BTU / fuel unit)
Coal	0.325	10,402 lbs
Natural Gas	0.311	1,022 ft^3
Residual Oil	0.326	149,700 gal
Distillate Oil	0.26	138,700 gal
Nuclear	0.314	985,321,000 lbs Uranium
Hydro	1	n/a
Wood	0.325	10,350 lbs

Default National Grid Total Fuel Energy by Fuel Type

Fuel Type (fuel units)	Pre-Combustion Energy (BTU / fuel unit)	Combustion Energy (BTU / fuel unit)	Total Energy Consumed (BTU / fuel unit)
Coal (lbs)	264	10,402	10,666
Natural Gas (ft^3)	129	1,022	1,151
Residual Oil (gal.)	21,000	149,700	170,700
Distillate Oil (gal.)	19,300	138,700	158,000
Uranium (lbs)	50,600,000	985,321,000	1,035,921,000
Hydro	0	3,413	3,413
Wood (lbs)	0	8,600	8,600

Total Fuel Energy by Fuel Type

Fuel Type (fuel units)	Fuel Consumed per Electric kWh delivered (fuel unit / kWh elect.)	Total (BTU / electric kWh)	Total aggregate (BTU / electric kWh)
Coal (lbs)	1.010	10,771	6,079
Natural Gas (ft^3)	10.723	12,343	1,203
Residual Oil (gal.)	0.070	11,956	314
Distillate Oil (gal.)	0.094	14,928	34
Uranium (lbs)	1.105E-05	11,444	2,533
Hydro	1.000	3,413	293
Wood (lbs)	1.221	10,504	25
Other	1.221	10,504	0

National Air Emissions by Fuel Usage

Air Emission	Coal	Natural Gas	Residual Oil	Distillate Oil	Nuclear	Hydro	Wood
Total PM	1.64E-03	4.67E-06	6.98E-06	9.59E-07	1.08E-04	0.00E+00	3.66E-06
NO_x	4.63E-03	5.33E-04	8.12E-05	1.30E-05	1.42E-04	0.00E+00	3.42E-06
SO_x	7.83E-03	2.06E-03	3.57E-04	4.45E-05	4.25E-04	0.00E+00	1.83E-07
CO	2.74E-04	2.77E-04	2.00E-05	2.34E-06	1.39E-05	0.00E+00	3.17E-05
CO_2 (biomass)	1.71E-04	2.93E-05	1.22E-05	1.31E-06	3.15E-04	0.00E+00	4.32E-03
CO_2 (non biomass)	1.23E+00	1.43E-01	5.19E-02	6.27E-03	1.66E-02	0.00E+00	0.00E+00
CH_4	2.68E-03	3.97E-04	8.61E-06	9.31E-07	3.67E-05	0.00E+00	0.00E+00

APPENDIX D

Collection Model Process Inputs and Equations

Locality	Average Collection Distance (Miles)
Culpeper & Rappahnnock	20
Fauquier	15
Madison	20
Orange	15
RRRC	30
Albemarle & City of Charlottesville	25
Fluvanna	20
Greene	20
Louisa	20
Nelson	20
TJPDC	30

Parameter	Value
Collection frequency	1 collection per week
Vehicle capacity	20 yd^3
Utilization factor	0.80 (occupied yd^3 / usable yd^3)
Economic life of vehicle	7 yrs
Vehicle fuel efficiency	5 miles / gallon
Unit price of vehicle	142,210 ($/vehicle)
Number of working	5 days/week
Working hours a day	7 hr / vehicle-day
Fringe benefit rate	0.46 (fringe benefit $ / wage $)
Other expense rate	9,579 ($/worker-yr)
Hourly wage of collector	10.25 ($/hr-person)
Hourly wage of driver	12.25 ($/hr-person)

Emission	Airborne Emission Release Rate (gm/mile)
CO	5.03
Total PM	0.25
SOx	0
CH_4	0
NOx	34.02
CO_2 (fossil)	543

APPENDIX E

Transfer Station Model Process Inputs and Equations

Transfer Station Capital Costs: Facility Area

STR_A = (1.25 * stor * 2000 lbs * 27 ft^3) / ht * D_cv

where STR_A, refuse storage area (ft^2/ TPD)
stor, storage time on the tipping floor (days)
ht, height of refuse stored on the tipping floor (ft)
D_cv, density of refuse on the tipping floor (lb/ yd^3)
1.25, factor to account for tipping floor expansion and vehicle maneuvering
2,000 lbs = 1 ton (conversion factor)
27 ft^3 = 1 yd^3 (conversion factor)

LD_A = (ld_day_a * (load_hr + tr_rep_hr) * 2000lbs) / (Ewh_d * tr_vol_cap * tr_d)

where LD_A, trailer loading area (ft^2/ TPD)
ld_bay_a, trailer loading area requirement (ft^2)
load_hr, time to load a trailer (hours)
tr_rep_hr, time to replace a full trailer (hours)
tr_vol_cap, transfer trailer capacity (yd^3)
tr_d, density of MSW in trailer vehicle (lb / yd^3)
2,000 lbs = 1 ton (conversion factor)

CV_UL_A = (single_vc_ul_a * cv_ul_hr * 2000 lbs * peak_fct) / (EWh_d * cv_load)

where CV_UL_A, collection vehicle unloading area (ft^2/ TPD)
single_cv_ul_a, area required for a single collection vehicle to unload (ft^2)
cv_ul_hr, time to unload a collection vehicle (hours)
peak_fct, peak collection vehicle arrival factor (no units)
Ewh_d, effective work day length (hr/day)
cv_load, average weight of MSW in single collection vehicle (lbs)
2,000 lbs = 1 ton (conversion factor)

FAC_A = (STR_A + LD_A + CV_UL_A) * (1 + off_area_r)

where FAC_A, total facility area (ft^2/ TPD)
off_area_r, fraction of facility attributed to office space (no units)

Transfer Station Capital Costs: Annual Capital Cost

$$\mathbf{const\_C = FAC\_A * const\_c}$$

where const_C, facility construction cost ($/TPD)
FAC_A, total facility area (ft^2/ TPD)
const_c, construction cost rate ($/ft^2)

$$\mathbf{siteW\_C = FAC\_A * land\_area\_r * sitew\_c}$$

where siteW_C, paving and site work cost ($/TPD)
land_area_r, land to building area ration (ft^2/ ft^2)
sitew_c, paving and site work cost rate ($/TPD)

$$\mathbf{land\_C = (FAC\_A * land\_area\_r * land\_c) / 43{,}561\ ft^2}$$

where land_C, capital cost of land ($/TPD)
land_c, land acquisition ($/acre)
43,560 ft^2 = 1 acre (conversion factor)

$$\mathbf{eng\_C = (const\_C + siteW\_C) * eng\_r}$$

where eng_C, capital cost for construction engineering and permitting ($/TPD)
eng_r, construction engineering and permitting contingency cost as a function of construction and sitework costs

Transfer Station Capital Costs: Total Annual Capital Cost

$$\mathbf{FAC\_AC = (const\_C + siteW\_C + land\_C + eng\_C) * CRF}$$

where FAC_AC, annual capital cost for facility ($/TPD) – year
CRF, capital recovery factor

Transfer Station Equipment Costs: Rolling Stock

$$\mathbf{RS\_TC = (RS\_cost * (1 + eq\_inst\_r)) * CRF}$$

where RS_TC, rolling stock purchase and installation costs ($/TPD – year)
RS_cost, cost of transfer station rolling ($/TPD)
eq_inst_r, installation cost as a fraction of purchase price (no units)

Transfer Station Equipment Costs: Compactor

$$\mathbf{COMP\_TC = (COMP\_cost * (1 + eq\_inst\_r))*CRF}$$

where COMP_TC, compactor purchase and installation costs ($/TPD – year)
COMP_cost, cost of transfer station compactor ($/TPD)

Transfer Station Equipment Costs: Total Annual Equipment Capital Cost

EQ_AC = RS_TC + COMP_TC

where EQ_AC, annual equipment capital cost per facility daily capacity ($/TPD - year)

Transfer Station Operating Costs: Labor and Management Costs

WG_AC = op_wage * ywd * op_req * (1 + mang_r)

where WG_AC, labor annual wage cost ($/TPD – year)
op_wage, equipment operator wages ($/hour)
op_req, operator labor hours required per ton (hour/day/TPD)
ywd, working days in a year (days/year)
mang_r, management rate as a fraction of labor cost (no units)

Transfer Station Operating Costs: Energy Costs

∑ (E_AC) = RS_E_AC + COMP_E_AC + FAC_E_AC

where ∑ (E_AC), rolling stock, compactor, and facility annual energy costs ($/TPD -yr)
RS_E_AC, rolling stock annual energy cost ($/TPD -yr)
COMP_E_AC, compactor annual energy cost ($/TPD – year)
FAC_E_AC, facility energy cost ($/TPD – yr)

RS_E_AC = dies_c * rs_e * ywd

where dies_c, cost of diesel fuel from common model ($/gallon)
rs_e, diesel fuel requirement (gallon / ton MSW processed)

COMP_E_AC = elec_c * comp_e * ywd

where comp_e, compactor energy usage (kWh/ton)
elec_c, electricity cost from common model ($/kWh)

FAC_E_AC = fac_e * FAC_A * elec_c * ywd

where FAC_fac_e, facility electricity usage (kWh/ ft^2 – day)
FAC_A, total facility area (ft^2/ TPD)

Transfer Station Operating Costs: Equipment Maintenance Costs

EQ_M_AC = eq_mc * (RS_TC + COMP_TC)

where EQ_M_AC, annual equipment maintenance cost ($/TPD -yr)
eq_mc, annual equipment maintenance cost as % of equipment cost (faction/year)
RS_TC, capital cost of rolling stock ($/TPD)
COMP_TC, capital cost of compactor ($/TPD)

Transfer Station Operating Costs: Total Annual Operating Cost

OP_AC = WG_AC + ∑ (E_AC) + EQ_M_AC

where OP_AC, total annual cost per ton processed per day ($/TPD – year)

Transfer Station Total Cost Factor

Cost_Factor = (FAC_AC + EQ_AC + OP_AC) / ywd

where Cost_Factor, cost per ton MSW processed ($/ton)
FAC_AC, annual capital cost for facility ($/ton per day – yr)
EQ_AC, annual equipment costs ($/ton per day – yr)
OP_AC, annual operating costs ($/ton per day – yr)
ywd = working days in a year (days/yr)

Transfer Station: Model Input Variable	Value
ywd, working days in a year (days/year)	260
stor, storage time on the tipping floor (days)	1
ht, height of refuse stored on the tipping floor (ft)	10
D_cv, density of refuse on the tipping floor (lb/ yd^3)	550
single_cv_ul_a, area required for a single collection vehicle to unload (ft^2)	525
cv_ul_hr, time to unload a collection vehicle (hours)	0.15
peak_fct, peak collection vehicle arrival factor (no units)	1.5
Ewh_d, effective work day length (hr/day)	7
cv_load, average weight of MSW in single collection vehicle (lb)	14,000
ld_bay_a, trailer loading area requirement (ft^2)	1,800
load_hr, time to load a trailer (hours)	0.15
tr_rep_hr, time to replace a full trailer (hours)	0.2
Ewh_d, effective work day length (hr/day)	7
tr_vol_cap, transfer trailer capacity (yd^3)	100
tr_d, density of MSW in trailer vehicle (lb / yd^3)	450
off_area_r, fraction of facility attributed to office space (no units)	0.1
const_c, construction cost rate ($/$ft^2$)	55
land_area_r, land to building area ration (ft^2 / ft^2)	10

sitew_c, paving and site work cost rate ($/TPD)	1.44
eng_r, engineering, permitting and contingency cost as a function of construction and site work costs	0.3
land_c, land acquisition ($/acre)	1,000
RS_cost, cost of transfer station rolling ($/TPD)	244
CRF, capital recovery factor	1
COMP_cost, cost of transfer station compactor ($/TPD)	190
eq_inst_r, installation cost as a fraction of purchase price	0.05
op_wage, equipment operator wages ($/hour)	10
op_req, operator labor hours required per ton (hour/day/TPD)	0.047
mang_r, management rate as a fraction of labor cost, no units	0.3
dies_c, cost of diesel fuel from common model ($/gallon)	2.48
rs_e, diesel fuel requirement (gallon / ton MSW processed)	0.0845
comp_e, compactor energy usage (kWh/ton)	0.53
elec_c, electricity cost from common model, $/kWh	0.090
fac_e, facility electricity usage (kWh/ ft^2– day)	0.001
eq_mc, annual equipment maintenance cost as percent of equipment cost (faction/year)	0.05
RS_cost, capital cost of rolling stock ($/TPD)	244

Transfer Station: LCI Energy Usage

TL_ENG_FACTOR = ELEC_FACTOR + DIES_FACTOR

where TL_ENG_FACTOR = total energy per ton of MSW processed (Btu/ton)
ELEC_FACTOR = total electrical energy per ton of MSW processed (Btu/ton)
DIES_FACTOR = total diesel energy per ton MSW processed (Btu/ton)

Transfer Station: LCI Air Emissions

i_FACTOR = i_elec + i_rs_c
for i = PM, NO_x, SO_x, CO, CO_2 (biomass), CO_2 (non - biomass), and CH_4

where i_FACTOR, total emission of i (lb/ton MSW processed)
i_elec, total emission of i, released in electricity consumption (lb/ton)
i_rs_c, total emission of i, released in rolling stock combustion of diesel (lb/ton)

i_elec = (comp_e + fac_e * FAC_A) * i_r_tot
for i = PM, NO_x, SO_x, CO, CO_2 (biomass), CO_2 (non - biomass), and CH_4

where comp_e, compactor energy usage (kWh/ton MSW)
fac_e, building electricity energy requirement (kWh/ft^2/day)
i_r_tot, electricity emission factor (electric energy model) (lb/kWh)

Rolling stock combustion of diesel: pollutant	**lb/ton MSW**
pm_rs_c	5.65E-03
no_rs_c	7.59E-02
hc_rs_c	5.32E-03
so_rs_c	6.68E-03
co_rs_c	1.87E-02
co2_bm_rs_c	0.00E+00
co2_rs_c	1.94E+00
CH_4_rs_c	0.00E+00

Electricity Emission Factor	**lb/kWh**
pm_r_tot	2.19E-03
no_r_tot	5.93E-03
so_r_tot	1.12E-02
co_r_tot	1.97E-03
co2_bm_r_tot	1.77E-02
co2_r_tot	1.33E+00
CH_4_r_tot	8.04E-06

APPENDIX F

Transportation Model Process Inputs and Equations

Transportation Costs

Daily_MSW_Trans = A_MSW_Gen * (1/ywd) * 2000 lbs

where Daily_MSW_Trans, daily MSW transported (lbs MSW/day)
A_MSW_Gen, annual MSW generation (tons MSW/yr)
ywd, working days per year (days/yr)
2000 lbs = 1 ton

Daily_MSW_Trans_Vol = Daily_MSW_Trans / MSW_Density

where Daily_MSW_Trans_Vol, daily MSW volume transported (yd^3 MSW/day)
MSW_Densty, density of MSW component (550 lbs MSW/yd^3)

Annual_Truck_Trips = (Daily_MSW_Trans_Vol / Truck_Capacity) * ywd

where Annual_Truck_Trips, annual number of truck trips (truck trip/yr)
Truck_Capacity, average capacity of truck (100 yd^3/truck trip)

Annual_Truck_Miles = Annual_Truck_Trips * Trip_Milage$_i$ * 2

where Annual_Truck_Miles, annual number of truck miles (mile/yr)
Trip_Milage$_i$, one-way distance for i = locality (mile/truck trip)
2, accounts for round trip

Cost_per_Mile = Diesel_Cost / Truck_Fuel_Eff

where Cost_per_Mile, cost per truck mile traveled ($/mile)
Diesel_Cost, cost of diesel fuel ($/gallon)

Total_Transportation_Cost = Cost_per_Mile * Annual_Truck_Miles

Transportation LCI Air Emissions

Annual_Diesel_Consumption = Annual_Truck_Miles / Truck_Fuel_Eff

where Annual_Diesel_Consumption, annual diesel fuel consumption (gallon/yr)

Truck_Fuel_Eff, average fuel efficiency (mile/gallon)

Annual_Trans_Emissions$_i$ = Emissions$_i$_per_Gal_Diesel * Annual_Diesel_Consumption

where Annual_Trans_Emissions$_i$, annual transportation emission, for i = pollutant (lb/yr)
Emissions$_i$_per_ Gal_Diesel, pollutant i, emitted per gallon of diesel combusted (lb/gal)

Emissions$_i$	**lbs. emissions/1,000 gallon**	**Emissions$_i$_per_Gal_Diesel (lbs. emissions/gallon)**
total particulates	30.00000	0.03
nitrogen oxides	210.00000	0.21
sulfur oxides	36.00000	0.036
carbon monoxide	210.00000	0.21
CO_2 (non-biomass)	23000.00000	23

Locality	**Trip_Milage$_i$ (Miles)**
Culpeper & Rappahnnock	100
Fauquier	0
Madison	90
Orange	80*
Albemarle & City of Charlottesville	80
Fluvanna	60
Greene	95
Louisa	55*
Nelson	75

*distance from proposed transfer station

APPENDIX G

WTE Facility Model Process Inputs and Equations

Capital Costs

WTE_cap_cost_per_ton = (Unit_WTE_cap_cost x CRF) / WTE_cap_factor

where WTE_cap_cost_per_ton, capital cost per ton of MSW processed ($/ton)
Unit_WTE_cap_cost, capital cost per unit of a the design capacity ($/(design capacity tons processed/yr))
CRF, capital recovery factor converts capital costs into annual terms
WTE_cap_factor, capacity factor (actual (wet ton/yr)/capacity (wet ton/yr)

$$\mathbf{CRF = (Disc\_rate * ((1+Disc\_rate)^{WTE\_lifetime}))/(1-((1+Disc\_rate)^{WTE\_lifetime}))}$$

where Disc_rate = 0.05
WTE_lifetime, expected lifetime of the WTE facility (yrs)

WTE_cap_cost = WTE_cap_cost_per_ton x WTE_feed_rate

where WTE_cap_cost, total annual capital cost of the facility ($/yr)
WTE_feed_rate, rate MSW is processed (MSW tons/yr)

Operation & Management Costs

WTE_O&M_cost_per_ton = Unit_WTE_O&M_cost / WTE_cap_factor

where WTE_O&M_cost_per_ton, annual O&M cost per ton ($/yr)/(ton MSW/yr)
Unit_WTE_O&M_cost, O&M cost per WTE rated capacity ($/yr)/(ton MSW/yr design capacity)

WTE_O&M_cost = WTE_O&M_cost_per_ton x WTE_feed_rate

where WTE_O&M_cost, total annual O&M cost of the facility ($/yr)

Total Annualized Cost

WTE_cost = WTE_cap_cost + WTE_O&M_cost

where WTE_cost, annual cost of the facility ($/yr)

Total Cost Per Ton MSW

WTE_cost_per_ton = WTE_cost / WTE_feed_rate

where WTE_cost_per_ton = cost per ton of MSW processed at the facility ($/ton)

LCI Emissions

$\text{WTE\_air}_{i,p}$ = $\text{Flue\_gas\_per\_ton}_i$ * Concentration_p

where $\text{WTE\_air}_{i,p}$,emissions of nonmetal air pollutant p per ton of MSW component i processed (lbs pollutant emitted / ton MSW component)
$\text{Flue_gas_per_ton}_{i\,,}$total amount of flue gas generated after air pollution control equipment is utilized measured as dry standard cubic meter (dscm) to 7% oxygen, generated from one tone of MSW component, i (dscm/ton MSW component)
Concentration_p , the concentration of pollutant, p in the flue gas after the air pollution control equipment is utilized (lbs pollutant/dscm)

Concentration_p = $\text{ppmvConcentration}_p$ * $(1/10^6)$ * MW_p * (1/22.4) * $(1/10^3)$ * (10^3) * 2.2
for p = SO_2, NO_x, and CO

where $\text{ppmvConcentration}_p$, the concentration p measured as, parts per million by volume (ppmv)
MW_p, the molecular weight of pollutant, p (SO_2 = 64; NO_x (as NO_x) = 46; CO =28)

Concentration_p = mgConcentration_p x $(1/10^6)$ x 2.2
for p = PM

where $\text{mgConcentration}_{p,}$ is the concentration of p, 7% oxygen (mg/dscm)

Concentration_p = ngConcentration_p x $(1/10^{12})$ x 2.2
for p = Dioxins / furans

where $\text{ngConcentration}_{p,}$ is the concentration of p, 7% oxygen (ng/dscm)

WTE_air_p = $\Sigma_i(\text{WTE\_air}_{i,p})$ x (WTE_feed_rate_i)
for p = metal and nonmetal air pollutants

where $\text{WTE\_air}_{p,}$ is the total annual air emissions of pollutant p (lbs/yr)
$\text{WTE\_air}_{i,p}$, emissions of nonmetal and metal air pollutants (lbs pollutant emitted / ton MSW component)

WTE_feed_rate$_i$, rate MSW is processed (wet tons MSW component/yr)

WTE Facility: Cost Input Variable	**Value**
Unit_WTE_capital_cost = capital cost per unit of design capacity ($/(design capacity tons processed/yr))	282.7
CRF, capital recovery factor	0.0802
WTE_capacity_factor, (actual (wet ton/yr)/capacity(wet ton/yr))	0.91
Discount_rate	0.05*
WTE_lifetime (years)	20*
Unit_WTE_O&M_cost = ($/yr)/(ton/yr design capacity)	59.27
Electricity price ($/kWh)	0.04

*MSW-DST default value

WTE Facility Non-Metal Emissions: After Stack Gas Treatment

WTE_air$_{i,p}$ (LB pollutant/ton MSW component)						
MSW Component	**CO$_2$**	**SO$_2$**	**NOx*****	**CO**	**Total PM**	**CH$_4$**
Yard Trimmings (Leaves)	1,290*	0.4404	1.0322	0.6423	0.1233	0.003
Yard Trimmings (Grass)	1,182*	0.4094	0.9596	0.5971	0.1146	0.003
Yard Trimmings (Branch)	1,290*	0.4404	1.0322	0.6423	0.1233	0.003
News Print	3,174*	1.0427	2.4437	1.5206	0.292	0.003
Corrugated Cardboard	2,949*	0.9663	2.2648	1.4092	0.2706	0.003
Office Paper	2,481*	0.8399	1.9685	1.2248	0.2352	0.003
Phone Books	3,029*	1.0024	2.3494	1.4618	0.2807	0.003
Books	2,887*	0.9604	2.2510	1.4006	0.269	0.003
Magazines	1,723*	0.5769	1.3521	0.8413	0.1615	0.003
3rd Class Mail	2,111*	0.7304	1.7120	1.0652	0.2045	0.003
HDPE (Translucent)	5,828**	2.5493	5.9749	3.7177	0.7138	0.003
HDPE (Pigmented)	5,828**	2.5493	5.9749	3.7177	0.7138	0.003
PET	4,250**	1.3321	3.1222	1.9427	0.3730	0.003
Ferrous Cans	96*	0.0312	0.0730	0.0454	0.0087	0.003
Aluminum Cans	97*	0.0315	0.0738	0.0459	0.0088	0.003
Mixed Glass	34*	0.0134	0.0315	0.0196	0.0038	0.003
Paper (Nonrecyclable)	2,481*	0.8400	1.9686	1.2249	0.23519	0.003
Food Waste	1,009*	0.3582	0.8395	0.5223	0.1003	0.003
Plastic (Non-Recyclable)	5,469**	2.2169	5.1959	3.233	0.6207	0.003
Misc. (CNNN)	2,689**	0.9355	2.1926	1.3643	0.2620	0.003

Ferrous (Nonrecyclable)	96*	0.0312	0.0730	0.0454	0.0087	0.003
Al (Non-recyclable)	97*	0.0315	0.0738	0.0459	0.0088	0.003
Glass (Non-recyclable)	34*	0.0134	0.0315	0.0196	0.0038	0.003
Misc. (NNNN)	-	0	0	0	0	0.003

*Biomass CO_2

**Fossil CO_2

*** NOx as NO

WTE Non-Metal Emission Factors

Parameter	Default for New facilities	Units
SOx	8	(ppmv @ 7% oxygen, dry)
NOx	136	(ppmv @ 7% oxygen, dry)
CO	26	(ppmv @ 7% oxygen, dry)
PM	4	(mg/dscm @ 7% oxygen, dry)
Dioxins / Furans	4.5	(ng/dscm @ 7% oxygen, dry)
Methane	0.003	lb emitted/ton MSW

APPENDIX H

Landfill Model Process Inputs and Equations

Landfill: Initial Construction Cost

$$\mathbf{V_w = (M_{wl} \text{ x } (2000 \text{ lbs/ton}) \text{ x } (365 \text{ days/yr}) \text{ x } N_y) / D_{msw}}$$

where V_w, required landfill capacity for waste (yd^3)
M_{wl}, expected MSW generation volume (tons MSW/year)
N_y, expected useful life of landfill (years)
D_{msw}, average density of waste after burial (lb/ yd^3)

$$\mathbf{V_a = V_w \text{ x } ((100 + P_{cvr1})/100)}$$

where V_a, available volume for the disposal site (yd^3)
P_{cvr1}, percent of total landfill volume occupied by cover (%)

$$\mathbf{H_b = D_e - D_{lls}}$$

where H_b, height of waste below grade (ft)
D_e, depth of excavation (ft)
D_{lls}, depth of liner and leachate collection system (ft)

$$\mathbf{L_{dv} = ((R_{LW}+1)*((H_a^2/ R_{da})+(H_b^2/R_{db})))+sqrt[((R_{LW}+1)2\ (((H_a^2/ R_{da})+(H_b^2/R_{db}))2) + ((4* R_{LW})*(H_a + H_b))*((27 * V_a) - (4/3*((H_a^3/ R_{da}^2) + (H_b^3/ R_{db}^2))))] / (2(H_a+ H_b))}$$

where L_{dv}, length of disposal volume (ft)
R_{LW}, length-to-width ratio
H_a, height of waste above grade (ft)
R_{da}, slope of the grade of the disposal volume above site grade
R_{db}, slope of the grade of the disposal volume below site grade
V_a, available volume for the disposal site (yd3)

$$\mathbf{W_{dv} = L_{dv} / R_{LW}}$$

where W_{dv}, width of disposal volume (ft)

$$\mathbf{A_s = (L_{dv} + 2\ L_b) * (Wdv + 2\ L_b) * (acre/43563\ ft^2)}$$

where L_b, buffer zone distance (ft)

$$\mathbf{C_L = c_1 * A_s}$$

where C_L, cost function for land ($)
c_1, unit cost of land ($/acre)

Landfill: Site Fencing Cost

$$\mathbf{P_s = 2 * (L_s + W_s)}$$

where P_s, site perimeter (ft)
L_s, total site length (ft)
W_s, total site width (ft)

$$\mathbf{L_s = W_s * R_{LW}}$$

$$\mathbf{C_F = c_5 * P_s}$$

where C_F, cost function of site fencing ($)
c_5, unit cost of industrial fencing, material and installation ($/linear ft)

Landfill: Site Buildings and Structures Cost

$$\mathbf{A_m = ((1000ft^2)/(50\ ton/day)) * M_{wl}}$$

where A_m, floor area of equipment storage building (ft^2)

$$\mathbf{C_{STR} = (c_9 * A_m) + c_{10} + c_{11}}$$

where $C_{STR,}$ cost of structures
c_9, cost of construction of a maintenance and equipment storage building
c_{10}, cost of a gatehouse/personnel support building and flare
c_{11}, cost of a public drop-off station

$$\mathbf{C_S = c_{12}\ x\ N_s}$$

where C_S, cost of site scales ($)
c_{12}, installed cost of industrial truck scale, capacity 50 tons ($)
N_s, the number of scales required

Landfill: Site Utility Installation Cost

$$\mathbf{C_U = c_{13} + (c_{14} \times L_s \times (1 - z_1)) + (c_{15} \times z_1) + (c_{16} \times (1 - z_2)) + (c_{17} \times z_2) + (c_{18} \times z_3)}$$

where c_{13}, unit cost of electrical connection to utility grid
c_{14}, unit cost of sanitary sewer connections and piping
c_{15}, unit cost of septic system
c_{16}, unit cost of potable water connection
c_{17}, unit cost of potable water well installation and connection
c_{18}, unit cost of gas connection
L_s, total site length (ft)
z_1, logical input, = +1 if septic system is used instead of public sewer, 0 otherwise
z_2, logical input, = +1 if on-site well water is used instead of public water, 0 otherwise
z_3, logical input, = +1 if gas is used on site, 0 otherwise

Landfill: Site Access Roads Cost

$$\mathbf{C_R = c_{22} \times (L_{sr} + (2\times (L_{dv} + W_{dv})) + 2L_b)) + (c_{23} \times L_{or} \times (5{,}280ft / mi))}$$

where CR, cost function of site access roads ($)
W_{dv}, width of disposal volume (ft)
c_{22}, unit cost of road construction suitable for heavy-vehicle traffic
c_{23}, unit cost of road construction for upgrade of existing roads
L_{or}, distance of required off-site roads to be upgraded (mi)
L_{sr}, distance of required roads for site entrance and access to on-site facilities (ft)

Landfill: Monitoring Wells Cost

$$\mathbf{C_{MW} = c_{24} * N_{MW} * L_{wd}}$$

where C_{MW}, cost of monitoring wells ($)
c_{24}, unit cost of well drilling and installation ($/linear ft of well depth)
N_{MW}, number of monitoring wells
L_{wd}, depth of typical well (ft)

Landfill: Initial Landscaping Cost

$$\mathbf{C_{IL} = c_{26} + (c_{25} \times f_3 \times (A_s - (L_{dv} \times W_{dv} \times (acre/43563\ ft^2))))}$$

where A_s, area of land required for landfill and buffer zone (acres)
C_{IL}, cost function of initial landscaping ($)
W_{dv}, width of disposal volume (ft)
c_{25}, unit cost of low-level landscaping ($/acre)
c_{26}, cost of high-level landscaping around buildings and site entrance ($)
f_3, fraction of buffer zone to be cleared and landscaped prior to operating landfill

Landfill: Leachate Management System Cost

$$\mathbf{C_{LC} = c_{34} + c_{35}}$$

where C_{LC}, cost function of leachate pumping and storage system (\$)
c_{34}, cost to procure and install leachate pump, associated piping and electrical (\$)
c_{35}, cost of leachate storage tank (\$)

Landfill: Site Suitability Study Cost

$$\mathbf{C_{PL} = c_{41}}$$

where C_{PL}, cost function of preoperational studies and activities (\$)
c_{41}, total cost of site preoperational studies and activities (\$)

Landfill: Total Initial Cost Function

$$\mathbf{C_{IC} = ((1+f_5)*f_{cr1}*(C_F+C_{STR}+C_S+C_U+C_R+C_{MW}+C_{IL}+C_{LC}+C_{PL}))/(V_w/N_y)}$$

$$\mathbf{f_{cr1} = (i*(1+i)^{Ny})/((1+i)^{Ny})-1)}$$

where C_{IC}, cost function for initial construction (\$/yd^3)
f_{cr1}, capital recovery factor for initial construction
V_w, required landfill capacity for waste (yd^3)
f_5, engineering design multiplier for capital investment
i, effective annual interest rate

Landfill: Cell Construction Site Clearing and Excavation Cost

$$\mathbf{C_c = c_2 * [((L_{dv} * W_{dv} * (acre/43563\ ft^2))/N_r)+((A_s-(L_{dv} * W_{dv} * (acre/43563\ ft^2))*f_3))]}$$

$$\mathbf{V_e = f_1 * [((L_{dv} + D_{lls})(W_{dv} + D_{lls}) * (D_e)) - ((D_e{}^2/R_{db}) * (L_{dv}+W_{dv}+(2 * D_{lls}))) +((4 * D_e^3) / (3* R_{db}^2))] * (yd^3/27ft^3)}$$

$$\mathbf{C_e = ((c_3 + (c_8 * ((L_{dv} + W_{dv}) / 2)*(1 / 5280)) * ((V_e/N_r)) * (1-f_2)) + ((c_4+ (c_{49} * L_{sd})) * (V_e/ N_r) * f_2)}$$

$$\mathbf{C_{CE} = C_c + C_e}$$

where c_2, unit cost of clearing land (\$/acre)
c_3, unit cost of standard excavation (\$/yd^3)
c_4, unit cost of difficult excavation (i.e., muck, rock, etc.) (\$/yd^3)
c_8, cost of on-site earth hauling (\$/yd^3-mi)

c_{49}, cost of off-site hauling of soil (\$/yd^3-mi)
D_e, depth of excavation (ft)
f_1, fraction of below-grade volume required to be excavated
f_2, fraction of excavated volume considered difficult to excavate
f_3, fraction of buffer zone to be cleared and landscaped prior to operating landfill
L_{sd}, distance to area for excess soil disposal (mi)
N_r, number of distinct regions of the landfill developed over the life of the facility
A_s, area of land required for landfill and buffer zone (acres)
C_c, total cost of site clearing (\$)
C_{CE}, cost function of site clearing and excavation (\$)
C_e, total cost of site excavation (\$)
V_e, excavated volume (yd^3)
V_{sh}, volume of soil to be hauled off site (yd^3)
W_{dv}, width of disposal volume (ft)

Landfill: Site Berm Cost

$$\mathbf{A_b = H_{bm} * ((W_{bu}+W_{bl}) / 2)}$$

$$\mathbf{W_{bl} = W_{bu} + ((2*H_{bm}) / R_b))}$$

$$\mathbf{P_{dv} = 2 * (L_{dv} + W_{dv})}$$

$$\mathbf{V_{bm} = P_{dv} * A_b * (yd^3/27ft^3)}$$

$$\mathbf{C_B = ((c_6*V_{bm}) + (c_7*V_{sbp})) / N_r}$$

where c_6, unit cost of earthen berm construction (\$/yd^3)
c_7, unit cost of procurement and delivery of soil for berm construction (\$/yd^3)
H_{bm}, height of berm (ft)
N_r, number of distinct regions of the landfill developed over the life of the facility
R_b, slope of the grade of the berm as rise over run
W_{bu}, width of the top of the berm (ft)
A_b, area of berm cross section (ft^2)
C_B, cost function of earthen berm (\$)
P_{dv}, disposal volume perimeter (ft)
V_{bm}, volume of the berm (yd^3)
V_{sbp}, volume of soil required to be purchased for berm construction (yd^3)
W_{bl}, width of the bottom of the berm (ft)
W_{dv}, width of disposal volume (ft)

Landfill: Liner System Cost

$$\mathbf{V_l = ((A_l*(1\text{-}f_4)*((z_4*D_{spl})+(z_4*z_6*D_{ssl}))) / 0.9)*(yd^3/27ft^3)}$$

$$\mathbf{V_{sa} = ((A_l *(f_4/(1\text{-} f_4))*((z_4*D_{spl})+(z_4*z_6*D_{ssl}))) / 0.9)*(yd^3/27ft^3)}$$

$$\mathbf{C_{LS} = (c_{32}*(V_l + V_{sa}))+(c_{30} + V_{sa})+((c_{29}*V_{slp})/N_r)+(c_{27}* A_l *(yd^3/27ft^3)*(z_4*(1+z_6)))}$$

$$\mathbf{A_l = ((2*(L_{dv}+W_{dv}) * [((H_b/R_{db}) * (sqrt(R_{db}^2 + 1))) + ((H_{bm}/R_b) * (sqrt(R_b^2 + 1)))]) + (L_{dv} * W_{dv})/N_r}$$

where c_{27}, unit cost of procurement and installation of flexible membrane liner ($\$/ft^2$)
c_{29}, unit cost of procurement and delivery of soil for liner construction ($\$/yd^3$)
c_{30}, unit cost of procurement and delivery of soil additive to decrease permeability ($\$/yd^3$)
c_{31}, unit cost of procurement, delivery, and installation of drainage material for leachate detection and cover (sand) ($\$/yd^3$)
c_{32}, unit cost of installation of compacted soil liner, including soil preparation ($\$/yd^3$)
D_{spl}, depth of compacted soil in the primary liner (ft)
D_{ssl}, depth of compacted soil in the secondary liner (ft)
f_4, fraction of soil additive to mix with native or purchased soil to achieve required permeability
H_{bm}, height of berm (ft)
N_r, number of distinct regions of the landfill developed over the life of the facility
R_b, slope of the grade of the berm as rise over run
z_4, logical input, = +1 if a liner is used, 0 otherwise
z_6, logical input, = +1 if a double composite liner is used, 0 otherwise (single composite)
A_l, area over which liner is installed (ft^2/cell)
C_{LS}, cost function of liner system (\$)
V_{sa}, volume of soil additive required (yd^3)
V_l, volume of soil for liner construction (yd^3/cell)
V_{slp}, volume of soil required to be purchased for liner construction (yd^3)
W_{dv}, width of disposal volume (ft)

Landfill: Leachate Control Cost

$$\mathbf{L_{plc} = (W_{dv} * CEILING((L_{dv} /L_4),1)) + L_{dv}}$$

$$\mathbf{V_{sglc} = D_{slc} * (L_{dv} + H_b + ((H_{bm} / R_b) * (sqrt((R_b^2) + 1)))) * (W_{dv} + H_b + ((H_{bm} / R_b) * (sqrt((R_b^2) + 1)))) * (yd^3 / 27ft^3)}$$

$$\mathbf{C_{LCP} = z_4 * (((c_{36} * L_{plc}) + (V_{sglc} * c_{33})) / N_r)}$$

where c_{33}, unit cost of purchase, delivery, and installation of leachate collection layer ($/yd^3)
c_{36}, cost to procure and install PVC piping ($/ft)
D_{slc}, depth of leachate collection system (ft)
H_{bm}, height of berm (ft)
L_4, distance between leachate collection pipes (ft)
N_r, number of distinct regions of the landfill developed over the life of the facility
R_b, slope of the grade of the berm as rise over run
z_4, logical input, = +1 if a liner is used, 0 otherwise
C_{LCP}, cost function of leachate collection piping ($)
L_{plc}, length of PVC piping installed for leachate collection (ft)
V_{sglc}, volume of sand or gravel in leachate collection trenches (yd^3)
W_{dv}, width of disposal volume (ft)

Landfill: Cell Pre-operational Costs

$$\mathbf{C_{CO} = c_{50}}$$

where c_{50}, total cost of cell-one preoperational studies and activities ($)
C_{CO}, cost function of cell-one preoperational studies and activities ($)

Landfill: Total Cell Construction Costs

$$\mathbf{f_{cr2} = (i * ((1+i)^{(Ny/Nr)})) / (((1 + i)^{(Ny/Nr)}) - 1)}$$

$$\mathbf{C_{CC} = ((1 + f_5) * (f_{cr2}) * (C_{CE} + C_B + C_{LS} + C_{LCP} + C_{CO}) / (V_W / N_y))}$$

where C_{CC}, cost function for cell one construction ($-year/cell-yd^3)
f_{cr2}, capital recovery factor for staged construction
V_W, required landfill capacity for waste (yd^3)

Landfill: Operating Costs

$$\mathbf{C_l = IF(M_{wl} > M_{wm}, ((1 + f_7) * ((c_{43} + c_{44}) * (M_{wl} - M_{wm})),(1 + f_7) * c_3))}$$

$$\mathbf{C_{eq} = c_{45} * M_{wl}}$$

$$\mathbf{C_u = f_9 * C_l}$$

$$\mathbf{C_{DO} = Cl + C_{eq} + C_{lt} + C_u}$$

where c_{43}, minimum annual labor costs ($/year)

c_{44}, incremental labor costs for each increase in landfill tonnage above M_{wm} (\$/yr)/(ton/day)
c_{45}, cost of equipment procurement and maintenance per mass of waste handled (\$/yr)/(ton/day)
c_{47}, leachate treatment and disposal cost including transport to publicly owned treatment works (POTW) (\$/gal)
d_{lcht}, density of leachate (lb/gal)
f_7, labor fringe rate
f_9, utilities costs fraction (of personnel costs)
M_{wm}, maximum daily tonnage handled by labor costs of c43 (ton/day)
R_{lgo}, rate of leachate generated (active cell)(gal/acre-day)

Landfill: Daily Cover Material Cost

$$D_{eff} = (1-(Pcvrl/100))*D_{msw}$$

$$ACM3 = (PHDPE1/100) * AHDPE * Ldv * Wdv * (1/43560)$$

$$VCM1 = (Poffsite/100) * Vcl$$

$$VCM2 = (Ponsite/100) * Vcl$$

$$VCM4 = Va * (Pcvr1/100) * (1/Deff) * (Prevgen/100)$$

$$CCM1 = (VCM1 * c42) / Ny$$

$$CCM2 = (VCM2 * c51) / Ny$$

$$CCM3 = (ACM3 * c52) / Ny$$

$$CCM4 = (VCM4 * c53)/Ny$$

$$CCM = CCM1 + CCM2 +CCM3 + CCM4$$

$$Vc1 = Vw * (Pcvrl/100)*(Psoil/100)$$

where AHDPE, area of HDPE per acre (ft^2/acre)
c42, unit cost of procurement and delivery of soil suitable for daily cover (\$/yd^3)
c51, unit cost of procurement of on-site daily cover soil (\$/yd^3)
c52, unit cost of procurement and installation of HDPE (\$/ft2)
c53, revenue-generating cover (\$/yd^3)
PHDPE1, percent of daily cover that is HDPE (%)
Pcvr1, percent of total landfill volume occupied by cover (%)

Prevgen, percent of daily cover that is revenue-generating cover (%)

ACM3, area of HDPE cover (ft^2/acre)
CCM, the total cost of daily cover ($/year)
CCM1, cost of off-site soil for daily cover ($/year)
CCM2, cost of on-site soil for daily cover ($/year)
CCM3, cost of HDPE for daily cover ($/year)
CCM4, revenue from revenue-generating cover ($/year)
Poffsite, percent of daily cover that is off-site soil (%)
Ponsite, percent of daily cover soil volume that can be obtained on site as calculated in the soil budget (%)
Vc1, volume of soil required for daily cover (yd^3)
VCM1, volume of off-site soil used for daily cover (yd^3)
VCM2, volume of on-site soil used for daily cover (yd^3)
VCM4, volume of revenue-generating cover (yd^3)
Wdv, width of disposal volume (ft)

Landfill: Total Operating Cost Function

CO = ((CDO + CCM) / (VW / Ny)) * (1 + f6)

where f6, engineering design multiplier for landfill operations
CO, cost function for operations ($/$yd^3$)
Vw, required landfill capacity for waste (yd^3)

Landfill: Gas Extraction

LHDPE = GCHDPE * VW * DMSW * (1 / DHDPE) * (1 ton / 2000 lb) * (1/0.0014 ft^2)

LPVC2 = (GCPVC + GMPVC) * VW * DMSW * (1/DPVC) * (1 ton / 2000 lb) * (1/0.0014 ft^2)

CGE = (LHDPE + LPVC2) * c36

where c36, cost to procure and install PVC piping ($/ft)
DHDPE, density of HDPE used for daily cover (lb/ft^3)
DPVC, density of PVC (lb/ft^3)
GCHDPE, amount of HDPE in gas collection system (lb/ton waste)
GCPVC, amount of PVC in gas collection system (lb/ton waste)
GMPVC, amount of PVC in gas monitoring system (lb/ton waste)

CGE, cost of gas collection system ($)
LHDPE, total HDPE in gas collection system (ft)

LPVC2, total PVC in gas collection system (ft)
Vw, required landfill capacity for waste (yd^3)

Landfill: Final Cover Cost

$$Atl = [[2 * (Ldv + Wdv) * [((Hb / Rdb) * (sqrt ((Rdb^2) + 1)) + ((Hbm / Rb) * (sqrt((Rdb^2) + 1))]] + (Ldv * Wdv)] / Nr$$

$$Scvr1 = (tsoil * Atl) * (yd^3 / 27\ ft^3)$$

$$Vtsa = Atl * (f4/(1-f4)) * (z4 * Dspl) * (yd^3/ 27\ ft^3)$$

$$Vsnd = Atl * tsand1 * (yd^3/ 27\ ft^3)$$

$$Vsnd2 = Atl * tsand2 * yd^3/ 27\ ft^3)$$

$$CSL = Vstlp * c7$$

$$CSA = Vtsa * c30$$

$$CCL = Vsfcp * c29$$

$$CMC = (scvr1 + Vtsa) * c32$$

$$CSND1 = Vsnd1 * c31$$

$$CSND2 = Vsnd2 * c31$$

$$CHDPE = c52*Atl$$

$$CGTX = (c55+c57)*Atl$$

$$CLD = Atl * c25 * (acre / 43560\ ft^2)$$

$$CFC = (CSL + CSA + CCL + CMC + CSND1 + CSND2 + CHDPE + CLD)$$

$$CFC = (CSL + CSA + CCL + CMC + CSND1 + CSND2 + CGTX + CLD)$$

where Atl, area of top of final cover (ft^2)
c7, unit cost of procurement and delivery of soil adequate for berm construction ($\$/yd^3$)
c25, unit cost of low-level landscaping ($/acre)
c29, unit cost of procurement and delivery of soil suitable for liner construction

($/yd^3)
c30, unit cost of procurement and delivery of soil additive to decrease permeability ($/yd^3)
c31, unit cost of procurement, delivery, and installation of drainage material for leachate detection and cover (sand) ($/yd^3)
c32, unit cost of installation of compacted soil liner, including soil preparation ($/yd^3)
c52, unit cost of procurement and installation of HDPE ($/ft^2)
c55, cost of procurement of geotextile ($/ft^2)
c57, cost of installing geotextile for final cover ($/ft^2)
CCL, cost of clay for final cover ($)
CFC, final cover cost ($)
CGTX, cost of geotextile liner ($)
CHDPE, cost of HDPE liner ($)
CLD, cost of low-level landscaping ($)
CMC, cost of mixing and compaction clay for final cover ($)
CSA, cost of procurement and delivery of soil additive ($)
CSL, cost of soil suitable for vegetative support soil and topsoil ($)
CSND1, cost of first layer of sand ($)
CSND2, cost of second layer of sand ($)
Dspl, depth of compacted soil in the primary liner (ft)
f4, fraction of soil additive to mix with native or purchased soil to achieve required permeability
Ha, height of waste above grade (ft)
Hbm, height of berm (ft)
scvr1, volume of soil for topsoil and vegetative support cover (yd^3)
tgtx, thickness of geotextile (mils)
tHDPE2, thickness of HDPE (mils)
tsand1, thickness of the first sand layer in final cover (ft)
tsand2, thickness of second sand layer in final cover (ft)
tsoil, depth of top soil and vegetation support soil (ft)
Vsfcp, volume of soil purchased for final cover (yd^3)
Vsnd, volume of sand in the first layer (yd^3)
Vsnd2, volume of sand in the second layer (yd^3)
Vstlp, volume of soil required to be purchased for cover construction (yd^3)
Vtsa, volume of soil additive to decrease permeability of liner and final cover (yd^3)
z4, logical input, = +1 if any liner is used, 0 otherwise

Landfill: Cost of Replacing Final Cover

CRC = CFC * (Pcvr2/100)

where Pcvr2, percent of final cover to be replaced over the entire post-closure period (%)

CFC, final cover cost ($)
CRC, cost of replacing final cover ($/ton waste)

Landfill: Perpetual Care Cost

$$\mathbf{Fcr3 = (((1 + i)^{Npc}) - 1) / (I * (1 + i)^{Npc})}$$

$$\mathbf{CPC = fcr3 * (c48 + (Nmw * c46))}$$

where c46, annual cost of well monitoring ($/well-year)
c48, annual perpetual care cost ($/year)
i, effective annual interest rate
Npc, number of years of perpetual care (years)
CPC, cost function of perpetual care ($/year)
fcr3, capital recovery factor for perpetual care costs
Nmw, number of monitoring wells

Landfill: Total Closure Cost Function

$$\mathbf{Fcr4 = i/(((1+i)\hat{}Ny)-1)}$$

$$\mathbf{CC = fcr4 * (((1 + f5) * (CGE + CFC + c60 + c61)) + (CPC + CRC)) / (VW / Ny)}$$

where f5, engineering design multiplier for capital investment
i, effective annual interest rate
c60, capital cost of turbine
c61, capital cost of internal combustion engine

CC, cost function for initial construction ($\$/yd^3$)
fcr4, capital recovery factor for closure costs
Vw, required landfill capacity for waste (yd^3)

Landfill: Total Cost Function

$$\mathbf{TOTALCOST1 = CIC + CCC + CO + CC}$$

$$\mathbf{TOTALCOST2 = ((2000lb/ton) * CTOTALCOST1) / Dmsw}$$

Landfill: Model Input Variable	Value
AHDPE, area of HDPE per acre (ft^2/acre)	43560
As, area of land required for landfill and buffer zone (acres)	100.4347
c1, unit cost of land ($/acre)	1,500
c2, unit cost of clearing land ($/acre)	2,425
c3, unit cost of standard excavation ($/$yd^3$)	2.00
c4, unit cost of difficult excavation (i.e., muck, rock, etc.) ($/$yd^3$)	3.00
c5, unit cost of industrial fencing, material and installation ($/linear ft)	11.95
c6, unit cost of earthen berm construction ($/$yd^3$)	2.5
c7, unit cost of procurement and delivery of earth adequate for berm construction ($/$yd^3$)	2.67
c8, cost of on-site earth hauling ($/$yd^3$-mi)	1.83
c9, cost of construction of a maintenance and equipment storage building ($/$ft^2$)	21.8
c10, cost of a gatehouse/personnel support building and flare ($)	335,750
c11, cost of a public drop-off station ($)	0
c12, installed cost of industrial truck scale, capacity 50 tons ($)	70,000
c13, unit cost of electrical connection to utility grid ($)	10,000
c14, unit cost of sanitary sewer connections and piping ($/linear ft)	10.2
c15, unit cost of septic system ($)	41,000
c16, unit cost of potable water connection ($)	10,000
c17, unit cost of potable water well installation and connection ($)	50,000
c18, unit cost of gas connection ($)	10,000
c22, unit cost of road construction suitable for heavy-vehicle traffic ($/linear ft)	35.28
c23, unit cost of road construction for upgrade of existing roads ($/linear ft)	35.28
c24, unit cost of well drilling and installation ($/linear ft of well depth)	22
c25, unit cost of low-level landscaping ($/acre)	1,450
c26, cost of high-level landscaping around buildings and site entrance ($)	5,000
c27, unit cost of procurement and installation of flexible membrane liner ($/$ft^2$)	1.5
c29, unit cost of procurement and delivery of soil suitable for liner construction ($/$yd^3$)	7
c30, unit cost of procurement and delivery of soil additive to decrease permeability ($/$yd^3$)	115
c31, unit cost of procurement, delivery, and installation of drainage material for leachate detection and cover (sand) ($/$yd^3$)	8.05
c32, unit cost of installation of compacted soil liner, including soil preparation ($/$yd^3$)	5
c33, unit cost of purchase, delivery, and installation of leachate collection layer (gravel) ($/$yd^3$)	8.3
c34, cost to procure and install leachate pump and associated piping and electrical ($)	10,000
c35, cost of leachate storage tank ($)	120,000
c36, cost to procure and install PVC piping ($/ft)	10.2
c41, total cost of site preoperational studies and activities ($)	250,000
c42, unit cost of procurement and delivery of soil suitable for daily cover ($/$yd^3$)	2.67
c43, minimum annual labor costs ($/year)	260,000
c44, incremental labor costs for each increase in landfill tonnage above Mwm ($/yr)/(ton/day)	$300
c45, cost of equipment procurement and maintenance per mass of waste handled ($/yr)/(ton/day)	1,800

c46, annual cost of well monitoring (\$/well-year)	2,000
c47, leachate treatment and disposal cost including transport to publicly owned treatment works (POTW) (\$/gal)	0.35
c48, annual perpetual care cost (\$/year)	222,000
c49, cost of off-site hauling of soil (\$/yd^3-mi)	0.50
c50, total cost of cell-one preoperational studies and activities (\$)	250000
c51, unit cost of procurement of on-site daily cover soil (\$/yd^3)	0
c52, unit cost of procurement and installation of HDPE (\$/ft^2)	1.5
c53, revenue-generating cover (\$/yd^3)	-5
c55, cost of procurement of geotextile (\$/ft^2)	0.11
c57, cost of installing geotextile for final cover (\$/ft^2)	0.06
c60, capital cost of turbine	4,000,000
c61, capital cost of internal combustion engine	1,200,000
De, depth of excavation (ft)	40
DHDPE, density of HDPE used for daily cover (lb/ft^3)	59.6
dlcht, density of leachate (lb/gal)	8.34
Dmsw, average density of waste after burial (lb/yd^3)	1,500
DPVC, density of PVC (lb/ft^3)	84.3
Dslc, depth of leachate collection system (ft)	1
Dspl, depth of compacted soil in the primary liner (ft)	2
Dssl, depth of compacted soil in the secondary liner (ft)	2
f1, fraction of below-grade volume required to be excavated	1
f2, fraction of excavated volume considered difficult to excavate	0.10
f3, fraction of buffer zone to be cleared and landscaped prior to operating landfill	0.05
f4, fraction of soil additive to mix with native or purchased soil to achieve required permeability	0.04
f5, engineering design multiplier for capital investment	0.1
f6, engineering design multiplier for landfill operations	0.1
f7, labor fringe rate	0.46
f9, utilities costs fraction (of personnel costs)	0.01
GCHDPE, amount of HDPE in gas collection system (lb/ton waste)	0.016
GCPVC, amount of PVC in gas collection system (lb/ton waste)	0.0081
GMPVC, amount of PVC in gas monitoring system (lb/ton waste)	7.30E-05
Ha, height of waste above grade (ft)	40
Hbm, height of berm (ft)	10
i, effective annual interest rate	0.05
L4, distance between leachate collection pipes (ft)	200
Lb, buffer zone distance (ft)	300
Lor, distance of required off-site roads to be upgraded (mi)	1
Ls, total site length (ft)	2,092
Lsd, distance to area for excess soil disposal (mi)	1
Lsr, distance of required roads for site entrance and for access to on-site facilities (ft)	600
Lw, distance between monitoring wells around perimeter of disposal volume (ft)	500
Lwd, depth of typical well (ft) (For well clusters, increase the depth proportionately)	50
Mwm, maximum daily tonnage handled by labor costs of c43 (ton/day)	400

Npc, number of years of perpetual care (years)	30
Nr, number of distinct regions of the landfill developed over the life of the facility	4
Ns, the number of scales required	1
Ny, expected useful life of landfill (years)	20
Pcvr1, percent of total landfill volume occupied by cover (%)	10
Pcvr2, percent of final cover to be replaced over the entire post-closure period (%)	10
PHDPE1, percent of daily cover that is HDPE (%)	15
Prevgen, percent of daily cover that is revenue-generating cover (%)	15
Rb, slope of the grade of the berm as rise over run	0.33
Rda, slope of the grade of the disposal volume above site grade	0.33
Rdb, slope of the grade of the disposal volume below site grade	0.33
Rlgo, rate of leachate generated (active cell)(gal/acre-day)	
RLW, length-to-width ratio	1
tgtx, thickness of geotextile (mils)	140
tHDPE2, thickness of HDPE (mils)	60
tsand1, thickness of the first sand layer in final cover (ft)	1
tsand2, thickness of second sand layer in final cover (ft)	1
tsoil, depth of top soil and vegetation support soil (ft)	3
Wbu, width of the top of the berm (ft)	12
z1, logical input, = +1 if septic system is used instead of public sewer, 0 otherwise	1
z2, logical input, = +1 if on-site well water is used instead of public water, 0 otherwise	0
z3, logical input, = +1 if gas is used on site, 0 otherwise	0
z4, logical input, = +1 if a liner is used, 0 otherwise	1
z6, logical input, = +1 if a double composite liner is used, 0 otherwise (single composite)	1

Landfill Model Parameter	Input	Units
General		
Active life of facility	20*	Years
Number of cells	5*	Number
Annual interest rate	0.05*	Percentage
Engineering rate (capital)	0.10*	Percent of capital cost
Engineering rate (operations)	0.10*	Percent of capital cost
Post closure period	30*	Years
Liner		
Does the Landfill have a Liner?	yes	yes/no
Fraction of clay additive to achieve minimum permeability	0.04*	percentage
Depth of soil in primary liner	2*	ft
Liner is Single or Double Composite	double	single/double
Depth of secondary liner	2*	ft
Gas Collection System		
Does landfill have a gas collection system?	yes	yes/no
Landfill gas collection system efficiency	75*	percentage

Landfill gas oxidation via cover soil	15*	percentage
How is landfill gas managed?	Recovery	Vent/Flare/Energy Recovery
Landfill gas quality carbon dioxide	45	percentage
Landfill gas quality methane	55	percentage

*MSW-DST default data