Rhode Island Resource Recovery Corporation

Long-Term Solid Waste Disposal Alternatives Study

Johnston, Rhode Island

July 17, 2018

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Executive Summary

In May 2015, the Rhode Island State Planning Council issued *"Solid Waste 2038"* the *"Rhode Island Comprehensive Solid Waste Management Plan (SWMP)"* a document developed to guide the solid waste management activities of the State of Rhode Island through the year 2038. In preparation of an update of this report, the Rhode Island Resource Recovery Corporation (Corporation) has identified and investigated the most promising long-term solid waste disposal alternatives, giving consideration to cost, risk, legislative requirements, and environmental impacts over a range of potential annual waste volumes. This Long-Term Solid Waste Disposal Alternatives Study (Study) provides a high-level review and assessment of potential future solid waste disposal technologies that may be suitable for the Corporation to initiate, permit, and construct as it moves into the future.

According to a recent study, in 2015 the Corporation processed approximately 280,000 tons of municipal sector waste; 248,000 tons industrial/commercial/institutional (ICI) sector waste; and 55,000 of bulky waste for a total of 583,000 tons of mixed solid wastes (MSW). The balance of the waste managed included approximately 196,000 tons of construction and demolition waste (C&D); 35,000 tons of "other waste"; and 233,000 tons of "special waste." Other and special waste includes recycling process wastes, soils, sludge, and other aggregate wastes. In 2015, the Corporation managed a total of 1,048,000 tons of waste.

In addition to the 1,048,000 tons of waste described above, the Corporation also processed approximately 100,000 tons of single stream recyclables through the on-site materials recycling facility (MRF) which recovered approximately 85,000 tons of recyclables. The Corporation also diverted approximately 40,000 tons of leaf and yard waste through the on-site aerobic windrow composting program. This brings the total materials managed by the Corporation in 2015 to an estimated 1,188,000 tons. For the purposes of this Study, 2015 is considered the basis year.

Rhode Island municipalities are required to deliver all residential sector wastes to the Corporation's Central Landfill in Johnston, RI. All other sector wastes are managed by the private collection and disposal markets. However, given the Central Landfill's convenient location and low tip fees, almost all of Rhode Island's waste is brought to the Central Landfill. Based on current disposal rate of about 1,000,000 tons per year (TPY), the landfill's Phase VI expansion will reach full capacity in 2034. The original design full capacity date was 2038, which was based on a disposal rate of 750,000 TPY.

This Study reviews a "long-list" of both "traditional" and "emerging technologies" from a high level. Based on the review criteria outlined further in this Study, the long-list of traditional and emerging technologies was narrowed to a "short-list" of "proven technologies" considered suitable for the Corporation to initiate, permit, and construct over the next SWMP planning period (2020 to 2040). Proven technologies were then further evaluated to identify benefits, drawbacks, costs, and critical path timelines for design, permitting, construction. The cost estimates included herein are not considered "bankable" and cannot be used for bonding or financial purposes; they can be used to compare technologies on a high-level, qualitative basis.

This Study suggests that the Corporation limit its focus to proven technologies. Proven technologies are considered solid waste processes and management methods that have a long commercial operating history of managing waste materials with similar characteristics and volume as the Corporation's waste stream. To be considered "proven", a technology must have 5-years of continuous operation at tonnages in excess of 500 tons per day (TPD) with at least 85% availability.

These evaluation factors are critical as while some emerging technologies do show promise, few are operating reliably (greater than 85% availability) in North America using unprocessed, or minimally processed, municipal solid waste feed streams at the volume the Corporation requires (approximately 1,000 to 2,500 TPD).

The short-list of proven technologies includes:

Landfilling

Landfilling involves the placement of waste into lined cells that capture and control rain and other precipitation that falls within the cell area and prevents water from reaching and polluting the groundwater and surrounding environment. A modern landfill also collects and utilizes landfill gases generated by waste decomposition. For purposes of this study it is assumed that continued landfilling at the Central Landfill or another location is a viable option. Current estimates have the existing Central Landfill running out of space in 2034. By that time the Central Landfill will need to be expanded or another landfill developed.

MSW Landfill Active Face; Black Base Liner Appears in Background.

Regardless of whether the Corporation continues to use and expand the Central Landfill or develops a new landfill at a different location, landfilling will be the least cost option. Landfills can manage all types of waste, including MSW, C&D, soils, sludges, and other special wastes. Based on cost and versatility, landfills will typically be the preferred choice. However, if environmental and social costs are added to the economic costs, the argument for landfills is not as clear. In addition, in its enabling legislation the Corporation,"...*shall also seek to minimize landfilling of any type of waste and phase out the use of landfills for waste disposal."* Irrespective of economics and legislation, the Corporation should seek to minimize landfilling through reduction, reuse, and recycling.

Advantages:

- Lowest Cost Option
- Proven Technology
- Can Manage All Waste Streams
- Current System – Requires No Changes for Municipal and Commercial Haulers

Disadvantages:

- Environmental Risks will Remain
- Post-Closure Monitoring Costs (minimum 30-years)
- Finite Resource
- Difficult to Permit (especially a new site)

Critical Path:

Developing any landfill expansion can be a long and arduous process depending on support and reactions from politicians and residents. If, at some point in the future, the Corporation considers expanding the Central Landfill, it is estimated that 5-6 years will be required to design, permit, and construct a potential Phase VII expansion at the Central Landfill.

Developing a new landfill at a new location will likely meet with significant public opposition. A contested expansion of an existing landfill in Maine took over 10-years from the first application until it received approval. To locate, site, design, permit, and build a new landfill facility will likely to take 10-12 years.

Transfer Station with Long Haul Waste Disposal

The purpose of transfer station is to take waste material from small collection trucks and consolidate that waste into larger transfer trailers. This allows for more cost effective long distance hauling. Transfer stations can utilize tractor trailer trucks, rail cars, or even barges. As local waste disposal facilities become more and more scarce, some New England communities are developing transfer stations to allow for the hauling of wastes to distant disposal facilities.

Typically rail haul becomes cost effective when the one-way travel distance exceeds 250 miles. These facilities can be capital intensive and add to the overall waste management costs. However, the additional costs can be offset by the lower tip fees at landfills located in New York, Pennsylvania, Ohio, and Virginia. That said, there are increased emissions associated from trucks and railroads used for hauling. These emissions must be added to the overall environmental impacts as the waste will likely be landfilled in the receiving state.

Factoria Transfer Station; King County, Washington

Advantages:

- Long-Term Solution
- Can Manage All Types of Waste
- Relatively Simple Operation
- Flexibility

Disadvantages:

- Disposal No Longer a Local Option
- Increased Air Emission Due to Hauling
- Rail Transfer Can Limit Disposal Locations
- Truck Transfer Can Limit Disposal Options

Critical Path:

Overall, it is estimated that developing a transfer stations(s) will take 5-7 years. Major factors include; 1) entering into a long-term agreement with the short and long railroads or a broker to manage the rail haul portions of the operation, 2) locating and acquiring a large enough parcel of land with rail access, and 3) securing a contract with an out of state disposal facility to accept the waste. It is assumed that once a suitable property is located, the remainder of the process will take approximately 3-years to design, permit, and construct.

Anaerobic Digestion (AD)

Over the past 5-years, AD is being used more and more as a way of processing source separated organics (SSO), specifically source separated food waste. AD is the controlled decomposition of organics in an oxygen-deficient environment. The process involves injecting organic waste material into an enclosed vessel where microbes are used to decompose the waste which produces a residual sludge and a biogas that consists mainly of methane, water, and carbon dioxide (CO_2). The biogas can be used to produce electricity or be processed further and compressed to be used as a vehicle fuel. The residual sludge can be treated further to produce compost that can be marketed as a fertilizer or soil amendment.

The organics can be either source separated or obtained from another processing technology such as a mixed waste processing facility (MWPF). AD is considered a proven technology and there are many functioning examples across the United States. It is estimated that an AD facility constructed by the Corporation could divert as much as 250 TPD from the Central Landfill.

The operation of an AD facility is heavily dependent on the quality of the organic feed stock (no plastics or other non-digestible items should be included). Therefore the feedstock must be highly processed, either at the source or at a pre-processing facility. The economic viability of any AD facility is dependent on the revenue generated by tip fees, the sale of the gas or electricity, and the sale of the residuals as a fertilizer or soil amendment product. Any upset to these income streams can cause a facility to be unprofitable.

Gill-Onions Anaerobic Digestion Facility; Oxnard, CA

Advantages:

- Diversion of Organic Waste from Landfilling
- Generates Electricity and/or Vehicle Fuel
- Produces a Fertilizer or Soil Amendment for Sale

Disadvantages:

- Requires Pre-Processing to Remove non-Digestible Materials
- Technical Operation
- High Capital Cost; High Operating Cost
- Heavily Dependent on Price of Electricity and/or Selling Composted Sludge as a Fertilizer
- High Capital Cost per Ton of Organics Managed
- Only Manages a Fraction of the Waste Stream

Critical Path:

To design, permit and construction an AD facility is not particularly difficult, but to secure a high quality organic waste stream of suitable volume can take time. Assuming any new facility is located on the Corporation's property in Johnston, the estimated timeline to construct an AD facility is 2-3 years.

Composting/Co-Composting

The Corporation currently uses aerobic windrow composting to process approximately 40,000 tons per year of leaf and yard waste at the Central Landfill. Composting is a proven, low-tech option for managing leaf & yard waste that can be expanded to Co-Composting using same equipment. Aerobic windrow co-composting typically mixes leaf and yard waste with source separated or mechanically separated organics from the MSW waste stream, as well as waste water treatment biosolids. There is no reason to believe that an expanded composting or co-composting operation will cost any more than the current operation.

Advantages:

- Low Capital and O&M Costs
- Builds on Existing Process
- If Expanded, Food Waste Could Provide Year Round Organic Source
- Can Sell Finished Compost Product

Disadvantages:

- Uses a Large Area
- Odors Can be an Issue
- Manages only Organic Fraction of Waste Stream

Critical Path

The Corporation currently operates a 40,000 TPY aerobic windrow composting operation. Expanding or modifying this existing operation is unlikely to have any major time constraints. Because any expansion will likely occur over several years, the operation will have time to adjust as tonnages increase.

Mixed Waste Processing Facilities (MWPFs)

To help combat low public participation rates of traditional recycling programs and minimize collection costs, some communities are turning to MWPFs to either capture additional recyclables or as a pre-sorting operation prior to a more advanced conversion technology. A MWPF generally accepts unprocessed mixed waste, which is then mechanically processed to recover recyclables and sometimes organics. MWPFs utilize a series of magnets, eddy current separators, grates, optical scanners/sorters, pneumatic separators, and hand picking lines to process and separate; metals, aluminum, paper, plastic, cardboard and, in some facilities, organics. A MWPF can achieve up to 50% diversion if organics separation is included. However, these facilities are capital intensive, expensive to operate and are heavily dependent on the recycling markets to generate income from the sale of materials.

Newby Island Resource Recovery Park; San Jose, CA

Advantages:

- Accepts Unprocessed Wastes
- Can Manage Many Types of Waste
- Can Achieve up to 50% Diversion (if organics are separated)
- Compatible with AD and/or Co-Composting

Disadvantages:

- High Capital Cost, High Operating Cost
- Heavily Dependent on Currently Unstable Recyclables Market
- Mixed Results at Existing MWPFs

Critical Path:

Assuming a MWPF will be built on a portion of the existing Corporation property off the footprint of the landfill, it is estimated that a MWPF will likely take approximately 3-5 years to design, permit and construct.

Thermal Technologies

For the short-listed technologies, “thermal technologies” refers to Waste-to-Energy (WTE) facilities. WTE facilities accept and burn waste and utilize the heat developed to generate electricity which is sold for revenue. The process has matured since the 1970s type “incinerators” and new air pollution control (APCs) technologies have reduced the level of emissions dramatically. The process also reduces the waste required for disposal by approximately 75% by mass and 90% by volume. Development of a new WTE facility could provide 30-50 years of waste processing capacity and also may extend the life of the Central Landfill disposal capacity by a corresponding 30-50 years. However, WTE facilities do not manage all wastes. Wastes such as soils, C&D, and sludges must be pre-processed or managed separately. Capital and operational costs are high and the economics are heavily dependent on tipping fees and the revenue generated by the sale of electricity to the distribution grid. Currently, electricity prices are low due to inexpensive natural gas and oil prices, which make WTE uneconomical. However, if electricity prices increase even a small amount, the economics improve dramatically.

Durham Region Waste-to-Energy Facility; Ontario, Canada

Advantages:

- Long-Term Solution for MSW Disposal
- Electrical Generation as Revenue Stream
- 70-75% Reduction in Mass; 90% Reduction in Volume

Disadvantages:

- Requires Landfill for Ash for Disposal
- Electrical Revenues are Currently Low
- Controversial
- High Capital and Operational Cost
- Need to Amend Enabling Legislation

Critical Path:

The first hurdle in the development of a WTE facility in Rhode Island is to change the Corporation's enabling legislation. This will require an act of legislation. Once new legislation is enacted, the time to design, permit and build a WTE facility will likely take 10-12 years, depending on the level of public opposition.

Conclusions

This Study reviewed a large number of proven and emerging solid waste disposal technologies. The Corporation is currently in the enviable position of having as many as 16 years of capacity remaining within the Phase VI landfill cells which affords some time for further evaluation and discussion.

However, as indicated above, several of the short-listed technologies have a critical path that requires action as these alternatives may require 10-12 years to plan, design, permit and construct.

Currently, emerging technologies have not matured enough to offer a reliable solid waste solution for the Corporation and the State of Rhode Island. However, continuing to expand existing processes and diverting as much recyclable and organic material from the Central Landfill will serve to extend the lifespan of the landfill while the Corporation continues to investigate and monitor these technologies.

Presently, the solid waste industry seems to be favoring plans that co-locate several technologies and processes (and sometimes manufacturing facilities) at a single location. As an example, a single waste site might have a MWPF, an AD facility, a composting operation, and a transfer station. These types of facilities are sometimes called an “Eco-Park.” This type of system could allow the Corporation to continue to support municipal single stream recycling programs and the continued use of the existing MRF. If paired with an expanded aerobic windrow composting program for leaf and yard wastes and the addition of an AD facility to manage food wastes, the Corporation could increase diversion of recyclables and organic wastes. However, each of the processes mentioned have residual waste materials that will require the continued use of the Central Landfill.

At some point the Central Landfill will reach its ultimate final capacity and, by that time, an emerging technology may have proven itself at the capacity and reliability to install at a future Corporation facility. Given the extended design and permitting timelines, at the point when the Central Landfill has only 10-12 years of capacity remaining (2022-2024), the Corporation’s must make a decision regarding the future primary disposal technology for solid waste management in Rhode Island. It cannot be stressed enough that time is of the essence and the Corporation will need to make their first major decision within the next 4-6 years.

The table below summarizes all the short-listed technologies based on potential Tons per Day, Capital Cost, Cost per Ton; Advantages/Disadvantages, and Critical Path Time Frame.

Short-List Technologies Summary

Short-Listed Technology	Assumed Tonnage (TPD)	Capital Cost ($)	Total Net Cost per Ton ($/Ton)*	Advantages	Disadvantages	Time Frame
LANDFILLING						
Central Landfill Expansion	2,500	$33M - $130M	$35-$36	Can manage all waste streams; least cost option; allows for up-front recycling and/or separation	Not consistent with enabling legislation; existing permanent liability; continuing maintenance and monitoring; finite resource	5-7 Years
New Landfill	2,500	$48M - $190M	$37-$39	Can manage all waste streams; second least cost option; allows for up-front recycling and/or separation	Not consistent with enabling legislation; new permanent liability; continuing maintenance and monitoring; finite resource	10-12 Years

Short-Listed Technology	Assumed Tonnage (TPD)	Capital Cost ($)	Total Net Cost per Ton ($/Ton)*	Advantages	Disadvantages	Time Frame
TRANSFER STATION						
Rail Haul	1,000-3,800	$52M - $140M	$89-$100	Simple, low-tech proven technology; cost effective for hauls greater than 250 miles one-way; maintains disposal options; can manage all waste streams; allows for up-front recycling and/or separation	Off-site disposal likely still be a landfill; limited landfills that accept rail cars; additional emissions due to transportation; exposure to liability at disposal location; exposure to labor strikes and fuel price escalation	3-5 Years
BIOLOGICAL TREATMENT						
Composting/ Co-composting	130 - 260	$0-$500K	$18-$19	Proven low-tech option for managing leaf & yard waste; Corporation already has successful 40K TPY operation; can be expanded using same equipment; reduces volume; can sell final compost material; can be expanded to include food waste	Limited amount of leaf & yard waste available; requires large footprint; can be odorous and attract vectors if not operated correctly (particularly if co-composted with food waste);	1 Year
Anaerobic Digester	150 - 250	$25M - $38M	$90 - $101	Can manage most organics including food waste, manure, sludge, and other organic wastes; produces methane gas that can be utilized; proven technology; could be used in post-MWPF and/or with source separated organics; can produce an organic fertilizer as residual	High capital costs; high operating costs; highly technical operation that is easily upset; pre-processing of some waste required to remove non-digestible materials; processing and sale of residuals to make cost effective	2-3 Years
MECHANICAL SEPARATION						
Mixed Waste Processing Facility (MWPF)	1,000 - 2,500	$41M - $93M	$37-$39	Can divert up to 50% of waste materials if organics are targeted; no need for producers to separate recyclables; can sell recyclables to offset costs pairs well with anaerobic digestion	Heavily dependent on recyclables market for revenue; 50% residuals that need disposal; high capital cost; high operating cost; mixed success for existing facilities	3-5 Years

Short-Listed Technology	Assumed Tonnage (TPD)	Capital Cost ($)	Total Net Cost per Ton ($/Ton)*	Advantages	Disadvantages	Time Frame
WASTE-to-ENERGY						
Mass-Burn or Refuse Derived Fuel (RDF)	700 - 2,500	$275M - $980M	$110-$115	Manages all combustible waste streams; reduces volume by 90% and mass by 75%; produces electricity as sellable product; could be sited at Central Landfill; provides solution for 30-50 years	Does not manage all C&D and sludge materials; requires a landfill for ash disposal; low electrical rates make economics difficult; highest capital costs; highest operating costs; need to amend enabling legislation; controversial	10-12 Years

* Operational Net Cost/Ton - Includes potential revenues from electric sales, compost sales, or recyclables sales; does not include tip fees.

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Contents

Tables

Figures

1 Introduction

In May 2015, the Rhode Island State Planning Council issued “Solid Waste 2038” the “Rhode Island Comprehensive Solid Waste Management Plan (SWMP).” Intended to guide the solid waste management activities of the State of Rhode Island through the year 2038, the plan is due to be updated in 2020. In preparing for this update, the Corporation contracted with HDR Engineering Inc. (HDR) to identify the most promising long-term solid waste disposal alternatives, giving consideration to cost, risk, legislative requirements, and environmental impacts over a range of potential waste volumes. This resulting Long-Term Solid Waste Disposal Alternatives Study (Study) provides a high-level review and assessment of potential future solid waste disposal technologies that may be suitable for the Corporation to initiate, permit, and construct as it moves into the future.

1.1 Rhode Island Wastes

1.1.1 Waste Characterization Study

Rhode Island exercises state-wide flow control over all wastes managed by Rhode Island’s 39 Cities and Towns requiring them to deliver all wastes and paper and packaging recyclables to the Corporation’s Central Landfill in Johnston, RI. In Rhode Island, this municipal sector waste stream is primarily residential but can include municipal school wastes and other municipal office wastes that, in other states, are typically managed by private haulers and considered commercial waste. Private haulers manage most industrial/commercial/institutional (ICI) accounts which include some residential wastes from multi-family homes, subscription routes in rural areas, condominium complexes, mobile home parks and other residential developments. Collectively, this unique Rhode Island waste stream of municipal sector and ICI waste is referred to as Mixed Solid Waste (MSW).

In 2015, DSM Environmental, under contract with the Corporation, issued the Rhode Island Solid Waste Characterization Study – Final Report. The study sampling was completed over the course of four seasons from November 2014 to August 2015. The study sampled 248 residential and commercial waste loads. Each load was hand sorted into 70 material categories and each material category was weighed.

According to the DSM study, in 2015, the Corporation processed approximately 280,000 tons of municipal sector waste, 248,000 tons commercial sector, and 55,000 of bulky waste for a total of 583,000 tons of MSW. The balance of the total 1,048,000 tons managed by the Corporation in 2015 included approximately 196,000 tons of construction and demolition waste (C&D); 35,000 tons of “other waste”; and 233,000 tons of “special waste.” Other and special wastes include recycling process wastes, soils, sludge, and other aggregate wastes.

In addition to the 1,048,000 tons detailed above, in 2015 the Corporation also processed approximately 100,000 tons of single stream recyclables through the on-site materials recycling facility (MRF) and recovered approximately 85,000 tons of recyclables. The Corporation also diverted approximately 40,000 tons of leaf and yard waste through the on-site composting program. This brings the total materials managed by the Corporation in 2015 to an estimated 1,188,000 tons.

If on-site leaf and yard waste composting is added to the current diversion equation, the Corporation's estimated 2015 diversion rate was approximately 21.4% of the municipal and ICI sector waste stream. In addition, the Corporation estimates that another 30,000 tons of off-site leaf & yard waste composting is diverted by municipalities using their own forces.

1.1.2 Waste Sort Results

The DSM study found that the waste delivered to the Central Landfill is relatively typical in composition to other waste streams in New England that DSM has characterized, such as Vermont (2012), Connecticut (2010), and Delaware (2007). On the positive side the DSM study concluded that RI is doing well with recycling in certain arenas such as municipal recyclables, and that significant opportunities exist for further diverting materials from disposal in others. For example:

1) An estimated 56% of all waste delivered to the Central Landfill for disposal was MSW and Bulky Waste (~580,000 tons);
2) Rhode Island is doing a "very good job" diverting municipal recyclables (approximately 85,000 tons of single stream recyclables (SSR) and 40,000 tons of leaf & yard waste were diverted from residential wastes;
3) Commercial customers do not appear to be doing as effective a job at diverting potential recyclables. Potentially 27% (66,300 tons) of the ICI waste stream is material that can be processed at the RIRRC MRF, primarily cardboard.
4) Food waste is the waste category with the largest potential for increased diversion to composting and/or aerobic or anaerobic digesters. According to the report, *"The largest single waste material in the residential waste stream is vegetative food waste, followed in 3rd and 4th place by leaf and yard debris and 'compostable paper', which combined represent 90,000 tons (rounded) of the total of 279,795 tons of municipal sector waste."* This equates to approximately 32% of the total municipal disposal.

Perhaps more importantly in this investigation of potential future waste disposal alternatives, the DSM study estimated that at least 179,000 tons or 34% of the ~580,000 tons of municipal and commercial mixed solid waste that was assessed is true trash that will continue to require a permanent disposal alternative moving into the future. In addition, there is an unknown percentage of the remaining 464,000 tons of other C&D and special wastes that were not characterized that will also require some level of permanent disposal. The complete 2015 DSM report can be downloaded at the Corporation's website @ http://www.rirrc.org/sites/default/files/2017-02/Waste%20Characterization%20Study%202015.pdf

1.2 Average Waste Generation Rates

According to the U.S. Census Bureau, the 2015 Rhode Island population was 1,056,298. According to the U.S. EPA 2014 Sustainable Materials Management (SMM) Fact Sheet, the average American produced 4.4 lbs. of waste per day in 2014. This estimate includes household and commercial wastes but does not include industrial waste, hazardous waste, or construction waste.(1) The math suggests that Rhode Island should produce about 848,207 tons per year of total waste. This estimate is about 20% below the total 2015 tonnage managed by the Corporation. However, the Central Landfill's 2015 tonnage includes approximately 200,000 tons of soils and sludges that are not readily accounted for in the U.S. EPA average. If that is taken into account, the 2015 total tonnage is close to the expected 2014 U.S. EPA average.

A 2008 Biocycle study "The State of Garbage in America" provides both population data and MSW tonnage data by state. HDR used the New England states data and estimated that New Englander's produce 1.128 tons/year/person. Using the 2015 Rhode Island population, this equates to 1,191,504 tons of waste produced annually. If recyclables and leaf and yard waste are added to the Corporation's 2015 tonnage, the tonnage managed is very close to the Biocycle New England average.

The Corporation estimates that private haulers operating in Rhode Island ship approximately 150,000 tons of waste out-of-state each year for disposal or processing. There is also a significant separation and recycling activity within the private sector, which is either managed in-state by private recycling brokers, or shipped out-of-state for further processing.

Based on these sources it seems that 2015 tonnages reported by the Corporation and the DSM report are reasonably consistent with New England averages. The 2015 tonnage disposed of (1,048,000 tons) will be used as a "base year" tonnage for this study.

1.3 Rates and Fee Structure Summary

The FY2018 (July 1, 2017 through June 30, 2018) rate sheet breaks down disposal costs/tip fees by commercial and municipal sectors and by specialty wastes. A summary of these is as follows:

Waste Type	Rate ($)	Notes
Commercial Wastes	$90/ton	Non-Contract Rate
	$55 - $82/ton	Dependent on contract waste amounts and eligibility
	$65/ton	Average Commercial Rate
Municipal Wastes	$39.50/ton	Municipal Waste (under cap)
Sludge	$110/ton	

The full FY 2018 rate sheet is included as Appendix A. It should be noted that in FY 2019 the Municipal Waste rate will increase to $47.00/ton and the average commercial rate will increase to $80.00/ton.

1.3.1 Landfill Economics

Currently, the costs for the Central Landfill are largely covered by the tip fees generated by the commercial waste sector, which subsidize the municipal sector fees. Without charging the commercial sector an average of $65+/ton for solid waste, C&D, soils, and sludges, the current municipal rate of $39.50/ton would likely have to increase. Municipal customer tipping rates are set by the Corporation based on projected cash requirements established in an adopted administrative rule included in the Corporation's Enabling Legislation. Commercial rates are set by the Corporation to market rates with the objective of meeting annual target disposal volumes.

The State has enacted flow control for municipal sector wastes (explained further in Section 1.5 below), which results in the disposal of almost all residential waste produced in Rhode Island at the Central Landfill. Commercial waste is currently not subject to flow control, although the governing statute leaves that possibility open to the Corporation. To control commercial waste flow, the Corporation occasionally increases the commercial tipping fee rates to reduce demand and limit the amount of commercial waste delivered to the landfill and reserve long-term capacity for residential wastes. The Corporation attempts to set the commercial tipping fee at a level that will keep the total tonnage of commercial and residential waste to about 750,000 tons per year, as recommended in

Solid Waste 2038. In 2017, in an attempt to reduce the amount of commercial disposal, the Corporation increased commercial tipping fees which raised the average fee from $60/ton to $65/ton. Thus far, this increase has not had any significant impact on the commercial disposal rate. In response to this, in FY2019 the Corporation will initiate a more aggressive increase of $15.00/ton across all commercial tipping rates bringing the average commercial rate to $80.00/ton.

It should also be noted that out-of-state (OOS) waste, both residential and commercial, is prohibited at the Central Landfill.

1.4 Enabling Legislation and Other Regulations

In 1974, the State of Rhode Island adopted the Corporation's Enabling Legislation. Below are excerpts from the Enabling Legislation and current Rhode Island Solid Waste Regulations. While most of the legislation speaks in general terms about the content of the SWMP and the Corporation's responsibilities, several clauses directly impact the SWMP and its contents.

1.4.1 Enabling Legislation - § 23-19-2 Legislative Findings:

The following subsections provide general statements regarding the Corporation's policies, responsibilities, and goals:

> *(8) Provision for necessary, cost-efficient, and environmentally sound systems, facilities, technology, and services for solid-waste management and resource recovery is a matter of important public interest and concern, and action taken in this regard will be for a public purpose and will benefit the public welfare;*
>
> *(9) The landfill disposal of solid waste, even under the most ideal conditions, creates a long-term potential for pollution and environmental degradation;*
>
> *(10) Recycling facilities must be integrated into the development of all solid-waste-disposal facilities under the jurisdiction of the Rhode Island resource recovery corporation;*
>
> *11) The Central Landfill is a public resource of limited and finite capacity that the state, as guardian and trustee for its people, has the right and the obligation to preserve for the use of its people;*
>
> *(12) The state, by creating the Rhode Island Resource Recovery Corporation and through it operating the Central Landfill, is a participant in the landfill services market and has entered that market for the purpose of serving the citizens, residents, and municipalities of this state; and*
>
> *13) Solid-waste diversion is necessary and therefore it is the policy goal of the state that not less than fifty percent (50%) of the solid waste generated be diverted through diversion, source reduction, re-use, recycling, or composting by 2025.*

1.4.2 Enabling Legislation - § 23-19-3 Declaration of Policy.

The subsections below provide a framework for the Corporation's SWMP:

> *(1) That the ultimate solid waste management objective of the state is to maximize recycling and reuse of solid waste;*

(5) That private industry be encouraged to continue playing a key role in the state's solid waste management programs;

(9) The creation, licensing, and operation of landfill solid waste disposal facilities should be limited to what is reasonably required to service the needs of the inhabitants and businesses of this state, having regard for alternative technologies for waste disposal;

(12) That the central landfill should be reserved for the disposal of solid waste generated within the state;

(14) That due to the myriad of over four hundred (400) toxic pollutants including lead, mercury, dioxins, and acid gasses known to be emitted by solid waste incinerators, the known and unknown threats posed by solid waste incinerators to the health and safety of Rhode Islanders, particularly children, along with the known and unknown threats to the environment are unacceptable.

(15) That despite the use of state of the art landfill liner systems and leachate collection systems, landfills, and particularly incinerator ash landfills, release toxic leachate into ground and surface waters which poses an unacceptable threat to public health, the environment, and the state's limited ground and surface water resources.

(16) That incineration of solid waste is the most costly method of waste disposal with known and unknown escalating costs that would place substantial and unreasonable burdens on both state and municipal budgets to the point of seriously jeopardizing the public's interest.

1.4.3 Enabling Legislation - § 23-19-11 Planning Requirements.

The subsections below state the requirements for the SWMP:

(4) In developing the plan, the corporation will assure that:

(i) The orderly extension of future solid waste facilities and management systems are provided for in a manner consistent with the needs and plans of the whole area, and in a manner consistent with the state departments of health and environmental management rules and regulations for locating and operating solid waste facilities;

(ii) All aspects of planning, zoning, population estimates, engineering, and economics are taken into consideration to delineate with all practical precision those portions of the area which may reasonably be expected to be served by a given time frame, as determined by the corporation;

(iii) Appropriate time schedules are set for the phasing in of the required component parts of the system.

(iv) Future solid waste disposal facilities shall be regional in size and emphasize the geographic and political nature of the surrounding area.

(7) The plan shall not include incineration of solid waste.

(8) The plan shall limit the use of landfills to providing temporary backup or bypass disposal capacity and residue disposals from waste processing facilities. The plan shall also seek to minimize landfilling of any type of waste and phase out the use of landfills for waste disposal.

1.4.4 Enabling Legislation – Summary

Based on the Corporation's Enabling Legislation, it is recognized that the state is striving to reduce, reuse and recycle to the extent practical (a minimum of 50% by 2025), reserve landfill space as a last resort for waste disposal, and eventually phase out the use of landfilling.

While the Corporation has always taken steps to meet the legislative standards set in 1974 and subsequent revisions, it should be recognized that technologies have developed over the last 44 years that have significantly reduced the environmental and health risks associated with various traditional disposal and conversion technologies. The enabling legislation also ignores new and emerging technologies that continue to be developed and tested.
The enabling legislation clearly indicates that "incineration" of solid waste is not permitted – based on the language and the era in which it was written, it is assumed that this means what is now referred to as "mass burn" facilities which encompasses most of the modern Waste-to-Energy (WTE) technologies. It is also assumed that to construct any type of future WTE technology will require legislative action to lift the "incineration" restriction.

1.5 Flow Control

Flow control, as it relates to solid wastes, means that local, or State, governments can require that wastes produced and collected within their jurisdiction be delivered to a local, or State, owned solid waste facility.

1.5.1 § 23-19-13 Municipal Participation in State Program

(a)(1) Any person or municipality which intends to transfer, treat, or dispose of solid waste originating or collected within the state, or which intends to make arrangements to do so, shall utilize, exclusively, a system or facility designated by the Corporation as provided under this chapter.

(2)(c) Municipalities, along with private producers of waste which contract with the Corporation for disposal of their wastes, shall continue to be free to make their own arrangements for collection of wastes at the source and/or the hauling of wastes to the designated processing and/or transfer stations, so long as those arrangements are in compliance with the provisions of Chapter 18.9 (Refuse Disposal) of this title and with this chapter, and any municipal license relating thereto.

1.5.2 U.S. Supreme Court Ruling

In 2007, the U.S. Supreme Court upheld the right of local governments to direct the flow of solid waste to publicly owned waste facilities without violating the Commerce Clause (United Haulers Association, Inc. v. Oneida-Herkimer Solid Waste Management Authority (Case No. 05-1345, released April 30, 2007)). This landmark solid waste case essentially allows counties (or states) to adopt a local "flow control" ordinance requiring locally-produced wastes to be delivered to local publicly-owned facilities.

In Rhode Island, flow control is currently being exercised over the municipally managed wastes only. However, most commercially collected waste is also delivered to the Central Landfill for economic reasons. The Corporation estimates that approximately 150,000 TPY of commercial waste is being diverted to out-of-state disposal or processing facilities.

1.6 Population

In April 2013, the RI Division of Planning issued a report entitled "Rhode Island Population Projections 2010-2040." The report stated, "The projections suggest that Rhode Island will continue to have very slow population growth through 2020 due to negative net migration, return to higher rates of net migration and population growth through the 2030s, at which point the growing number of older residents will again cause slight decline in the state's population."(2)

According to the U.S. Census, the estimated 2015 Rhode Island population was 1,056,298; the 2010 population was estimated to be 1,052,931 or a 0.3% increase over 5 years.(3)

Based on these sources, it is reasonable to assume a relatively flat population curve over the next 10-30 years.

In addition, according to the United States Environmental Protection Agency (USEPA), municipal solid waste generation has not returned to pre-recession (2008) levels and has plateaued over the past 5-years.(4) This is typically attributed to increases in recycling, packaging reductions to reduce shipping costs, and an overall reduction in paper products due to electronic/on-line information sources (newspapers; e-mail; website catalogs; etc.).(5)

Because of the flat population growth and waste generation stream, for the purposes of this report, it is assumed that the long-term waste generation rate will remain constant over the next SWMP update period (2020 – 2040).

1.7 Industry Trends

Trends in solid waste in New England over the past 5-10 years have been focused on:

1) Organics/Food Waste Management (Separation, Collection, Processing, and Anaerobic Digestion)
2) Zero-Waste to Landfill (Product Stewardship; Education; Reuse, Reduce, Recycling; Organics Management)
3) Advanced Processing/Separation of Traditional Recyclables (Material Recycling Facilities (MRFs) and Mixed Waste Processing Facilities(MWPF))
4) Emerging Technologies (Gasification, Plasma Arc Gasification, Pyrolysis, Depolymerization, Hydrolysis, etc.)
5) Long Distance Hauling (Truck or Rail)

Many states have enacted diversion goals to help drive advanced recycling efforts and divert waste away from landfills, or in some states, mass-burn facilities. Rhode Island has adopted a goal to achieve 50% diversion from landfilling by 2025. It should be noted that even with the best available operations, facilities, technologies, and regulatory requirements, there will be some fraction of the waste stream that will need to be further processed, utilized, or landfilled.

In the next section, HDR will identify and evaluate a suite of traditional solid waste management processes along with several emerging technologies that either alone or use in concert can help to reach the State's 50% recycling/diversion goal by 2025 and also extend the useful life of the planned Phase VI landfill expansion past the current 2034 useful life estimate.

1.8 Market Trends

Over the past several years the market trends in New England have not been favorable for recycling or disposal. Below is a summary of the recycling and tipping fee trends over the past several years.

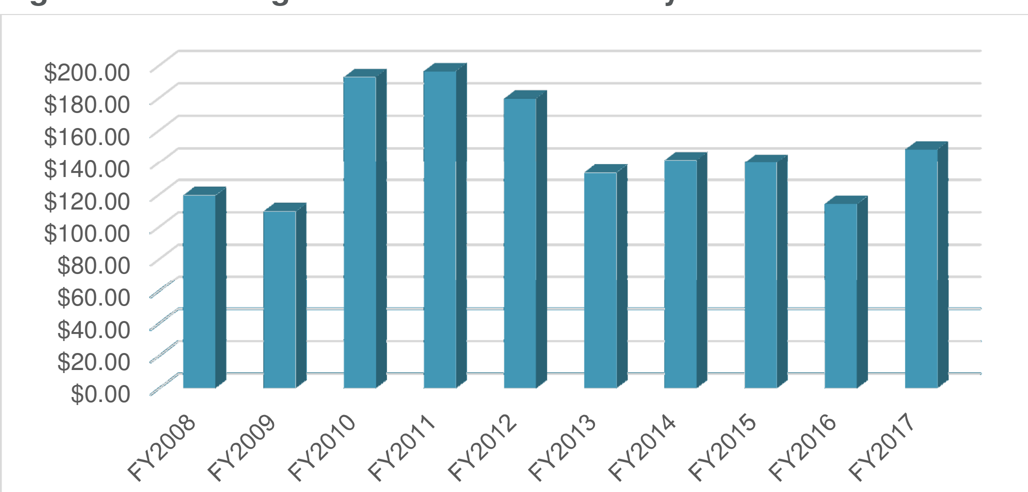
1.8.1 Recycling Trends

Many municipalities across the United States are attempting to increase collection efficiencies by implementing single stream recycling (SSR) programs, or converting existing dual stream recycling programs to SSR. SSR improves curbside recycling collection efficiencies by enabling automated collection and by reducing the number of trucks needed for collection as all materials can be collected by a single truck. However, SSR typically results in higher contamination and process residuals. The Northeast leads the country insofar as 85% of the population has access to curbside recycling, and the Northeast typically has a higher density of population as compared to the mid-west and west.[(6)]

The Northeast states are also leaders in deposit systems of beverage containers. Six of the ten Northeast states have enacted deposit systems (Rhode Island and New Hampshire do not have a deposit program); whereas only two Midwest states and two Western states have deposit programs, and no Southern states have deposit programs.

Once collected and sorted into different commodities, recyclables need a market for end processors to purchase the materials and ultimately recycle them into new products or uses. Historically, recycled commodity markets have been quite volatile. The recyclables market has been sluggish over the past 5 years (see Figure 1-1: Average Price for Curbside Recycled Commodities).

Figure 1-1: Average Price for Curbside Recycled Commodities



Source: Rhode Island Resource Recovery Corporation Facility Materials Recycling Facility, December 2017

Price decreases after 2011 are usually attributed to contamination issues for curbside recyclables; increased scrutiny of quality by end users (especially China's imposition of a "green fence" to reject poor quality materials produced by material recovery facilities in the US); and decreases in the price of oil.

In July 2017, China announced its "National Sword" program which will further restrict recyclable materials from entering that country. The program bans 24 additional materials and requires recyclables to meet a 0.5% contamination rate. Shipment containers that fail to meet the new contamination levels will be rejected and the entire container sent back.

Between March and November of 2017 the Corporation's Materials Recycling Facility (MRF) experienced average commodity prices of $111.68/ton for fiber; $406.09/ton for metals; and $317.40/ton for Plastics. Currently, glass is, for all intents and purposes, unsellable in any form. As a result of the National Sword program, as of March 2018, the Corporation is now paying fiber processors to accept mixed paper when it has historically been paid for that material. The Corporation has previously weathered normal market volatility; however, the China program is a new, not fully understood, factor impacting today's recyclables market.

1.8.2 New England Tipping/Disposal Fee Trends

Landfill tipping fees for MSW across southern New England range from $60 to $75/ton. Prices for long-term disposal guaranteed tonnages can typically be negotiated lower given a large guaranteed annual tonnage delivered.

Tipping fees at New England waste-to-energy facilities are also hovering around $75/ton. In 2017, one regional waste authority in Connecticut negotiated a three-year contract at a waste-to-energy facility for about $92/ton that adjusts down to $82/ton after the first year.

While waste tonnage generated has leveled off since the "Great Recession of 2008", the amount of New England regional waste disposal capacity continues to decrease with the closure of landfills and waste-to-energy plants. Connecticut has one (1) active MSW landfill (a small town landfill in South Windsor, CT) and five (5) waste-to-energy facilities after the closing of the Wallingford Waste-to-Energy plant. Connecticut currently exports a small amount of waste. Massachusetts is already a large exporter of waste and with the Southbridge, Chicopee, and Taunton landfills closing within the next 3-years, the export tonnages will continue to grow. New Hampshire's Turnkey Landfill is currently permitted until 2025. If Turnkey closes, over 1,000,000 tons of annual landfill capacity will be lost. Furthermore, while horizontal and vertical landfill expansions have been approved at existing landfill sites (typically after a long and arduous permitting path), a new "green field" landfill has not been approved in Connecticut, Massachusetts, or Rhode Island since 1995 (Crapo Hill Landfill).

In an open market situation, a flat waste generation curve and decreasing disposal supply will cause an increase in demand for waste disposal in the region. This increase in demand will likely result in increased disposal fees. It is likely that tipping fees at landfills and waste-to-energy facilities will be moving towards the $100/ton level as landfill space decreases. This will make long distance hauling to landfills in NY, PA, VA and OH more cost competitive.

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2 Overview of Available Technologies

The following chapter provides an overview of the broad spectrum of waste disposal/processing technologies available to the Corporation. The resulting “long-list” of potential alternatives includes both traditional and emerging technologies.

2.1 Landfilling

Landfilling of solid waste is the most common method of disposal in North America. The Corporation owns and operates the Central Landfill in Johnston, Rhode Island where over 1,000,000 tons of MSW, C&D, soils, and sludges are deposited each year. Landfilling involves the placement of waste into lined and capped cells which provide hydraulic isolation as well as preventing the uncontrolled migration of gases which are created during the decomposition process.

For purposes of this assessment, landfilling is considered an established disposal technology, and it is assumed that continued landfilling at the Central Landfill is a viable economic option that will proceed as permitted. We note however that the major motivation for this effort is the fact that the permitted capacity of the Central Landfill is limited and that the Corporation and the State will soon need to decide how it will dispose of its wastes beyond the currently projected Central Landfill Phase VI closure date of 2034. Options include investigating the possibility of further expansion of the Central Landfill beyond Phase VI, the development of a new landfill elsewhere in Rhode Island, or hauling the State’s wastes long distances for permanent disposal at out-of-state landfill facilities.

2.1.1 Liner Systems

In Rhode Island all new landfills and all lateral expansions to existing landfills that receive waste are required to have double composite liners installed prior to the placement of waste. The double composite liner system must include a primary leachate collection and removal system consisting of a 24-inch granular soil layer with a leachate collection pipe network. The primary leachate collection and removal system lies above the primary (upper) composite liner. The primary composite liner consists of a geomembrane that directly overlays an 18 inch low permeability soil layer. The primary composite liner lies above the secondary leachate collection and removal system. The secondary leachate collection and removal system consists of either a leachate collection pipe network with a 12-inch granular soil layer, or an effective layer of geosynthetic material. The secondary leachate collection and removal system lies above the secondary (lower) composite liner, which consists of a geomembrane that directly overlays a 24-inch low permeability soil layer. Regulations require that the primary liners be a minimum of 45-mil and the secondary liner be a minimum of 36-mil (minimum 80-mil and 60-mil, respectively, if an HDPE liner).

The liner system must be installed above the uppermost in-situ soil layer or select fill that must be graded and prepared for landfill construction. A foundation analysis must be performed to determine the structural integrity of the subgrade to support the loads and stresses imposed by the weight of the landfill and to support overlying facility components. Rhode Island regulations require a minimum 5-foot separation between the seasonal high groundwater elevation and the bottom most elevation of the liner system.

2.1.2 Leachate Collection and Removal Systems

State and federal regulations require new landfills and lateral expansions for all landfills to include a leachate collection system that prevents leachate from accumulating on the liner to a depth of more than 30 centimeters (1-foot), so that it does not pose a danger of leaking into the ground water. Currently, leachate is collected and conveyed to on-site storage tanks. The leachate is treated at the on-site leachate treatment facility prior to being directed to the Narragansett Bay Commission (NBC) sewer system for final treatment and discharge.

2.1.3 Landfill Gas Generation and Collection Systems

Landfill gas (LFG) is generated as the organic material in the landfill decomposes. The amount and composition of the LFG produced varies greatly according to the characteristics of the waste placed in the landfill and the climate at the landfill location. Factors that have the greatest impact on the LFG produced include waste composition (e.g., organic content, age), oxygen levels, and moisture content and temperature, which can be influenced by climate. Landfill gas is typically 50% methane and 50% carbon dioxide and water vapor, by volume. Trace amounts of nitrogen, oxygen, hydrogen, non-methane organic compounds (NMOCs), and inorganic compounds are also present. Some of these compounds are the source of odors. Emissions can be reduced through the installation of an efficient landfill gas collection system, and then flaring the LFG or combusting it to produce energy.

The Corporation has a long-term contract with Broadrock Gas Services, LLC (Broadrock) who has exclusive rights to all of the current landfill gas. Broadrock is responsible for construction and maintenance of the landfill gas collection system. The revised methane gas royalty agreement expires when the operation of the gas collection facility to generate power is no longer economically feasible to continue. Since landfill gas rights are already under contract to Broadrock, this report does not go into detail about landfill gas or future landfill gas management and use options.

2.1.4 Analysis

Landfilling is a very well demonstrated and commercially viable technology for waste disposal. Landfills of various sizes are currently operating in the U.S. and throughout the world. The most beneficial aspect of a landfill is that it can accept for disposal any regulated material that cannot be converted, recovered or reused by another technology, and can produce LFG to be collected and utilized from the organic portion of the waste. In addition, potential local benefits include the creation of construction jobs during the construction period and a number of permanent jobs, depending on the size of the landfill. Drawbacks include the space utilized for a landfill, a lost opportunity to convert the waste into energy or a usable product, its non-aesthetic nature, leachate and gas by-products, potential for odors and leaks into the local water tables, and difficulty in siting new facilities.

The existing Central Landfill is a finite resource and will eventually reach capacity. Given that all of the potential solid waste management options do require some level of landfill disposal, alternative landfill disposal sites will need to be utilized, either in-state and run by the Corporation or out-of-state under agreement with another landfill operator.

2.1.5 Costs

Overall, landfilling is considered the most cost effective disposal method for solid waste in the United States. However, new landfill construction has been restricted in New England by regulatory hurdles, bans, and public opposition to siting new landfill facilities. With the exception of horizontal and vertical expansions of existing landfills, there has not been a new "greenfield" MSW landfill opened in any New England state since 1995.

The Corporation's tipping fees are structured to charge the commercial sector the full market rate, currently an average of about $65/ton. In FY2019, the Corporation will charge municipal accounts a tipping fee of $47/ton. The higher commercial rate allows the Corporation to subsidize the residential tipping fee. Overall operational costs for the landfill are estimated at $30/ton (this cost is strictly for landfill operation). Recyclables are accepted free of charge and delivered to the MRF for processing and sale.

2.2 Transfer Station and Long Distance Waste Disposal

2.2.1 Rail Haul

On the east coast of the United States, most Class I rail freight service is provided by the "major railroad" carriers CSX Corporation (CSX) and Norfolk Southern Corporation (NS). However, neither CSX nor NS own rail lines within Rhode Island. To connect to these major railroads, a freight operation must coordinate with the "regional railroad." In Rhode Island, the regional railroad is the Providence-Worcester Railroad (P&W). The regional railroad coordinates with the major railroads to schedule freight cars on and off the major railroad lines to allow for the efficient transportation of goods across the country. The P&W also serves as the "switching railroad" that connects freight to the CSX railroad in Worcester, MA and the NS railroad in Carver, MA.

There are two (2) main ways to arrange rail transportation of solid wastes:

1) Direct Rail Transportation – an example of this would be a transfer station that can directly load waste into gondola cars or intermodal containers and connect directly to the P&W regional rail service line via an on-site rail spur. A gondola car can hold approximately 100 tons of waste; each flatbed rail car can hold 4 intermodal containers and can manage about 88 tons of waste.

2) Indirect Rail Transportation – an example of this system is a transfer station that can compact waste into an intermodal container which is then hauled via truck to a rail "freight intermodal facility" where the intermodal containers are lifted off the truck and placed onto a flatbed rail car. Each flatbed rail car can hold 4 intermodal containers, allowing each flatbed railcar can to manage about 88 tons of waste. This indirect method requires an additional step of trucking the intermodal container to the intermodal rail facility, increasing costs.

There is a third option that is becoming more common which is the shipment of bailed waste on flatbed trucks and rail cars. This method can help reduce transportation costs by providing the truck or rail company with the ability to backhaul other goods on the return trip. However, these cost savings need to be weighed against the additional costs incurred to bale the waste at the transfer station to the specifications and requirements of the haulers. In addition, based on conversations with transfer station operators, currently there is a shortage of trucks/truckers willing to haul baled waste.

Construction and Demolition (C&D) waste is currently being shipped from New England states to Ohio for disposal in gondola railcars. While shipping C&D is regulated, there are different standards for shipping putrescible wastes versus non-putrescible wastes (such as C&D). Putrescible wastes are normally required by either the State or by the railroads themselves to be shipped in sealed containers. This added cost is assumed by the shipper, not the railroad.

Examples of sealed containers include intermodal containers or Gondola cars with bolt on tops, or recently CSX was requiring MSW to be baled and wrapped in plastic and arranged in open gondola cars and topped with 12-inches of crushed C&D for cover. Most MSW being shipped by rail in the northeast is shipped in intermodal containers with bolt on tops. These containers can manage 22 tons/container and each flatbed rail car can manage 4 containers each.

2.2.1.1 Analysis

Nationwide, hauling waste in transfer trailers is typically the most cost effective option for haul distances in the range of 15 to 250 miles. However, the 250 mile upper limit can be highly variable and factors such as labor and operation and maintenance (O&M) costs, payload limits, and travel routes can increase or decrease this range. Assuming waste is being hauled from a transfer station with rail access, these factors need to be compared against the costs associated with hauling waste by rail, which can include dray charges (explained later in this section), capital costs to purchase the necessary quantity of gondola or intermodal containers, and other rail service charges.

Taking these factors into account, rail transportation typically becomes cost effective when distances exceed a 250 mile one-way threshold (500-miles round trip). Rail is almost always more cost effective for hauls in the 600 mile range (one-way). (Reference - Rail Haul Opportunities – an extract report as prepared by Malcolm Pirnie, Inc. for the City of New Haven – January 2008). The difference in cost between operations using intermodal containers versus gondola cars depends on existing infrastructure and proximity to freight intermodal facilities.

Other benefits of rail hauling include an increase in tonnage per vessel. The typical gondola car has a shipping capacity of approximately 100-tons (134 tons is the maximum per car weight – the car itself weighs about 30 tons). Rail is also considered safer than truck transport in terms of collisions per mile travelled. On average rail has an efficiency of 400 ton-miles per gallon whereas tractor trailers are currently around 130 ton-miles per gallon. The main downside to rail is the lack of timely transport, which can be a critical factor when dealing with waste that can develop odor issues if left in long-term storage and delays that can impact the supply of available empty freight cars.[(7)]

2.2.1.2 Costs

In 2016, HDR estimated truck hauling charges for a trailer hauling 22 tons of trash at $2.25/mile 250 miles one-way to be $25.57/ton. HDR estimated truck hauling charges for a trailer hauling 22 tons of trash 500 miles one-way to be $51.14/ton. However, when hauling MSW, the mileage must account for the round trip as most MSW tractor trailer do not/cannot carry a paid return load; so the rates estimated above would double to $51.14/ton and $102.28/ton, for a round trip haul of 250 miles and 500 miles, respectively.

Rail costs are different. Much of the cost of rail hauling is incurred getting the waste material onto the rail car and connected to a rail long-line, after those costs are incurred, the costs for hauling the waste between 250 and 1,000 miles becomes progressively cheaper by the mile.

HDR's review of a recent rail haul contract to rail haul salt from ProvPort, RI to Fall River, MA (about a 20-mile haul) found that a loaded gondola car (about 100 net tons of salt) cost $2,000 per railcar. This equates to approximately $20/ton or $1.00 per ton mile.

Based on discussions with rail professionals, the estimated cost to haul a 100 ton open gondola car from the northeast United States to a landfill in Ohio (about 750 miles one way) is estimated to be approximately $4,000, or about $40/ton or about $0.05/ton mile. Using four (4) 22-ton intermodal containers on a flat bed rail car raises this cost to about $45.45/ton or about $0.06/ton mile.

Based on HDR's review of recent long haul rail haul contracts, a "rule of thumb" budgetary cost estimate for rail haul is $0.05 - $0.10 per ton mile depending on guaranteed tonnages, contract duration, car/container load density, and distance hauled. This is strictly for rail hauling and does not include transload costs, dray, or disposal costs.

The drayage is the cost to manage the cargo while on railroad property, i.e. from where the shipper drops off the cargo to where the customer picks it up. There is typically a front drayage charge and back drayage charge. The front dray will include the lifting of intermodal containers off trucks and onto rail cars and the back dray will include the lifting of the intermodal off the railcar and onto a truck. However, hauling waste from a transfer station to the rail facility and from the rail facility to a landfill would be in addition to the drayage.

Ideally, waste is transferred directly into gondola cars at a transfer facility with direct rail line access and is shipped via rail to a landfill with direct rail line access that can off-load gondola cars. This type of process eliminates many dray charges and hauling fees.

It should be noted that coordination with short and long line railroads can be difficult. There are brokers who specialize in rail haul coordination can be used to help smooth out the process at an added expense.

2.3 Organics Management

Organics are being touted more and more as the "low hanging fruit" for increasing diversion of the waste stream. Most nationwide waste characterization studies emphasize that about 30% of the mixed solid waste stream (by weight) is organic and could be separated and either composted or digested. According to the 2015 DSM study, Rhode Island waste disposed of by the municipal sector consists of 17.1% food waste, 7.8% leaf and yard waste, and 7.3% compostable paper. These three (3) categories make up 32.2% of the residential waste stream or about 100,000 TPY. If commercial ICI accounts are included, another 63,000 TPY could be diverted. In summary, about one-third of the mixed solid waste stream is organic material that could potentially be composted or digested. In addition, the Corporation also accepts about 20,000 TPY of biosolids that may also be composted or digested.

RI Gen. Law § 23-18.9-17 – Food Waste Ban

> *(a) On and after January 1, 2016, each covered entity and each covered educational institution shall ensure that the organic waste materials that are generated by the covered*

entity or at the covered educational facility are recycled at an authorized, composting facility or anaerobic digestion facility or by another authorized recycling method if:

(1) The covered entity or covered educational facility generates not less than one hundred four (104) tons per year of organic waste material; and

(2) The covered entity or covered educational facility is located not more than fifteen (15) miles from an authorized composting facility or anaerobic digestion facility with available capacity to accept such material.

(b) A covered entity or covered educational institution may petition the department for a waiver of the requirements of subsection (a) of this section if the tipping fee charged by the Rhode Island resource recovery corporation for non-contract commercial sector waste is less than the fee charged by each composting facility or anaerobic digestion facility located within fifteen (15) miles of the covered entity's location.

2.3.1 Aerobic Composting

Aerobic composting is a biochemical process that stabilizes the putrescible fraction of an organic material under controlled conditions. It is a naturally occurring process that breaks down organic material into humus. Composting is typically performed aerobically in a moist environment. The process generates heat and CO_2. The process must be managed to keep it within an ideal temperature range to allow bacteria to work most effectively and to sterilize undesirable organisms. Composting technologies can use a building or other structure, or the raw material can be placed outdoors in windrows or piles. The process also requires a way to control the moisture content and periodically turn the material. Generally, composting can be performed in-vessel or in the open-air, and is typically used for the "green waste" portions of the waste stream only.

Aerobic composting can include a number of different processes, however the two most common are aerobic windrow composting and forced aerated static pile composting. The Corporation currently uses aerobic windrow composting to process approximately 40,000 tons per year of leaf and yard waste at the Central Landfill. Because it is assumed that the Corporation will continue to use the ongoing source separated leaf and yard waste windrow composting operation, this report concentrates on windrow style composting.

Aerobic windrow composting is typically used with source separated yard waste. However, it can be expanded to include most of the organic fraction of the waste stream and, more specifically, source separated organics such as food waste. The process known as co-composting uses leaf and yard wastes, wood chips, food waste, waste papers, other organic portions of the MSW waste stream separated by a processing facility such as a MWPF or source separated. The process can also include waste water treatment biosolids. The organic waste materials are placed in elongated piles called windrows that are aerated naturally through a "chimney effect," and/or aerated mechanically by physically turning the windrows with a machine. In some cases the windrows are pierced with air lances to improve porosity and promote aeration. Frequent turning of the pile introduces oxygen, accelerates physical degradation of feedstock and provides an opportunity to adjust the moisture content to the optimum level. This technology is particularly odorous if food waste and/or biosolids are included in the feedstock. The average time required for active aerated composting is 8 to 12 weeks.

Figure 2-1: Windrow Aerobic Composting Facility

Rhode Island Active Composting Facilities

The following is a list of active composing facilities in Rhode Island from the RIDEM website.

RIDEM – Regulation No. 8 "Waste Composting Facilities" (2016)

- Barrington Compost Facility, Wampanoag Trail, Barrington
- Burrillville Compost Facility, Whipple Avenue, Burrillville
- Charlestown Compost Facility, Sand Hill Road, Charlestown
- East Providence Facility, Forbes Street, East Providence
- Jamestown Compost Facility, North Road, Jamestown
- RIRRC, Johnston Central Landfill, Shun Pike, Johnston
- North Kingstown Compost Facility, 345 Devil's Foot Road, North Kingstown
- Pawtucket Compost Facility, 240 Grotto Avenue, Pawtucket
- Donnigan Park LLC, 100 Amherst Street, Providence
- Providence Swan Point Cemetery, 535 Blackstone Blvd, Providence
- Smithfield Peat Compost Facility, 295 Washington Highway, Tiverton
- DeMelio Home and Site, 1041 Old Stafford Road, Tiverton
- Site-Ready Materials + Recycling, 322 Eagleville Road, Tiverton
- Warren Compost Facility, 21 Birch Swamp Road, Warren
- Warwick Compost Facility & Manufacturing, Range Road, Warwick

Other Facilities that Accept Food Waste (2017)

There are only two facilities in Rhode Island that accept or collect food waste for composting:

- Earth Care Farm, 89A Country Drive, Charlestown
- The Compost Plant, Warren

2.3.1.3 Analysis

Windrow composting is used by most communities and commercial operations throughout the United States for composting leaf and yard with other source separated or mechanically separated organic fractions of the MSW waste streams. MSW composting of relatively unprocessed MSW waste stream to reduce waste disposal volume is rare. Based on a survey by Biocycle (November 2010), there were eleven (11) operating mixed MSW composting facilities in operation in the United States. These include facilities in California (Gilroy and Mariposa), Massachusetts (Marlborough and Nantucket), Minnesota (Truman), Montana (West Yellowstone), New York (Delaware County), Ohio (Medina), South Dakota (Rapid City), Tennessee (Sevierville) and Wisconsin (Columbia County).[8]

Canadian facilities include the Edmonton Composting Facility, located in Alberta, Canada one of the largest co-composting facilities in North America; handling up to 200,000 metric tons per year of residential waste and up to 25,000 metric tons per year of dewatered sludge. The Edmonton facility features an in-vessel, mechanical, rotating drum technology that co-composts the waste and biosolids. While the facilities listed above were operating for several years, there were also several large scale facilities that failed for technical and/or financial reasons, including in Florida (Miami and Pembroke Pines), Oregon (Portland), Maryland (Baltimore) and Georgia (Atlanta).

The relatively low capital and low O&M cost makes the continued windrow composting of source separated leaf and yard waste a good fit for the Corporation's leaf and yard wastes as there is space and a good buffer zone from neighbors. The current operation at the Central Landfill is about 125 TPD (40,000 TPY). Typically, the limiting factor for any expansion of the process is available area. Given the success of the current operation, expansion may be a good option, especially for additional source separated leaf and yard wastes. Expanding the existing compost operation to include waste organics/food waste will require advanced separation techniques to remove inorganic contaminants such as plastics, metals, and glass from the organic fraction. This process can be expensive and, if not done properly, any inorganic contaminants will drive down the quality and price of the final compost product.

2.3.1.4 Costs

To provide a reference point, the estimated capital cost to start a new, 60,000 TPY (200 TPD) aerobic windrow operation is approximately $5.4M. Most of this cost is associated with major equipment including at least two (2) front-end loaders, a grinder, a mechanical windrow turner, a screener, off-road dump truck, and various other miscellaneous machines and equipment. If the capital costs are depreciated over 10-years and a $40/ton operation and maintenance cost is added, the estimated cost to conduct aerobic windrow composting is estimated to be $49/ton.

The Corporation estimates that the cost per ton of composted leaf and yard waste is $42/ton and their finished Grade A compost is sold to the public for $30/cubic yard or $8.00 for a 40 pound bag.

2.3.2 Anaerobic Digestion (AD)

Anaerobic digestion (AD) is most commonly used to process waste water treatment plant (WWTP) biosolids. Over the past 5-years, AD is being used more and more as a way of processing the source separated organics (SSO), specifically source separated food waste.

AD is the process of decomposing organics in an oxygen-deficient environment. The AD process may either be a wet or dry process depending on the total solids content being treated in the reaction vessel. Both types of AD processes involve the injection of the organic material into an enclosed vessel where microbes are used to decompose the waste to produce a liquid, a solid residual sludge material, and a biogas that consists mainly of methane, water, and carbon dioxide (CO_2). The resulting low- to mid-energy-content biogas can be utilized in a reciprocating engine or gas turbine to produce electricity, or can be further processed and compressed to be used as a vehicle fuel. The remaining residual sludge material, which is typically between 10-30% (by weight) of the organic waste input depending on the type of AD process used, can also be processed further (e.g. cured aerobically in a compost facility) to produce a compost that can be marketed as a soil amendment.

The incoming mixed MSW and/or SSO requires a pre-treatment process that involves shredding, pulping and removal of inorganic and non-digestible fractions of the waste stream. These processes were first employed in the 1980's under the term Mechanical Biological Treatment (MBT). A few facilities were developed in the United States using MBT technologies; however, for the most part, these facilities ceased to operate years ago due to a variety of issues.

The evolution of the technology has re-introduced the United States to the benefits of AD. In many cases, this technology can be used in conjunction with composting, curbside collection of food wastes, mixed waste processing facilities, or a refuse-derived fuel (RDF) process.

This evaluation concentrates on wet system AD. Wet systems require the feedstock to be prepared into liquid slurry in a tank or similar type of container. Biologically inert materials that are present in the feedstock, such as metals, glass, and plastics are undesirable and considered contamination and must be removed. There are several factors that influence the design and performance of AD facilities including: slurry solids percentage; the concentration and composition of nutrients in the feedstock; temperature of the digesting mass; and retention time of the material in the reactor; pH; and oxygen level.

Typical systems can be operated using either of the following levels of solids:

a. High-Solids: between 15 and 40% solids in a liquid slurry or paste; and
b. Low-Solids: typically less than 15% solids.

Since mid-2013, JC-Biomethane in Junction City, Oregon has operated a 60-80 TPD wet-type anaerobic digestion facility. This facility, as shown in Figure 2-2, uses a Conventional Stir Tank Reactor (CSTR) design for the digestion. It accepts commercial organics, such as food waste and agricultural residues to produce approximately 1.5 MW of power from 450 cubic feet per minute (CFM) of digester gas. This facility relies on post-consumer food waste from commercial sources to make up 80% of the feedstock; less than 5% of the feedstock comes from fats, oil and grease (F.O.G.) and manure. It does not accept residential food wastes.

Figure 2-2: Photo of JC-Biomethane's Anaerobic Digestion Facility in Junction City, Oregon

*Courtesy of Register-Guard News

The most conventional use of the biogas produced from any AD process is using it as a fuel in internal combustion engines and gas turbines to produce electricity. A by-product of the process is a residual sludge (10-40% by volume) that can be further processed via aerobic composting windrows into compost or mulch or further processed into fertilizer pellets. However, if the residual sludge is too contaminated with glass, metal, and plastic it may need to be landfilled.

The greater Toronto area is home to two (2) commercial-scale plants that are designed specifically for processing source separated organics (SSO); the Dufferin Organic Processing Facility; and the Disco Road AD Facility. Toronto built the $74M Disco Road Waste Management Facility in 2013, a state-of-the-art anaerobic facility with a capacity of 75,000 metric tons/year with a potential electrical generation capacity of 2.8 MW, however they are currently flaring the gas.

In May 2016, Village Greene Ventures broke ground on a new AD facility at Brunswick Landing, the 3,200-acre former Naval Air Station turned business park in Brunswick, Maine. The Brunswick AD facility will produce 1 MW of electrical power from 180 TPD of organic wastes that includes wastewater biosolids, food waste, and other organic waste materials. As of June 2016, the facility was running at 60%. There is a similar size AD facility running at Stonyvale Farm in Exeter, Maine and a growing number of AD facilities in the United States operating on mixed MSW, SSO, and/or co-digested organic wastes with WWTP biosolids. Stonyvale Farm's facility is permitting to accept all forms of digestible organic materials; including liquids, solids, and a range of slurry products.

Existing Rhode Island Anaerobic Digestion Facilities

The Blue Sphere Corporation is currently constructing a 250-300 TPD, 3.2 MW AD facility on a parcel that abuts the Central Landfill to the northeast. The facility is expected to begin accepting food waste and other organics in 2018. The Blue Sphere location is within a 15-mile radius of Providence, RI. Based on Rhode Island law, any large generator of food waste (>2 tons per week) within 15 miles of an accepting facility must recycle their food waste.

2.3.2.1 Analysis

Benefits of this technology include diversion of organic waste from landfills, management of WWTP biosolids, the production of energy, and potential use of the processed by-products. There are many commercial plants in United States operating on source separated organics, food waste, WWTP biosolids, and some on the organic fraction of MSW. However, the AD operations can require a high level of pre-processing to remove inorganics from the MSW stream (metals, glass, plastics and inerts) and a reduction in the size of organics prior to digestion.

2.3.2.2 Costs

AD facilities typically carry moderate capital costs in the $10-$30M range. The Blue Sphere facility is likely to accept 250-300 TPD, is currently under construction and is reported to cost approximately $27M. The 60-80 TPD JC-Biomethane facility in Junction City, Oregon cost $16M. Typically, O&M costs (including annualized capital cost) range from $45/ton to $65/ton. Economic success of an AD facility is sometimes hinged upon if the residue can be processed and sold as a soil amendment or fertilizer product. Table 2-1 summarizes available information regarding AD costs.

Table 2-1: Summary of Capital and O&M Costs for AD Facilities

Facility	Waste Food/Organics (TPD)	Tipping Fee ($/ton)	Energy Output	Capital Cost ($M)	Capital Cost per TPY ($)	O&M Cost per ton ($)[1]
JC-Biomethane Biogas Plant, Junction City, Oregon (2)	70		1.55 MW	$16	$626	
Village Green Ventures, Brunswick, Maine (estimate) (3)	180		1MW	$10	$152	
East Bay Municipal Utility District (1)	20-40	$40	220kWh/ton		$266-$333 ($300)	$40-55 ($47.50)
Toronto (metric ton) (1)	110		107m³/metric tons biogas	$18	$450	$90
University of Wisconsin (pilot) (1)	16		400kW	$2.3	$383	
Cedar Grove Composting, WA (1)	770		8MW	$87	$309	
Humboldt County, CA (1)	27	$60	2400mWh/yr	$6	$600	$34
W2E³ , SC (1)	131	$35	3.2MW	$23	$479	
Blue Sphere, Rhode Island(4)	250-300	$65	3.2MW	$27	$296	
Disco Road AD, Toronto, ON(5)	200		110m³/metric tons biogas	$52	$712	$68
North American Average (1)					$431	$60

Notes:
(1) "Feasibility Study for Anaerobic Digestion of Food Waste in St. Bernard, Louisiana." Kristi Moriarty, NREL Technical Report, NREL/TP-7430-57082, January 2013. https://www.nrel.gov/docs/fy13osti/57082.pdf
(2) "JC-Biomethane Biogas Plant, Junction City, Oregon" American Biogas Council, Biogas Project Profile, July 6, 2015.
(3) "Brunswick Project will Turn Waste into Renewable Energy." J. Craig Andersen, Portland Press Herald, July 25, 2015.
(4) "Blue Sphere WTEWTE facility nears completion with 'White Test' process", Waste Dive, August 30, 2016 & "Rhode Island's First Digester Expected to take Food Scrap in June", EcoRI News, May 08, 2017
(5) https://www.biocycle.net/2008/09/22/toronto-moves-forward-with-anaerobic-digestion-of-residential-sso/

According to the NREL 2013 report, the national average capital cost for development of AD facility is $561,000 per ton of daily capacity and O&M costs are $48/ton. For example, the capital cost of a facility designed to process 60,000 TPY (164 TPD) will be approximately $33.7M and the O&M cost will be approximately $2.9M/year.[9]

2.3.3 Aerobic Digestion

Aerobic digestion is the process of metabolizing the biogenic fraction of the MSW stream in the presence of microorganisms and oxygen. During the aerobic process, the mass of the material is reduced through the liberation of CO_2 and water, and the pathogens are destroyed. The digested material can be utilized as a fertilizer or soil amendment, but unlike AD processes, there is no biogas produced. Similar to AD, the aerobic digestion process can also be either a wet or dry process. The dry aerobic digestion process involves removal of the non-digestible material, putting the MSW or SSO stream into an enclosed aerobic digestion vessel, and then further stabilization in aerated piles. Wet aerobic digestion involves the separation and pulping of the biogenic fraction of the mixed MSW or SSO, mixing, aeration and the destruction of pathogens in the presence of microbes, and finally separation into the solid and liquid products.

2.3.3.1 Analysis

Aerobic digestion has not been widely used for the processing of mixed MSW or SSO, and there is little reliable information and costs from the technology vendors that have tested or demonstrated the aerobic process on any full scale operation.

2.3.3.2 Costs

There is no reliable cost information on the capital or operating costs of aerobic digestion at a scale that would be beneficial to the Corporation.

2.4 Mechanical Technologies

Mechanical treatment technologies are those processes that mechanically separate various products (e.g. metals, plastics, etc.) from the waste stream while reducing the size of the remaining waste materials. In some instances, mechanical technologies may include the use of steam conditioning to recover a fibrous material from the waste stream that can be used as a fuel or other purposes. Some examples of mechanical treatment processes include advanced material recovery and steam classification or autoclave technologies.

2.4.1 Mixed Waste Processing Facilities (MWPFs)

MWPF generally accept mixed MSW and process these materials to recover recyclables and other reusable materials leaving the residual waste for landfilling or another appropriate waste processing application. The modern MWPFs predecessor was called a “dirty” MRF and typically recovered only a small percentage of the highest value recyclables that could be easily separated from the waste stream. Today’s MWPFs can sort and recover many types of recyclable materials using optical sorters, eddy currents, magnets, and pneumatic sorters as well as traditional picking lines.

To help combat low public participation rates of traditional recycling programs and minimize collection costs, such as collection of curbside source separated recyclables and source separated organics, some communities are turning to MWPFs to either capture additional recyclables or as a pre-sorting operation prior to more advanced conversion technologies.

The MWPF process begins with unsorted and unseparated solid waste from residential and/or commercial collection vehicles being off-loaded onto a tipping floor. Materials are first sorted on the floor using manual labor and mobile equipment to remove larger or bulky items such as appliances, dimensional wood, metal, or large pieces of plastics that might clog or interrupt operations of the advanced processing systems.

Materials are then processed through multi-stage screens to separate fiber (cardboard, newspaper, and mixed paper), plastic, metal and glass containers, and small contaminants. This is usually accomplished through the use of mechanical, optical or pneumatic screening equipment to separate materials into size classifications and/or light versus heavier materials. Fiber is usually hand sorted off elevated conveyor platforms into commodities and dropped into bunkers below. Containers are processed through ferrous magnets, eddy-current magnets, air screens and hand sorting. The small contaminant stream (dirt, rocks, broken glass and ceramics, bottle caps, etc.) may be further processed by optical/pneumatic sorting. Sorted material is moved from bunkers and baled (fiber, plastic, metal) or loaded directly into roll-off trucks (glass). The remaining material is shipped to a local landfill or another appropriate waste processing/conversion facility.

The typical purpose of this type of MWPF is to remove recyclable and organic material from municipal solid waste prior to landfilling or for pre-processing prior to an advanced conversion technology or other technologies such as engineered fuel production (also known as Refuse Derived Fuel (RDF), waste-to-energy, composting, or anaerobic digestion. Traditional “dirty” MRFs typically recover about 10-25% of the recyclable waste stream. There are claims that an advanced MWPF can achieve up to 50% recovery rate. However, diversion rates above 50% can only be achieved if the facility diverts both recyclable and other organic and non-recyclable materials such as food waste and leaf and yard waste.

There is a wide range of capacities operating throughout the world. Typical capacity is between 200 TPD and 1,500 TPD using multiple sort lines and operating additional shifts. MWPFs can have a useful operating life of 20 to 30 years if proper maintenance is provided. Many MWPFs will be retrofitted throughout their lifespan to replace equipment that wears out; to provide new processing equipment in response to changing waste stream composition; to adapt to commodity market fluctuations; or to meet downstream recovery and/or feedstock specifications.

2.4.1.1 Analysis

MWPFs are a fully developed technology used in the United States and the world to process MSW (either mixed or commingled), to recover recyclable and reusable materials and to prepare materials for further downstream processing. The technology has the ability to process a wide range of MSW materials and yield potentially high recyclable recovery rates. It is a well proven technology, and various mechanical, pneumatic, and optical processes are updated continually. This technology is being used more and more as a pre-processing step in preparing feedstock for thermal, biological, and chemical processes.

That said, there are no MWPFs operating in the Eastern United States except those that are a pre-processing operation for generating RDF for an advanced thermal process such as waste-to-energy or other emerging technologies. The only true MWPF’s operate in regions where elevated recovery and/or ancillary processing technologies are necessary to meet state mandates. The Western Placer facility accepts MSW from communities that do not have municipally sponsored source separated recyclables program. The San Jose California, Newby Island Resource Recovery Park (NIRRP) facility accepts and processes only commercial wastes under an exclusive franchise agreement and is required to meet a contractually specified landfill diversion rate. The NIRRP facility removes both recyclables and prepares an organic feedstock for a downstream dry fermentation anaerobic digester facility. The San Jose California Green Waste Recovery MRF accepts MSW from multi-family residential units that do not have source separated recycling or have poor source separated recycling participation rates. The Sunnyvale Materials and Recycling Transfer Station (SMaRT) in Sunnyvale, California is the only MWPF that receives MSW from communities that sponsor source separation and collection of recyclables. The SMaRT facility is currently undergoing a re-evaluation because costs are higher than expected and diversion percentages are lower than expected and some participating communities are considering other options.

The success of a MWPF is dependent on fluctuations in the commodity market and local waste stream and establishment of an end user for the separated recyclables. In January 2018, China banned 24 additional materials from entering their country as recyclable materials. If the market is poor or no end-user is available, 60-80% of the incoming recyclables may end up being landfilled. Environmental impacts must be mitigated such as noise, dust, and odor. In addition, some of the commodities recovered from a MWPF can be contaminated with MSW to varying degrees depending on the processes in use.

The most common issue is that the available equipment is not able to both pull recyclables out of the MSW waste stream and have it clean enough to be used by the recycling industries end-users. In addition, the economics of recycling have not recovered to a point that make recycling worth the effort and expense. Detractors also point out that the low price of landfilling in the U.S. makes the advanced recycling process uneconomical in comparison.

If Rhode Island continues to promote state-wide source separated recycling collection, the benefit of a MWPF will likely be minimal. The benefits of MWPF can increase if designed to recover recyclables and organics and utilize the residuals for RDF production. The Corporation should carefully evaluate the development of a MWPF strictly for the recovery of additional recyclables.

Figure 2-3: Picture of the Western Placer Waste Management Authority MWPF

2.4.1.2 Costs

In 2011, the County of Kauai, HI received a report that estimated a capital cost for a MWPF to be $25,000 - $30,000 per ton of daily design capacity (approximately $45M for a 1,500 TPD facility).

O&M costs consist primarily of labor, equipment maintenance, and disposal costs for residue. A 2006 study found, “The average O&M cost for the smallest MRFs (less than 6 TPD throughput) was $201.78 per ton.”[(10)] However, O&M costs typical decrease on a per ton basis as operation get larger. “Facility O&M costs decrease to about $46.09 per ton for facilities processing 121 to 218 TPD, and then rose slightly to $55.87 per ton for MRFs processing more than 218 tons per day.”[(10)] These O&M costs typically do not include costs to dispose of residual materials.

Table 2-2 summarizes available cost data for MWPFs in the United States.

Table 2-2: Summary of Available Costs for MWPFs

Facility	Waste Throughput (TPD)	Capital Cost (2018$ M)	O&M Cost per Year (US $ M)	Capital Cost *per TPD* (2018$)	O&M Cost per ton (2018$) (Excludes Disposal of Residues)
Western Placer Waste Management Authority, Roseville, CA	1,200	$40M	$17M	$33,000	$65
Infinitus Renewable Energy Park, Montgomery, AL[(2)(3)]	~700-800	$42M (Phase 1)	Closed in 2015 for Financial Restructuring Citing Falling Recyclable Market	$56,000	$32
Sun Valley MRF, CA [(1)]	1,500	$56M		$37,000	
American Forest & Paper Study[(4)]	1,000	$49M		$49,000	$52
Sunnyvale Materials Recovery and Transfer Station (SMaRT Station®), Sunnyvale, CA	1,500	$21M	$13M (FY2011/2012)	$14,000	$68

Notes:
(1) http://www.bulkhandlingsystems.com/athens-services-opens-state-art-mixed-waste-mrf/
(2) http://www.montgomeryadvertiser.com/story/news/local/community/2016/07/20/cost-doing-business-irep/87348250/
(3) http://www.recyclingtoday.com/article/montgomery-alabama-infinitus-waste-processing-temporary-closure/
(4) http://www.afandpa.org/docs/default-source/default-document-library/final_mixed-waste-processing-economic-and-policy-study.pdf

2.4.2 Mechanical Biological Treatment

Mechanical biological treatment (or "MBT") is a variation on composting and/or anaerobic digestion (AD) and materials recovery. This technology is generally designed to process a fully commingled MSW stream. Processed materials include marketable metals, glass, other recyclables, and a refuse-derived fuel that can be used in thermal processing technologies. Limited composting is used to break the MSW down and dry the waste. The order of mechanical separating, shredding, and composting can vary. MBT is an effective and flexible waste-management method and can be built in various sizes. The RDF produced by an MBT process must be handled in some way: fired directly in a boiler; converted to energy via a thermal process (e.g., combustion, gasification, etc.); or selling it to a third party (e.g. cement kiln).

2.4.2.1 Analysis

This technology has been used widely in Europe, including in the United Kingdom, Spain, Italy and Germany, due in large part to European Union regulations prohibiting the disposal of non-treated solid waste in a landfill. There has not been widespread commercial application of this technology on mixed MSW streams in North America.

The Bedminster Bioconversion in-vessel, mechanical, rotating drum technology (also referred to as "rotary digesters") used at the Edmonton Composting Facility is an example of a commercially available MBT technology that has experience processing residential waste.

Entsorga, an Italian technology company, is in the process of developing an MBT facility in Martinsburg, West Virginia. The City of Toronto is also considering developing a commercial-scale MBT facility at its Green Lane Landfill Site located southwest of London, Ontario.

2.4.2.2 Costs

A 2018 Solid Waste Association of North America (SWANA) Study cited capital costs per ton of daily processing capacity for MBT facilities in the United Kingdom (circa 2012) ranged from $243,000 to $275,000 per ton per day of capacity.(11) As an example, a 300 TPD facility (approximately 100,000 TPY) would likely cost about $75 - $80M.

2.4.3 Steam Classification (Autoclave or Hydrothermal Treatment)

Steam Classification (a.k.a., “hydrothermal treatment”) technology uses heat and pressure to separate the cellulosic material from other portions of the municipal solid waste stream. The resulting material can be used as a solid fuel for power production; as a feedstock for further processing through anaerobic digestion, gasification, or composting; or as a fiber product that can be converted into corrugated cardboard. The technique uses a large autoclave in which steam is introduced to the MSW at about 110°C (or 230°F) to 160°C (320°F) for a predetermined amount of time. This sterilizes the MSW and begins to break it down so that the fibers can be separated from the other materials. The composition of the material changes, with most plastics shrinking into small balls of resin and fibers into a wet pulp. Glass, metals, cloth, and some other materials undergo little change other than the loss of labels. Fabrics and certain other materials in the feedstock can hamper the recovery of fibers. In most systems, the feedstock is fed into the autoclave in batches rather than in a continuous flow. The fiber product can be suitable for use as a fuel or as material for manufacturing cardboard or paper. Other by-products might include the glass, metal, and plastics separated from the fiber, which could have some value in certain markets.

2.4.3.1 Analysis

Although autoclaving is a well-understood technology, there are few examples of large-scale commercial applications in North America with mixed MSW as a feedstock. There are commercial-scale facilities in Japan and Europe, including Sterecycle’s Rotherham plant, the UK’s first commercial scale autoclave plant, which experienced a deadly accident in January 2011 and fell into receivership in October 2012.(12) Many existing commercial-scale steam classification facilities treat mostly medical wastes. There are a number of pilot facilities in North America, but the batch feeding process and equipment size have limited the capacity of these facilities. There are also vendors (e.g., WastAway) that claim to have a commercial-scale continuous-flow process, with projects being developed in the Caribbean (e.g. Aruba, U.S. Virgin Islands). However, these claims could not be confirmed.

Some examples of vendors offering the steam classification technology include: RRS; Downstream Waste Recovery; Sterecycle; WastAway; Re3; Clean Earth Solutions; and Estech.

2.4.3.2 Costs

There is no reliable cost information on the capital or operating costs of waste autoclave technologies at a scale that would be beneficial to the Corporation.

2.5 Thermal Technologies – Waste-to-Energy

Thermal processing technologies are those processes that use or generate significant amounts of heat that is used to create steam to drive electrical generators. A by-product of the technology is ash that typically needs to be landfilled. This section provides brief descriptions and examples of available waste-to-energy technologies.

2.5.1 Mass Burn Combustion

Mass burn combustion technology can be divided into two main types: (a) grate based, waterwall boiler installations; and (b) modular, shop erected combustion units with shop fabricated waste heat recovery boilers.

Larger mass burn combustion facilities (> 500 TPD) typically feed MSW directly into a waterwall boiler system with no preprocessing other than the removal of large bulky items such as furniture and white goods. The MSW is typically pushed onto a grate by a ram connected to hydraulic cylinders. Air is admitted under the grates, into the bed of material, and additional air is supplied above the grates. The resulting flue gases pass through the boiler and the sensible heat energy is recovered in the boiler tubes (waterwall) to generate steam. This creates three streams of material: steam, flue gases and ash. The steam can be sold directly to an end-user such as a manufacturing facility or district heating loop, or sent to a turbine generator and converted into electrical power, or a combination of these uses.

Smaller mass burn combustion facilities typically use a modular unit (or multiple modular units). Each modular unit typically uses less than 200 TPD and is historically used in facilities where the total available throughput is under 500 TPD. In these smaller systems, MSW is fed into a refractory lined combustor where the waste is combusted on refractory lined hearths, or within a refractory lined oscillating combustor (e.g. Laurent Bouillet). Some modular combustors use a two-stage combustion process in which the first chamber operates in a low-oxygen environment and the combustion is completed in the second chamber. Typically there is no heat recovery in the refractory combustors, but rather, the flue gases exit the combustors and enter a heat recovery steam generator (HRSG), or waste heat boiler, where steam is generated by the heat in the flue gas, resulting in the same three streams; steam, flue gas and ash. The steam is either sent to a steam turbine to generate electricity or it can be piped directly to an end user as process steam, or for district heating, or a combination of these uses.

All mass burn technologies utilize an extensive set of air pollution control (APC) devices for flue gas clean-up. The typical APC equipment used include: either selective catalytic reduction (SCR) or non-catalytic reduction (SNCR) for NO_x emissions reduction; spray dryer absorbers (SDA) or scrubbers for acid gas reduction; activated carbon injection (CI) for mercury and dioxins reduction; and a fabric filter baghouse (FF) for particulate and heavy metals removal.

The bottom ash from mass burn combustion may also be used as a construction base material, which is a common end-use for this by-product in Europe. The fly ash from the boiler and flue gas treatment equipment is collected separately and can either be treated or disposed in a landfill.

Large-scale and modular mass burn combustion technology is used in commercial operations at more than 80 facilities in the U.S., seven in Canada and more than 500 in Europe, as well as a number in Asia.

2.5.2 Refuse-Derived Fuel (RDF) Combustion

This technology prepares MSW by shredding, screening, and removing non-combustible materials prior to thermal conversion. The goal of this technology is to derive a better, more homogenous fuel (uniform in size, composition and heat value) that can be used in a more conventional solid-fuel boiler as compared to a mass burn combustion waterwall boiler. The fuel goes by various names, but generally is categorized as a RDF. The RDF process typically results in a fuel yield in the 80-90% range (i.e., 80-90% of the incoming MSW is converted to RDF). The remaining 10-20% of the incoming waste that is not converted to RDF is composed of either recovered ferrous metals (1-5%) which can be sold to market, or process residue (15-19%) that must be disposed of in a landfill. In most cases, the fuel is used at the same facility where it is processed, although this does not have to be the case. The RDF is blown or fed into a boiler for semi-suspension firing. Combustion is completed on a traveling grate. Thermal recovery occurs in an integral boiler. The APC equipment arrangement for an RDF facility would be similar to that of a mass-burn combustion system.

RDF technology is an established technology that is used at a number of plants in the U.S., Europe and Asia (generally larger plants with capacities greater than 1,500 tons per day). There are also a number of commercial-ready technologies that convert the waste stream into a stabilized RDF pellet that can be fired in an existing solid fuel boiler or cement kiln.

2.5.3 Fluidized Bed Combustion

This technology uses a bubbling or circulating fluidized bed of liquefied sand to combust processed MSW. The technology requires the use of a front-end processing system to produce a consistently sized feedstock similar to the system described above for RDF technology. Typically, these processes require more front end separation and size reduction, and result in lower fuel yields (less fuel per ton of MSW input), with less moisture (typically a 10% reduction) and a resulting higher heating value per ton of processed material when compared to unprocessed MSW. Much of the metal, glass, and other non-combustible materials are removed during the front-end processing. Combustion performance and stable operation is reported to be a challenge at some facilities, although some operational advantages can offer opportunities for better performance. A downstream waste heat boiler is used for thermal recovery.

One advantage of the fluidized bed technology is that lime can be added directly to the combustion chamber, which helps better control acidic gases (e.g. sulfur dioxide (SO_2)). Generally, NO_x emissions are lower in fluidized bed units than for mass-burn facilities. However, APC equipment is still required and is generally similar to that of mass-burn and RDF combustion.

Fluidized bed technology is in limited commercial use in the U.S. for waste applications. Only one (1) commercial-scale facility is currently operating in La Crosse, Wisconsin. Fluidized bed combustion is more commonly used for certain biomass materials and for coal combustion. It is more often considered for more uniform waste streams, such as wood wastes, tires, and sludge.

2.5.4 Analysis

Mass burn and RDF are thermal technologies widely used in the United States, Canada and around the world. There are over 80 WTE facilities operating in the United States and Canada alone. Most were constructed in the 1980’s and 1990’s and are nearing the end of their intended operational lifespan.

The economics of a WTE facility is heavily dependent on two factors; 1) the price negotiated for the electricity sold to the grid; and 2) the tipping fees received for waste brought to the facility.

Figure 2-4 shows the Durham York Energy Center, a modern 480 TPD mass burn WTE facility that passed acceptance testing in the winter of 2015. In addition, the 3,000-tpd West Palm Beach County (Florida) mass burn WTE facility began commercial operation in the spring of 2015.

Figure 2-4: Photo of the 480 TPD Durham-York WTE Facility in Ontario, Canada

2.5.5 Costs

Table 2-3 below summarizes the capital costs of various mass burn technologies. O&M costs are included where reliable information was obtained. Based on the information available the average capital cost to build a modern WTE facility is approximately $392,000 per ton of daily design capacity and the annual O&M costs are approximately $41,000 per ton of daily design capacity.

Table 2-3: Summary of WTE Facilities in US and Canada

Facility	Type of Facility	Waste Throughput (TPD)	Electrical Output (MW)	Capital Cost ($M2017)	O&M Cost per Year ($M)	Capital Cost per TPD ($2017)
Durham York Energy Center, Ontario (2015)[1]	New	480	19.4	262	14.7	547,200
H-POWER, Honolulu[2]	Upgrade	900	33	370	56	412,200
Palm Beach Renewable Energy Facility 2, West Palm Beach, FL (2015) [3]	Upgrade	3,000	95	712		237,000

Facility	Type of Facility	Waste Throughput (TPD)	Electrical Output (MW)	Capital Cost ($M2017)	O&M Cost per Year ($M)	Capital Cost per TPD ($2017)
Lee County Waste to Energy Facility, FL	Expansion	636	20	165		260,000
Hillsborough	Expansion	600	17	170		283,000
Olmsted Waste-to-Energy Facility, Rochester, MN	Expansion	200	6	101		507,000
Covanta Dublin, Ireland (2017) [4]	New	1,650 MetricTons	58	$650M U.S.		357,500
Mid-Conn, Hartford CT (Estimate + 20%)	Potential Expansion	1,500		558	45	372,000
AVERAGE in 2017 $		1,142 Tons	35 MW	$348	$38.6	$372,000

Notes:
All tonnage shown in U.S. tons; dollars are in U.S. dollars; TPD = tons per day
1. https://www.durhamyorkwaste.ca/FAQ/FAQ.aspx#cost
2. http://swana.org/portals/0/awards/2014/Wastepercent20topercent20Energy/Honolulupercent20_Waste-to-Energy.pdf
3. www.swa.org/375/Palm-Beach-Renewable-Energy-Facility-
4. Covanta Q4 2016 Earnings Call Final Transcript, Page 11

2.6 Thermal Technologies – Emerging Technologies

Emerging thermal processing technologies are those processes that use or generate significant amounts of heat that converts the waste stream into a flue gas or syngas and a solid residue (e.g. ash or char). This section provides brief descriptions and examples of emerging thermal technologies.

2.6.1 Gasification

Gasification converts carbonaceous material into a synthesis gas or "syngas" composed primarily of carbon monoxide and hydrogen. Following a cleaning process to remove contaminants this syngas can be used as a fuel to generate electricity directly in a combustion turbine or internal reciprocating engine, or fired directly in a heat recovery steam generator (HRSG) to generate electricity via steam condensing turbine. The syngas generated can also be used as a chemical building block in the synthesis of gasoline, diesel fuel, alcohols and other chemicals. The feedstock for several gasification technologies must be prepared into refuse derived fuel (RDF) developed from the incoming MSW, or the technology may only process a specific subset of waste materials such as wood waste, tires, carpet, scrap plastic, or other waste streams. This technology typically requires advanced front end separation and size reduction, and result in lower fuel yields (less fuel per ton of MSW input).

The feedstock reacts in the gasifier with steam and sometimes air or oxygen at high temperatures and pressures in a reducing (oxygen-deficient) environment. In addition to carbon monoxide and hydrogen, the syngas consists of water, smaller quantities of carbon dioxide (CO_2), and some methane (CH_4) and contaminants including tars and volatile heavy metals.

Processing of the syngas can be completed in an oxygen-deficient environment, or the gas generated can be partially or fully combusted in the same chamber. The low- to mid-mega joule syngas can be combusted in a boiler, or following a cleanup process a gas turbine, or engine or used in chemical refining. Of these alternatives, boiler combustion is the most common, but the cycle efficiency can be improved if the gas can be processed in an engine or gas turbine, particularly if the waste heat is then used to generate steam and additional electricity in a combined cycle facility.

Industry experts generally expect that the syngas produced by the process will be lower in pollutant concentrations, but air pollution control (APC) equipment and syngas cleaning systems will still be required. Any mercury in the feedstock is expected to volatilize and will need to be captured from the exhaust gas or refinery. The remaining ash and char produced by the gasification process may be marketed as a construction base, or disposed of in a landfill if a market does not exist.

Figure 2-5: Photo of the 250 TPD Homan Gasification Plant in Fukuoka, Japan

*HDR Photo of Homan Gasification Plant in Fukuoka, Japan

2.6.1.1 Analysis

Gasification technology has been used for almost 100 years and has been commercially demonstrated on select waste streams, particularly coal and wood wastes. However, the technology does wide scale proven commercial-scale success using mixed MSW in North America. In Asia, notably Japan and South Korea, there are several commercial-scale gasification facilities in operation that process MSW with unit sizes that range between 150-250 TPD. In Japan, one goal of the process is to generate an inert ash product that can be reused as a construction material to limit the amount of material having to be diverted to landfill, which are scarce. In addition, several university-size research and development units were built and were tested in North America and abroad, but have not achieved widespread commercial applications.

There are hybrid, two-stage gasification/combustion processes that do not require advanced, and expensive, pre-processing of the incoming MSW feedstock. These technologies are more similar to a modular WTE than a traditional gasification technology. For example, the CLEERGAS® technology has been processing about 350 TPD of unprocessed MSW in Tulsa, Oklahoma with a 93% availability rate since 2011. During a February 2016 investor call, Covanta said it would like to put its gasification technology, Covanta CLEERGAS, into commercial operation. Covanta's CEO stated, "They're difficult from an economic standpoint, but over time, I think both technologies will have a place in the market."

2.6.1.2 Cost

The capital cost of the 220 TPD Thermiska TPS plant in Italy was approximately $170M with the RDF plant making up about $63M (37%) of that cost. Operation and maintenance costs for the Thermiska TPS plant is estimated at $36/ton. It is assumed that a similar gasification system will be approximately $110M plus an additional $60M for pre-processing equipment; or about $170M for a 220 TPD facility.

Gasification, in all its forms, tends to be more modular in size and design and have comparable or higher capital costs than a similar size WTE facility, especially if it requires waste pre-processing. While they do have lower emissions and generate less ash, if the RIRRC was to consider a thermal technology, these benefits will not likely offset the higher costs of constructing a suitably sized gasification plant.

2.6.2 Pyrolysis

Pyrolysis is generally defined as the process of heating MSW in an oxygen-deficient environment to produce a combustible gaseous or liquid product and a carbon-rich solid residue. This is similar to what is done to produce coke from coal or charcoal from wood. The feedstock can be the entire municipal waste stream, but, in some cases, pre-sorting or processing is used to obtain a refuse-derived fuel. Similar to gasification, once contaminants have been removed the gas or liquid derived from the process can be used in an internal combustion engine or gas turbine or as a feedstock for chemical production. Generally, pyrolysis occurs at a lower temperature than gasification, although the basic processes are similar.

2.6.2.1 Analysis

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

Some examples of vendors that offer the pyrolysis technology include: Mitsui; Compact Power; PKA; Thide Environmental; WasteGen UK; International Environmental Solutions (IES); SMUDA Technologies (plastics only); and Utah Valley Energy.

2.6.2.2 Costs

Little reliable information is available on the capital and operational costs of pyrolysis using MSW as a feed stream. Pyrolysis has a higher capital costs than other proven technologies and the long-term reliability of such emerging technologies remains in question. Therefore, there is no obvious benefit that a pyrolysis plant has over another more proven technology.

2.6.3 Plasma Arc Gasification

Plasma arc technology uses carbon electrodes to produce a very-high-temperature arc ranging between 3,000 to 7,000 degrees Celsius that vaporizes the feedstock. The high-energy electric arc that is struck between the two carbon electrodes creates a high temperature ionized gas (or plasma). The intense heat of the plasma breaks the MSW and the other organic materials fed to the reaction chamber into basic elemental compounds. The inorganic fractions (glass, metals, etc.) of the MSW stream are melted to form a liquid slag material which when cooled and hardened encapsulates heavy metals. The ash material forms an inert glass-like slag material that may be marketable as a construction aggregate. Metals can be recovered from both feedstock pre-processing and from the post-processing slag material.

Similar to gasification and pyrolysis processes, the MSW feedstock is pre-processed to remove bulky waste and other undesirable materials, as well as for size reduction. Plasma technology also produces a syngas; this fuel can be fired directly in a boiler, or the syngas can be cleaned and combusted directly in an internal combustion engine or gas turbine. Electricity and/or thermal energy (i.e. steam, hot water) can be produced by this technology. Vendors of this technology claim efficiencies that are comparable to conventional mass burn technologies (600-700+ kWh/ton (net)). Some vendors are claiming even higher efficiencies (900-1,200 kWh/ton (net)). These higher efficiencies may be feasible if a combined cycle power system is proposed. However, the electricity required to generate the plasma arc, as well as the other auxiliary systems required, brings into question whether more electrical power or other energy products can be produced than what is consumed in the process.

2.6.3.1 Analysis

This technology claims to achieve lower harmful emissions than more conventional technologies, like mass burn and RDF processes. However, APC equipment similar to other technologies would still be required for the clean-up of the syngas or other off-gases.

The Alter NRG has a 48 TPD demonstration facility in Madison, Pennsylvania in the U.S. and PyroGenesis Canada, Inc., based out of Montreal, Quebec, has a demonstration unit (approximately 10 TPD) located on Hurlburt Air Force Base in Florida that has been in various stages of start-up since 2010. To date, most arc plasma operations either run on a homogeneous fuel supply, or have not been successfully scaled to accommodate large scale operation.

2.6.3.2 Costs

Plasma technology has recently received considerable negative attention. Several large-scale projects have failed in North America and Europe including a 600 TPD facility in Saint Lucie County, Florida that recently closed; the Tees Valley Facility in Billingham, England that recently stopped construction of its 350,000 metric tonne per year facility after spending $500M; and the Plasco Energy Facility in Ottawa, Ontario filed for creditor protection in February 2015.

In the past 2-years, plasma-arc gasification has experienced several high profile closures and shut-downs. Because plasma-arc has a higher capital costs than a similar size WTE facility and a poor track record using MSW as a feed stream, there is no obvious benefit that a plasma-arc facility has over a traditional WTE technology.

2.7 Chemical Processing Technologies

Chemical treatment technologies are those processes that convert the waste stream into usable by-products via one or a series of chemical reactions. Some common examples of chemical treatment technologies include hydrolysis, catalytic depolymerization, and hybrid technologies.

2.7.1 Hydrolysis

The hydrolysis process involves the reaction of the water and cellulose fractions in the MSW feedstock (e.g., paper, food waste, yard waste, etc.) with a strong acid (e.g., sulfuric acid) to produce sugars. In the next process step, these sugars are fermented to produce an organic alcohol. This alcohol is then distilled to produce a fuel-grade ethanol solution. Hydrolysis is a multi-step process that includes four major steps: Pre-treatment; Hydrolysis; Fermentation; and Distillation. Separation of the MSW stream is necessary to remove the inorganic/inert materials (glass, plastic, metal, etc.) from the organic materials (food waste, yard waste, paper, etc.). The organic material is shredded to reduce the size and to make the feedstock more homogenous. The shredded organic material is placed into a reactor where it is introduced to the acid catalyst. The cellulose in the organic material is converted into simple sugars. These sugars can then be fermented and converted into an alcohol which is distilled into fuel-grade ethanol. The by-products from this process are carbon dioxide (from the fermentation step), gypsum (from the hydrolysis step) and lignin (non-cellulose material from the hydrolysis step). Since the acid acts only as a catalyst, it can be extracted and recycled back into the process.

2.7.1.1 Analysis

There have been some demonstration and pilot-scale hydrolysis applications completed using mixed MSW and other select waste streams. However, there has been no widespread commercial application of this technology in North America or abroad.

Some examples of vendors that offer some form of the hydrolysis technology include: Fiberight; Masada OxyNol; Biofine; and Arkenol Fuels.

2.7.1.2 Costs

In July 2016, Fiberight LLC was authorized to begin construction of a $69 million ($230,000/TPD of design capacity) state-of-the-art waste-to-energy plant in Hampden, Maine. The process includes advanced separation, pre-processing, and washing followed by separate processes for enzymatic hydrolysis and anaerobic digestion. Construction of the campus like facility began in 2016 as a $5M access road and associated infrastructure will be constructed using the community cooperative organization's funds. Initially, the facility is projected to manage 110,000 tons per year from approximately 115 Maine communities that have already signed up to send their waste to Fiberight. The facility was originally scheduled to begin receiving waste in April 2018; the revised estimated date for full operation is December 2018.

At $230,000 per TPD of design capacity, the cost of this technology is in line with other technologies. However, at this time there is little information regarding the operational cost of this technology. At this time, HDR would suggest to take a "wait and see" approach with respect to this process.

2.7.2 Depolymerization Waste-to-Fuel

One type of waste-to-fuel technology is the catalytic depolymerization process. During this process, the plastics, synthetic-fiber components and water in the MSW feedstock react with a catalyst under non-atmospheric pressure and temperatures to produce a crude oil. This crude oil can then be distilled to produce a synthetic gasoline or fuel-grade diesel. There are four major steps in a catalytic depolymerization process: Pre-processing, Process Fluid Upgrading, Catalytic Reaction, and Separation and Distillation.

This catalytic depolymerization process is somewhat similar to that used at an oil refinery to convert crude oil into usable products. This technology is most effective with processing a waste stream with a high plastic content and may not be suitable for a mixed MSW stream. The need for a high-plastics content feedstock also limits the size of the facility.

The City of Edmonton project in Alberta, Canada uses the Enerkem technology and is an example of a hybrid commercial-scale facility that uses mechanical pre-processing of waste followed by gasification and finally the Fischer-Tropsch process to create a biodiesel fuel.

In both cases, the pre-processing step is very similar to the RDF process where the MSW feedstock is separated into process residue, metals and RDF. This process typically requires additional processing to produce a much smaller particle size with less contamination. The next step in the process is preparing this RDF. The RDF is mixed with water and a carrier oil (hydraulic oil) to create RDF sludge. This RDF sludge is sent through a catalytic turbine where the reaction under high temperature and pressure produces light oil. The light oil is then distilled to separate the synthetic gasoline or diesel oil.

2.7.2.1 Analysis

There are no large-scale commercial catalytic depolymerization facilities operating in North America that use a mixed MSW stream as a feedstock. There are some facilities in Europe that claim to utilize a similar process to convert waste plastics, waste oils, and some quantities of mixed MSW. One vendor (KDV) has built a commercial-scale facility in Spain that has been in operation since the second half of 2009 that they claim uses a mixed MSW stream. However, HDR's efforts at confirming these claims through obtaining operating data or an update on the status of this facility were not successful.

Some examples of vendors that provide catalytic depolymerization-type technologies include: ConFuel K2; AlphaKat/KDV; Changing World Technologies; and Green Power Inc.

2.7.2.2 Costs

The City of Edmonton project in Alberta, Canada is an example of a hybrid commercial-scale facility. The facility will cost over $100M to construct in addition to the $40M spent by the City of Edmonton to construct a 100,000 ton per year waste pre-processing (RDF type) facility.

Waste-to-Fuel has a higher capital costs than other proven technologies and the long-term reliability of such emerging technologies remains in question. Therefore there is no obvious benefit that a waste-to-fuel plant (catalytic depolymerization or hybrid facility) has over other, more cost effective and proven technologies. HDR would suggest a “wait and see” approach to this technology.

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3 Potentially Suitable Technologies

3.1 Long-List of Technologies

Table 3-1 summarizes the discussion above and identifies a long-list of technology alternatives that are available when considering future disposal options.

Table 3-1: Summary of Available Waste Disposal Technology Classes

Technology Class	Primary Type of Waste Handled [1,2]
Landfill Technology Class	
Landfill	All Solid Wastes
Rail Haul \ Long Haul to Landfill	All Solid Wastes
Organics Management/ Biological Technologies	
Aerobic Composting	Biodegradable fraction of Mixed MSW; Source Separated Organics (SSO/Food Waste); Leaf and Yard Wastes
Anaerobic Digestion (AD)	Biodegradable fraction of Mixed MSW; SSO/Food Waste; Agricultural Wastes
Aerobic Digestion	Biodegradable fraction of Mixed MSW; SSO\Food Waste
Mechanical Technology Class	
Mixed Waste Processing Facility	Mixed MSW; Recyclable Materials
Mechanical Biological Treatment	Mixed MSW; SSO/Food Waste; Leaf and Yard WastesCan be combined with Anaerobic Digestion
Steam Classification	Mixed MSW; Wastewater Biosolids
Thermal Technologies - Traditional	
Mass Burn Combustion	Mixed MSW
Refuse Derived Fuel (RDF)	Pre-processed Mixed MSW
Fluidized Bed Combustion	Pre-processed MSW; Wood Wastes; Wastewater Biosolids
Thermal Technologies – Emerging)	
Gasification	Pre-processed MSW; Coal; Wood Waste
Pyrolysis	Pre-processed MSW
Plasma Arc Refuse Derived Fuel (RDF)	Pre-processed MSW; Hazardous Wastes
Chemical Technology Class	
Hydrolysis	Cellulosic fraction of MSW (e.g. paper, food waste, yard waste) can be combined with Anaerobic Digestion
Catalytic Depolymerization	Plastic and synthetic fiber fraction of MSW; Plastics; Pre-processed MSW; Coal; Wood Waste

Notes:
1 Based on actual experience and operating data, although in some cases it's based on vendor claims that need to be substantiated in next phase of Assessment.
2 Some technologies have experience with the management of a broader range of waste streams; however, for the purposes of this report, we have only identified waste streams for which the Corporation has management responsibility.

3.2 Short-List of Technologies

The primary goal of this study is to identify the most promising long-term solid waste disposal options, giving consideration to cost, risk, and environmental impacts over a range of potential waste volumes to be managed.

HDR developed a "Long-List" of technologies in the previous section. This section evaluates the long-list and narrows it to a "Short-List" of technologies suitable for the Corporation to consider as they develop their future waste management strategy.

HDR assumes that the Corporation is responsible to accept and manage:

- A minimum of 310,000 TPY of municipal sector mixed solid wastes only; and
- A maximum of 1,150,000 TPY of all wastes which includes:
  - 700,000 TPY of residential and ICI mixed solid waste
  - 200,000 TPY of unprocessed C&D
  - 250,000 TPY of other waste including soils, processed residuals, sludges, ash, etc.

By using these extremes, the Corporation will better understand the spectrum of solid waste management options that are available throughout the range of potential tonnages.

From a technical perspective, the primary differentiator between most of these technologies is past performance with, and their commercial readiness for, a large scale MSW feed stream. The assessment of commercial readiness is largely based on reference facilities. The only way to truly demonstrate the ability of a technology is to have a reference facility of similar size and processing a similar feedstock with actual development and operating data that can be compiled and evaluated. For this study the test criteria for commercial readiness of a proposed technology were multiple facilities operating within the United States for a minimum of 5-years at a minimum of 500 TPD of MSW with a 85% availability rate. The Corporation is responsible for managing the solid waste for the entire State of Rhode Island any technology selected must meet these minimum criteria to be considered further.

The following defines each screening criteria applied in the evaluation to arrive at the Short-List of potential technologies:

a. **Commercial Readiness.** The degree to which the technology and the proposed components have been demonstrated in North America on mixed MSW of similar character and quantity (>500 TPD);

b. **Applicability to Residential and ICI Waste.** The degree to which the proposed technology is suitable to manage the entire residential and ICI waste streams;

c. **Ability to Complement Existing Recycling and Diversion Efforts.** The degree to which the proposed technology does not compete with and can potentially enhance recycling and diversion processes already in place; and

d. **Consistency with the Corporation's Mission and Goals.** The degree to which the technology supports the Corporation's Mission and Goals.

Table 3-2 below, identifies each of the technologies and provides an assessment of their commercial readiness based on known reference facilities.

Table 3-2: Technology and Screen Criteria Summary

Technology	Screening Criteria				Short-Listed?
	Commercial Readiness?	Applicability to MSW and ICI Wastes?	Compliments Existing Recycling and Diversion Efforts?	Consistent with the Corporation's Mission and Goals?	
Landfills					
Continued use of Landfills	Yes – Currently Using Successfully at >750K TPY	Yes – Currently Using Successfully	Yes – Allows as much Up-Front Recycling and Separation as Warranted	Conditional – Continued Use of Landfilling	Yes – Lowest Cost Option, but a Finite Resource
Long-Haul to Landfill	Yes – Rail or Truck hauling at >750K TPY	Yes – Can Accept All Waste Types	Yes – Allows as much Up-Front Recycling and Separation as Warranted	Conditional – Continued Use of Landfilling	Yes – To Be Cost Effective Likely Will Require Rail Hauling
Organics Management					
Aerobic Composting/Co-Composting	Yes – Currently Using Aerated Windrow Composting Successfully for Source Separated Leaf & Yard waste at > 40,000 TPY	Yes – Can process Source Separated Leaf & Yard Wastes and Co-Composting can additionally process Source Separated Food waste and organics.	Yes – Currently being used successfully	Yes – Conserves landfill space for other wastes	Yes – Corporation already has windrow composting for leaf and yard waste and many communities also provide this service. Continue and perhaps expand existing operation for Leaf & Yard Wastes to include food wastes
Anaerobic Digestion	Yes – for Biosolids and Source Separated Organics at tonnages between 50 TPD and 180 TPD.	No – Only Practicable for Source Separated Organics and Biosolids	Yes – Could Be Used in Conjunction with Advanced Mechanical Separation	Yes – Conserves landfill space and supports New State Regulations	Yes – If Used in Conjunction with Advanced Separation or source separated food waste.
Aerobic Digestion	No/Yes – Not Widespread Use for Entire MSW Waste Stream;	No – Will Only Manage Biodegradable Wastes	No – Will Compete with existing SSO Programs;	Yes – But Corporation already provides for	No

Technology	Screening Criteria				Short-Listed?
	Commercial Readiness?	Applicability to MSW and ICI Wastes?	Compliments Existing Recycling and Diversion Efforts?	Consistent with the Corporation's Mission and Goals?	
	but one example at 200,000 TPY		Requires Intensive Pre-Processing to Remove non Bio-degradable materials from the Waste Stream to Produce Saleable Compost Material	composting of leaf and yard wastes	
Mechanical Technology					
Mixed Waste Processing Facilities	Yes – Utilized in Many States – Could Be an Extension of Proposed existing or proposed MRF – tonnage in the 1,000 TPD to 2,250 TPD.	Yes – A Large Enough Facility Could Manage Entire MSW/ICI waste Stream (700K TPY)	Yes/No – Potential to compliment or become substitute for existing or proposed MRF	Yes – Supports Recycling and Reserves Landfill for Non-Recyclables	Yes– Meets all criteria established however, if Corporation continues to promote single stream recycling this program will have limited impact. However, it may be needed as part of a larger Refuse Derived Fuel program.
Mechanical Biological Treatment	Yes - Commercial-scale facilities in operation in Europe (Germany) and Canada (Edmonton).	Yes - The technology targets recyclables and organic fraction of the waste stream	No - Recyclables currently source separated by residents and commercial accounts this would not compliment MBT.	Yes - The technology can help increase recycling, especially if it targets the organic fraction of the waste stream	No – Currently the cost is too high, and no known MBT facilities in US at tonnages suitable for use at RIRRC.
Steam Classification	No - Some commercial-scale facilities in operation in Europe (England and Germany) and Japan that treat medical wastes but not at >500 TPD levels	No - The batch process is not ideal for a waste stream as large as the RIRRC's.	No - The batch process is not ideal for a waste stream as large as the RIRRC.	No - The technology targets the organic fraction of the waste stream, which could be managed by a proven technology.	No

Technology	Screening Criteria				Short-Listed?
	Commercial Readiness?	Applicability to MSW and ICI Wastes?	Compliments Existing Recycling and Diversion Efforts?	Consistent with the Corporation's Mission and Goals?	
Thermal -Traditional					
Mass Burn	Yes – Used throughout the world at various tonnages up to 3,000 TPD	Yes – Can Manage the entire MSW stream	Yes – can be used in conjunction with current or enhanced recycling efforts	No – Enabling Legislation does not allow WTE Combustion Technologies	Yes – Meets all criteria except for enabling legislation
Refuse Derived Fuel (RDF)	Yes – Over 30 years of operating experience in North America; (SEMASS; MA; Detroit, MI; Hartford, CT)	Yes - Proven capability of handling a wide variety of waste stream quantities and compositions	Yes - can be used in conjunction with current or enhanced recycling efforts	No – Enabling Legislation does not allow WTE Combustion Technologies	Yes – when combined with MWPF and AD it will meet all criteria except for enabling legislation
Fluidized Bed Combustion	Yes – Fluidized Bed Combustion is a proven technology.	Yes/No – Only one commercial facility in LaCrosse Wisc. operating on MSW.	Yes - can be used in conjunction with current or enhanced recycling efforts.	No – Enabling Legislation does not allow WTE Combustion Technologies	No – Fluidized Bed has only one facility operating on mixed solid waste in the U.S., Mass burn and RDF are better suited if using thermal technologies.
Thermal - Emerging					
Gasification	No - Not with MSW in North America at comparable scale (>500 TPD). Commercial scale facilities in Europe and Japan operating on select feedstocks and some municipal solid wastes (<200 TPD)	No - Technology vendors claim to have experience operating on MSW, but long term proven operation on MSW in North America waste stream is not proven.	Potentially - Could be coupled with other chemical processes (e.g. Fischer Tropsch process) to produce a biofuel (i.e. Enerkem in Edmonton, Alberta)	No – Not a proven and reliable technology using MSW.	No – Not enough track record in North America using unprocessed MSW as a fuel at tonnages similar to RIRRC (>500 TPD).
Pyrolysis	No - Commercial-scale facilities in Europe (Germany) operating on	No - Technology vendors claim to have experience operating on	Potentially - Could be coupled with other chemical processes.	No – Not a proven and reliable technology using MSW.	No – Not enough track record using MSW as a fuel at tonnages similar to

Technology	Screening Criteria				Short-Listed?
	Commercial Readiness?	Applicability to MSW and ICI Wastes?	Compliments Existing Recycling and Diversion Efforts?	Consistent with the Corporation's Mission and Goals?	
	select feedstocks and some MSW. Not proven reliable at large scale using MSW.	MSW, but not in quantities and types similar to RI.			RIRRC.
Plasma-Arc Gasification	No – All commercial-scale facilities attempted (St. Lucie, Florida and Alter NRG) and Canada (Plasco in Ottawa), and Europe (Tees Valley, GB) have failed.	No – No long term proven operation on MSW stream at sufficient tonnage and time span.	Potentially - Most plasma arc technologies require some preprocessing of the waste stream for size reduction that may provide additional recovery of marketable metals (ferrous and non-ferrous).	No – Not a proven and reliable technology using MSW.	No – Not proven technology using MSW as a fuel at tonnages similar to RIRRC.
Chemical Technology					
Hydrolysis	No - No widespread commercial operation of technology on mixed MSW > than 500 TPD.	No - The technology targets the organic fraction of the waste stream, which could be managed by a proven technology.	No - The technology targets the organic fraction of the waste stream, which could be managed by a proven technology.	No - No widespread commercial operation of technology on mixed MSW.	No - No widespread commercial operation of technology on mixed MSW.
Catalytic Depolymerization	No - Some commercial and demonstration scale facilities in Europe and North America on select feedstocks (waste plastics, oils, biomass). No widespread commercial operation of technology on mixed MSW at >500 TPD.	No - The technology uses the mixed plastics and organic fraction of the waste stream, which could be managed successfully using a proven technology.	No - The technology uses the mixed plastics and organic fraction of the waste stream, which could be managed successfully using a proven technology.	No - No widespread commercial operation of technology on mixed MSW.	No - No widespread commercial operation of technology on mixed MSW at tonnages similar to RIRRC.

Based on the table above, HDR has developed a Short-List of technologies that are available, compatible, economical, and consistent with the Corporation's missions and goals.

The shortlisted technologies include:

- Continued Landfilling Including Long Distance Hauling
- Aerobic Windrow Composting for Leaf and Yard Waste and potentially co-composting with source separated or mechanically separated organics.
- Anaerobic Digesters
- Mixed Waste Processing Facility
- Waste to Energy Facility (Mass Burn or RDF)

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4 Benefits, Drawbacks, Costs and Critical Paths

This section provides additional analysis of the disposal technologies short-listed for further consideration. It includes discussions of the technologies' expected benefits, drawbacks, potential costs and the timelines or critical paths for construction and or operation.

4.1 Landfilling

The Corporation is operating under the State of Rhode Island approved Solid Waste Management Plan (2038 Plan) which relies upon the 100-acre Phase VI expansion area that is currently in operation and will allow continued landfilling until 2034 under current disposal rates.

Regardless of what technology is selected by the Corporation to be the focal point of the future solid waste management strategy, there will always be a continued need for a landfill to handle residual wastes and other difficult to manage materials. Future options include additional expansions of the Corporation's Central Landfill, development of a new landfill elsewhere in the State, or hauling the State's waste to out of state landfills.

4.1.1 Central Landfill Phase VII Expansion

4.1.1.1 Benefits

After the Phase VI expansion reaches its final capacity, there is the opportunity to develop additional expansions, i.e. Phase VII. Although plans for a potential Phase VII are not currently being developed, there is a potential to expand the landfill both vertically and horizontally. Expanding the landfill will supply the Corporation with additional volume and extend the life of the landfill. As described earlier, landfilling is typically the most cost effective disposal option and expanding the Central Landfill will cause minimal disruption to existing operations (assuming they remain the same).

4.1.1.2 Drawbacks

The risks of expanding and continuing to landfill are relatively low in the short term as permitted landfill space can always be used in the future. However, there is a risk of relying on this option as facility expansions are not guaranteed and are typically not accepted by local communities. In addition, there will be a point where no additional expansions are possible leaving the Corporation, and the State, in a position where their only option will be to cease accepting waste or develop an alternative disposal method.

4.1.1.3 Cost-Per-Ton

There is no reason to believe that the cost of continuing to expand and operate the landfill at the current daily tonnage received will increase any faster than inflation. However, there is a minimum staff level that must be maintained regardless of tonnage received each year. Staff levels for a 1,500 TPD landfill versus 3,000 TPD landfill may not be much different, although the cost per ton will increase with a reduction in daily tonnage. It is estimated that the cost of operating the Central Landfill in 2017 was approximately $30.00/ton; this is the lowest cost per ton of any option discussed within this study. Regardless of daily tonnage received or planned, continuing to expand and utilize the landfill will remain, in all likelihood, the Corporation's least cost disposal option with an estimated net cost per ton of $35-36/ton.

4.1.1.4 Critical Path

In most cases, developing a landfill expansion can be a long and arduous process. A recent expansion of an existing landfill in Maine took over 10-years from the first application to receiving approval. Based on previous expansions experiences and the current permitting climate, it is recommended that the Corporation allocate about 5-6 years to design and permit a potential Phase VII expansion.

4.1.2 Additional In-State Landfill Construction

In 1989 the Corporation commissioned the University of Rhode Island (URI) to evaluate additional landfill sites within the State. The study consisted of using data and models to select the most acceptable future landfill sites possible. This report resulted in a final short list of candidate landfill sites. Simultaneously, the Department of Resource Economics (REN) also developed a model for evaluating the economic and social impacts of a landfill and developed a separate list of potential sites.

The URI process produced a short list of 11 potential sites. Comparing the URI short list to the top 12 results of the REN site rankings showed a 66% overlap of sites. Interestingly, the locations of four (4) sites in the final short list either include or abut parts of the existing Central Landfill.

If a new landfill were to be considered, a similar comprehensive process would need to be undertaken. For this study, there was no attempt to determine if any of the original shortlisted sites are still available.

4.1.2.1 Benefits

Benefits to developing a new landfill site are the same as developing a Phase VII expansion. As described earlier, landfilling is typically the most cost effective disposal option. If a new landfill site can be found, secured and developed, it could provide the Corporation and State with continued low cost disposal of solid waste for decades.

4.1.2.2 Drawbacks

Continuing the practice of landfilling as the primary disposal method of wastes is losing favor in the Northeast states due to public opposition. The USEPA ranks landfilling as the "least preferred" option on the solid waste management hierarchy. There has not been a new landfill site developed anywhere in New England since 1995. Public opposition has increased the cost and extended the timeframe of permitting a new site to a point where there is little private interest in locating a new landfill. Modern landfills design and construction methods help mitigate potential environmental issues. Landfills do require upkeep and maintenance long after they are capped and closed.

4.1.2.3 Costs-Per-Ton

There is no reason to believe that the cost of operating a new landfill of similar size will be any different than operating the existing Central Landfill. However, there is a minimum staff level that must be maintained regardless of tonnage received each year. However, a new site requires additional costs such as property selection and acquisition costs, extenuated permitting and legal costs, and additional host community payments. When these costs are included the estimated net cost of operating a landfill increases to an estimated $37-$39/ton. Irrespective of planned tonnage or specific of type of waste to be disposed, a new landfill facility will remain one of the lowest cost options for waste disposal, second only to expanding the existing landfill.

4.1.2.4 Critical Path

Developing a new landfill in the Northeast is a long and arduous process. A recent expansion of an existing landfill in Maine took over 10-years from the first application to receiving approval. A new landfill facility is likely to take a similar path as the Maine facility and it is recommended that the Corporation plan on 10-12 years to locate, site, design, permit and construct a new landfill facility.

4.2 Transfer Station Out-of-State/Long Haul Landfill

Solid wastes can be hauled to distant out-of-state landfills for disposal by truck or by rail. Any landfill with enough capacity will be several hundred miles from Johnston, RI. Given the distance, rail haul will likely be the most cost effective method of transporting solid waste.

In Rhode Island, the regional railroad is the Providence-Worcester Railroad (P&W). The regional railroad coordinates with the major railroads to schedule freight cars on and off the major railroad lines to allow for the efficient transportation of goods across the country. This option is based on the Corporation purchasing industrial zoned land with rail access and developing a transfer station that allows for directly loading waste into gondola cars or compacts waste into intermodal containers and loading directing onto flatbed rail cars. Currently, CSX is requiring any gondola cars carrying waste to be fitted with a watertight cover.

Each gondola car can hold approximately 100 tons of waste. A flat bed rail car carrying 4 intermodal containers can carry 88 tons of waste. As an example, if all 583,000 tons of MSW/ICI waste were loaded into intermodal container it would require approximately 85 containers and 22 flat bed rail cars each day (312 days/year). If the remaining 464,000 tons of C&D, Special Waste and Other Waste was loaded into gondola cars, it would require about 15 gondola cars each day (312 days/year). To manage all solid waste via rail will require approximately 85 intermodal containers, 22 flat bed rail cars, and 15 open topped gondola cars each day for 312 day each year.

4.2.1 Benefits

The expected benefit of the rail haul option is that it is a long-term solution that can manage the entire state’s waste stream. Landfills in Virginia, South Carolina, Ohio, and Pennsylvania have decades of capacity. This scenario can be also be implemented now or after the Central Landfill reaches its final capacity. Once implemented, the Corporation will be able to close the Central Landfill or mothball the remaining volume for future use.

4.2.2 Drawbacks

This has two (2) major drawbacks/risks:

1) The Corporation and the State will give up solid waste autonomy. Future waste streams will be subject to fluctuation in rail-road pricing, tipping fees, and potential waste taxes; and

2) There is little potential to increase recycling efforts with the exception of adding a MRF or MWPF which will increase the costs.

4.2.3 Cost-Per-Ton

Based on HDR's review of recent rail haul contracts, a "rule of thumb" budgetary cost estimate for rail haul is $0.05 - $0.10 per ton mile depending on guaranteed tonnages, contract duration, car/container load density, and distance hauled. This is strictly for rail hauling and does not include transload costs, dray, or disposal costs.

Figure 4-2 below displays a capital cost curve for transfer station construction. Based on the curve below and on estimates for other required capital expenses such as land purchase, rail access improvements and rail cars, HDR estimates a 1,000 TPD transfer station will have capital costs of approximately $51,500,000; a 2,500 TPD transfer station will have a capital cost of approximately $99,000,000; and a 3,700 TPD transfer station will have a capital cost of approximately $140,500,000.

Figure 4-1: Capital Cost Curve for Transfer Stations

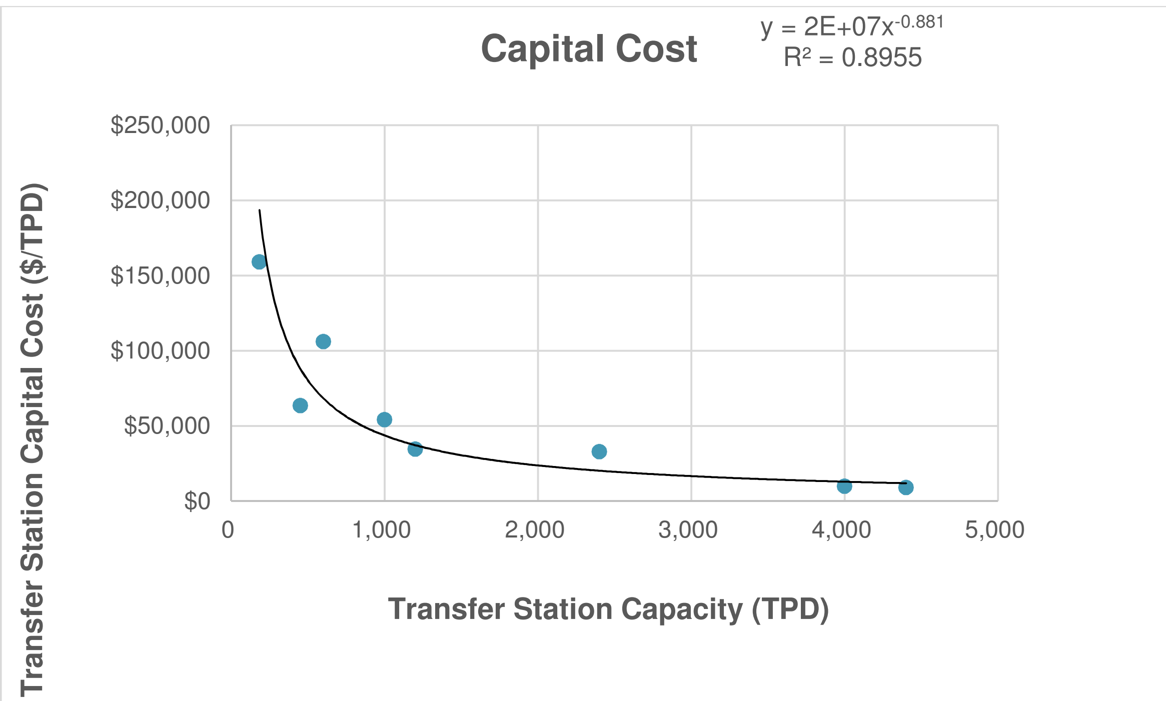


Table 4-1: Transfer Station with Rail Haul Capital, Operation & Maintenance, and Disposal Costs

Tonnage (TPD)	Capital Cost ($)	Annual O&M Cost* ($)	Annual Debt Service** ($)	Net Cost Per Ton*** ($)
1,000 TPD(1)	$51,500,000	$24,180,000	$5,763,000	$100
2,500 TPD(2)	$99,000,000	$58,032,000	$11,080,000	$92
3,700 TPD(3)	$140,500,000	$87,048,000	$15,723,000	$89

(1) Capital Costs of $40M plus $11.5M in rail yard, switch improvements and rail cars.
(2) Capital Costs of $82M plus $17M in rail yard, switch improvements and rail cars.
(3) Capital Costs of $118M plus $22.5M in rail yard, switch improvements and rail cars.
* Includes $4000/car transport, $150/car dray, $10/ton in transfer costs, and $26/ton disposal.
** 10-year bond issued at 2.1%.
*** Assumes no revenue

The cost per ton shown above is the Annual O&M Cost plus the Annual Debt Service divided by the annual tonnage.

4.2.4 Critical Path

The critical path schedule begins with the decision to pursue a SWMP that relies upon the long haul of waste to out-of-state facilities. Major factors in selecting this scenario are 1) entering into a long-term agreement with the short and long railroads or a broker to manage the rail haul portions of the operation, 2) locating and acquiring a large enough parcel with rail access, and 3) securing a contract with an out of state disposal facility to accept the waste from Rhode Island. It is assumed that once suitable properties are located, the remainder the process will take approximately 2-3 years to design, permit, and construct the facilities. Overall, it is estimated that this scenario will take 5-7 years from start to finish.

4.3 Organics Management

4.3.1 Aerobic Co-Composting

The Corporation currently uses aerobic windrow composting to process approximately 40,000 tons per year of leaf and yard waste at the Central Landfill. Aerobic windrow co-composting typically mixes leaf and yard waste with source separated or mechanically separated organics from the MSW waste stream. Co-composting uses leaf and yard wastes, wood chips, food waste, waste papers, and other separated organics and compostable materials, as well as waste water treatment biosolids.

4.3.1.1 Benefits

The relatively low capital and O&M cost makes the continued windrow composting and potentially co-composting a good fit for the Corporation. The current operation at the Central Landfill is about 40,000 TPY with most of the material arriving between April and November. If expanded, to include food waste and other compostable materials, the delivery of materials would be year round. In all likelihood, any expansion will occur gradually over several years allowing for adjustments as tonnage increase.

4.3.1.2 Drawbacks

Aerobic windrow composting and co-composting does take up a large amount of space. The current program is using approximately 7-acres (approximately 6 tons/acre). If 35% of organics currently within the MSW and ICI waste streams are diverted, this will nearly double the tonnage (and double the area required to approximately 14-acres. Although the Corporation has not had any issues to date, odors can become an issue if the windrows are not managed properly.

4.3.1.3 Costs-Per-Ton

The Corporation estimates the composting O&M cost is approximately $42/ton. It is estimated that leaf and yard waste lose about 45% of its mass during decomposition. The finished Grade A compost is sold wholesale to attempt to recoup some of the costs associated with the operations, as the majority of the material received is from the Municipalities and accepted with a zero tip fee. The material selling price is subject to market fluctuations but has historically returned approximately $5/cubic yard ($7.50/ton) to the Corporation. In addition, the Corporation sells a small amount of material to the public for $30/cubic yard ($44/ton) and $8.00 per 40 pound bag ($400/ton).

Table 4-2: Preliminary Opinion of Probable Costs – Co-Composting

Tonnage (TPD)	Capital Cost ($)	Annual O&M Cost** ($)	Annual Debt Service*** ($)	Net Cost Per Ton**** ($)
130 (existing program)*	$0	$1,680,000	$0	$17
260 (expanded program)	$500K	$3,415,000	$56,000	$18

* Assumes no additional capital costs needed for existing or expanded operation
** Assumes no increase in current cost per ton for composting operation
*** 10-year bond issued at 2.1%
**** Net Cost/Ton assumes sale of compost at $30/CY

There is no reason to believe that an expanded composting or co-composting operation will cost any more than the current operation.

4.3.1.4 Critical Path

The Corporation currently operates a 40,000 TPY aerobic windrow composting operation. Expanding or modifying this existing operation is unlikely to have any major time constraints. Because any expansion will likely occur over several years, the operation will have time to adjust as tonnages increase.

4.3.2 Anaerobic Digester

Based on the 2015 waste characterization study, approximately 30% of MSW and ICI waste are made up of organic materials. If the organic material is separated either by a source separation program (curbside) or as part of a mixed waste processing facility, that fraction could be directed to an anaerobic digester.

4.3.2.1 Benefits

If 35% of organics currently within the MSW and ICI waste streams can be recovered, approximately 250 TPD could be diverted from the landfill to an anaerobic digester; or about 75,000 TPY.

This tonnage of organic material could produce approximately 3-7 MW of gross electrical power for use either on-site or sold to the electric utility grid if processed by an anaerobic digester. If landfilled, this tonnage would still biodegrade and produce methane gas. However the landfill gas collection system efficiency (typically about 85%) would not produce as much energy and would allow fugitive emissions to escape to the atmosphere. The controlled environment of an AD facility allows for a nearly 100% capture rate.

4.3.2.2 Drawbacks

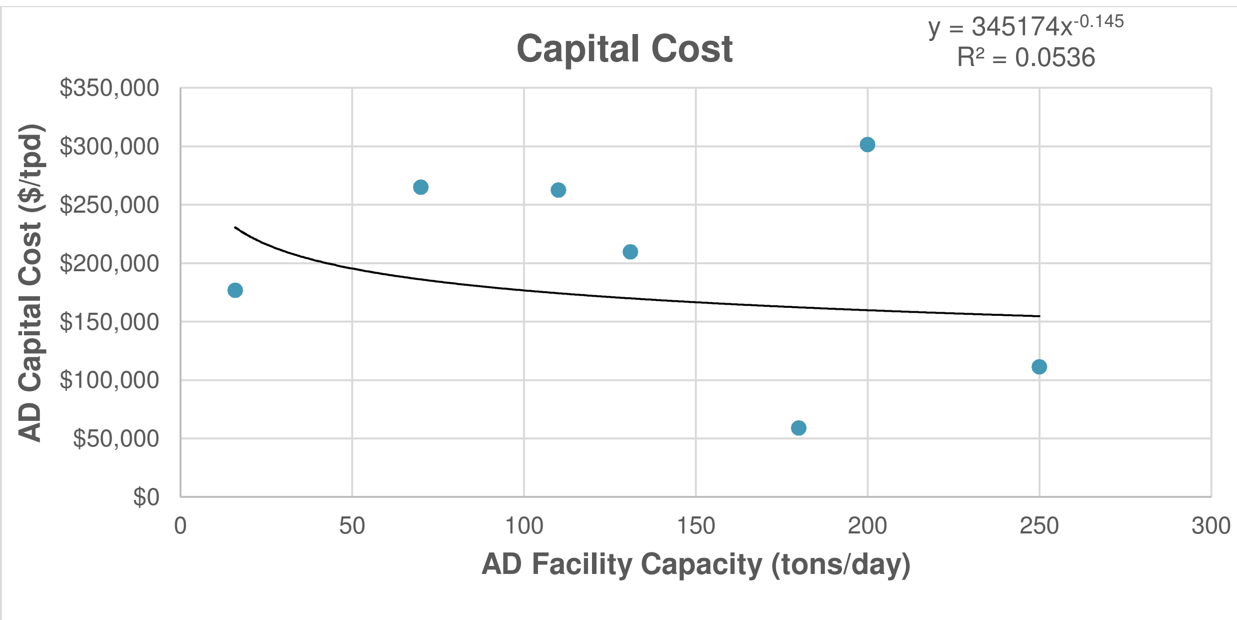
There is an existing anaerobic digester operated by Blue Sphere that abuts the Central Landfill property. The Corporation may end up competing with Blue Sphere for organic wastes.

Current purchase power agreements (PPAs) are fetching about $0.02 to $0.04/Kwh which does not help the economics of the power generated by an anaerobic digester.

4.3.2.3 Costs-Per-Ton

Figure 4-2 below provides a capital cost curve for construction of AD facilities. The curve is based on reported capital costs for seven (7) AD facilities in North America. Capital costs from previous AD facility construction projects were adjusted to 2018 dollars

Figure 4-2: Capital Costs Curve for Anaerobic Digesters



The cost curve above is relatively flat. According to the curve, a 150 TPD facility will have a capital cost of approximately $170,000 per ton of daily design capacity or about $25.5 million. A 250 TPD facility will have a capital cost of approximately $160,000 per ton of daily design capacity or about $38 million.

Table 4-3: Preliminary Opinion of Probable Costs – Anaerobic Digester

Tonnage (TPD)	Capital Cost* ($)	Annual O&M Cost** ($)	Annual Debt Service*** ($)	Cost Per Ton****($)
150 (Res)	$25,500,000	$2,790,000	$2,854,000	$101
250 (Res and ICI)	$40,000,000	$4,500,000	$4,297,000	$90

* from Capital Cost Curve.
** Estimated $60/ton O&M costs.
*** 10-year bond issued at 2.1%.
**** Assumes sale of electricity at $.04/kw-hr.

O&M costs are assumed to be linear at $60/ton.

4.3.2.4 Critical Path

Permitting and construction of an anaerobic facility are not typically difficult, but securing enough, high quality organic waste may take some time. The estimated timeline for siting, designing, permitting, and constructing an anaerobic digestion facility is 2-3 years.

4.4 Mechanical Separation

4.4.1 Mixed Waste Processing Facility (MWPF)

To help combat low public participation rates of traditional recycling programs, such as curbside source separated collection of recyclables, some communities are turning to MWPFs to capture additional recyclables or as operation for more advance conversion technologies that require more processed waste or Refuse Derived Fuel.

It would be possible to divert all of the Corporation's 583,000 tons/year of MSW and ICI wastes through a 2,500 TPD MWPF. An advanced MWPF can achieve up to 50% diversion (1,000 TPD) if traditional recyclables **and** food waste/organics are targeted for removal. The balance of the waste stream is then either landfilled or used as fuel in a thermal application.

4.4.2 Benefits

MWPFs are a fully developed technology to recover and divert wastes from landfills. This technology has the ability to process a wide range of MSW materials and yield potentially high recyclable recovery rates. The separation and recovery technologies continue to improve. A MWPF can be combined with several other technologies as part of an Eco-Campus type solid waste management facility. Theoretically, this technology could divert up to 1,000 TPD from the landfill if used in conjunction with other technologies.

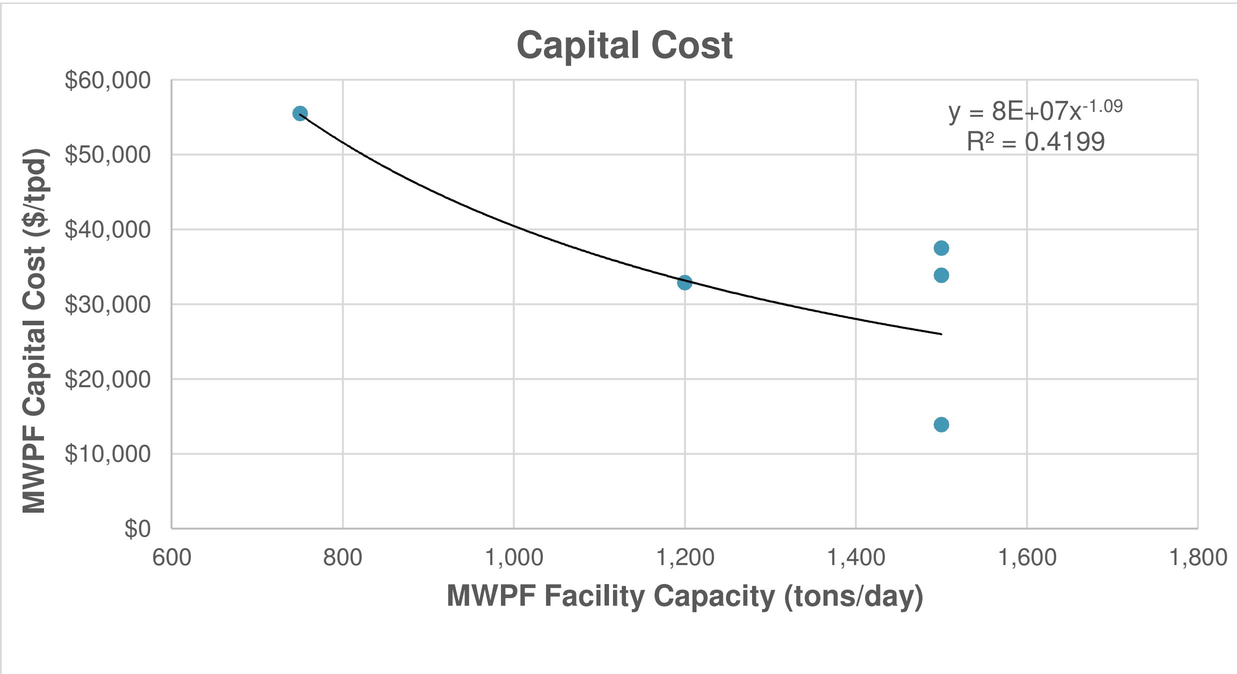
4.4.3 Drawbacks

The largest risks associated with any MWPF project, is the volatility of the recycling markets. In 2008, the recyclables market crashed (except for steel) and recycling processors revenues dropped dramatically. China's new "National Sword" program will ban 24 additional materials from entering their country and will enforce a maximum contamination rate of 0.5%. This has already caused the recycling commodities markets in the United States to drop. China's actions will increase the cost of processing recyclables while decreasing the value of processed recyclable materials. If the market is poor or no end-user is available, 60-80% of the incoming MSW may end up being landfilled.

4.4.4 Costs-Per-Ton

Figure 4-3 below provides a Capital Cost Curve based on the reported capital costs of five (5) MWPF developed in the United States. Capital costs from previous MWPF construction projects were adjusted to 2018 dollars.

Figure 4-3: Capital Cost Curve for MWPFs



Based on the capital cost curve above, the capital costs for a 1,000 TPD MWPF is estimated to be $41,000 per ton of daily design capacity or $41 million. HDR estimated the capital cost for 2,500 TPD MWPF to be $37,184 per ton of daily design capacity or $93 million.

Table 4-4: Preliminary Opinion of Probable Costs – MWPF

Tonnage (TPD)	Capital Cost ($)	Annual O&M Cost*** ($)	Annual Debt Service**** ($)	Net Cost Per Ton***** ($)
1,000	$41,000,000*	$16,066,000	$4,588,000	$39
2,500	$92,960,000**	$40,164,000	$10,403,000	$37

* Estimated $41,000/tpd of capacity from Capital Cost Curve.
** Estimated $37,184/tpd of capacity.
*** Estimated $54/ton O&M costs without debt payment or residual disposal costs.
**** 10-year bond issued at 2.1%.
***** Revenue based on average sale of recyclables at $84.72/ton.

Operation and maintenance (O&M) costs consist primarily of labor, equipment maintenance and disposal costs for residue. A 2006 study found that the average O&M cost for facilities processing over 218 tons per day was approximately $56/ton including debt service.[10] HDR has estimated a $54/ton O&M cost without debt service or residuals disposal costs.

4.4.5 Critical Path

It is estimated that a modern MWPF will likely take approximately 3-5 years to design, permit and construct. This assumes the location will be on the existing Central Landfill property; therefore no additional time is spent locating and permitting a new site.

4.5 Waste-to-Energy Facility

A Waste-to-Energy (WTE) facility is a thermal processing technology where waste materials are burned to produce large amounts of heat that is used to create steam to drive electrical generators. The process will typically reduce the mass and volume of the solid waste disposed by 75% and 90%, respectively. Therefore while this process reduces the overall volume of waste, a landfill is still required for the residual ash. However, this process will increase the landfill lifespan.

Large (mass burn or RDF) combustion facilities are typically > 500 TPD. Smaller combustion facilities typically use a modular unit (or multiple modular units) on the order of less than 200 TPD.

Large-scale and modular mass burn and RDF combustion technology is used in commercial operations at 80 facilities in the U.S. and Canada and more than 400 in Europe, as well as more than 400 in Asia (mostly in Japan and China).

Most WTE facilities in North America were constructed between the early 1980's and early 1990's and are nearing the end of their intended operational lifespan. However, with regular maintenance, these facilities can continue to operate indefinitely. There were several expansions of existing WTE facilities, and some new WTE facilities constructed in the last 3 years.

All WTE technologies utilize an extensive set of air pollution control (APC) devices for flue gas clean-up. A summary of contaminants from exit gases is included in the table below. As you can see, major improvements have been made since the 1990s. It should be noted that nitrogen oxide (NOx) emissions can be reduced further with specialty control technologies.

Table 4-5: Emissions from Large and Small MSW Combustion Facilities Pre- vs. Post-MACT Comparison

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

Source USEPA https://archive.epa.gov/epawaste/nonhaz/municipal/web/html/airem.html#1

In addition, dioxin and furan emissions declined more than 99% from 4,400 grams TEQ in 1990 to 15 grams TEQ in 2005.

4.5.1 Benefits

The expected benefit of constructing a WTE facility is the stability and autonomy in waste management that the program will bring to the Corporation and to the State. Once built and in operation, the technology will decrease the tonnage of waste required to be landfilled by 75%. For example, a 1,600 TPD facility will require only 400 TPD of ash disposal capacity; or save approximately 375,000 TPY of landfill capacity.

Because the Corporation will own the facility, it can impose flow control which ensures the facility enough waste to operate. The program will also allow for the generation of electricity for sale to the grid.

4.5.2 Drawbacks

The first hurdle to overcome in proceeding towards a WTE facility is the fact that the Corporation's enabling legislation specifically prohibits this type of technology from being considered. As a first step, the Corporation will need to amend its enabling legislation to allow combustion technologies. After that, the major drawbacks are permitting and cost.

Cost is also a major drawback. Depending on the size of the facility, the capital cost will likely range from approximately $275M to $980M and total annual costs could for range from $36M to $113M. The current low electrical rates are also impacting the economics of WTE making most new facilities un-attractive to investors. However, even a modest increase in rates will dramatically improve the economics.

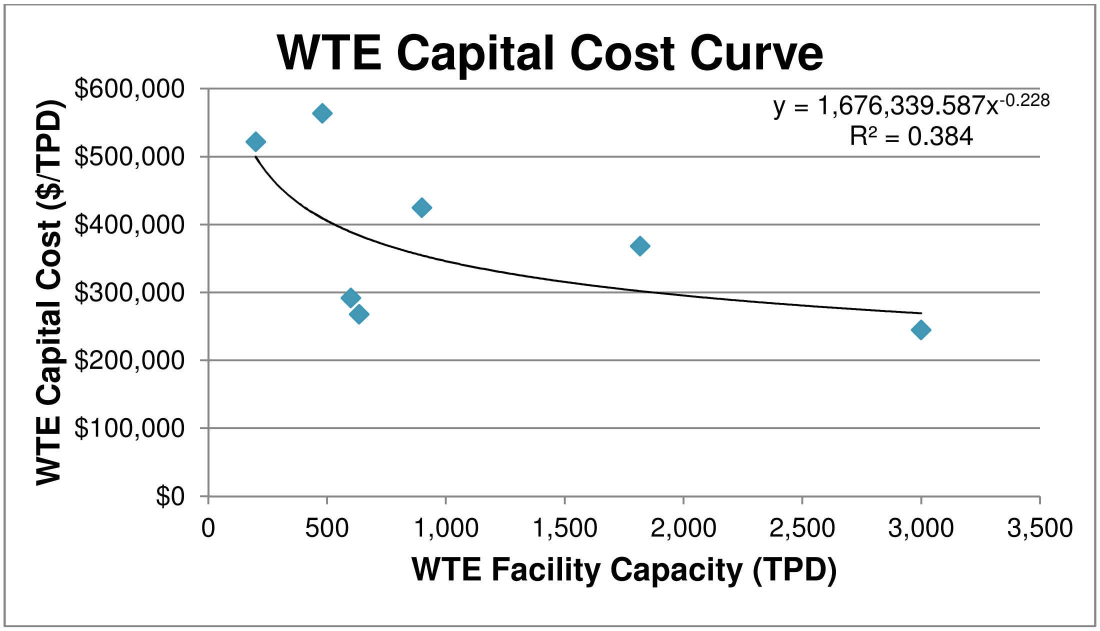
Permitting of a WTE facility can be difficult. It is not uncommon for siting, design, permitting, and construction to take over 10-years.

4.5.3 Costs-Per-Ton

The economics of a WTE facility is heavily dependent on two factors; 1) the price negotiated for the electricity sold to the grid; and 2) the tipping fees received for waste brought to the facility.

Figure 4-4 provides a capital cost curve based on seven (7) WTE facilities constructed between 2007 and 2016. The capital costs were adjusted to 2018 dollars. The cost curve does not differentiate between the types of WTE technologies, but does provide cost opinions for facilities of various sizes.

Figure 4-4: Capital Cost Curve – Waste-to-Energy



This may be used as a tool to estimate a preliminary opinion of probable construction cost for various sized WTE facilities. For example, a 1,000 TPD WTE would be estimated to have a capital cost of $350,000 per ton of daily design capacity; or a total estimated cost of approximately $350 million. A 2,000 TPD WTE facility would be estimated to have a capital cost of approximately $310,000 per ton of daily design capacity; or a total estimated capital cost of $600 million. Capital costs from previous WTE facility construction were adjusted to 2018 dollars.

Based on the curve above and other factors, HDR utilized a flat cost of approximately $392,000/TPD of capacity to develop the opinion of probable construction cost below.

Table 4-6: Preliminary Opinion of Probable Costs – WTE

Tonnage (TPD)	Capital Cost* ($)	Annual O&M Cost** ($)	Annual Debt Service*** ($)	Net Cost Per Ton**** ($)
700	$274,307,000	$18,700,000	$16,938,000	$115
1,000	$391,867,000	$24,000,000	$24,197,000	$113
1,600	$626,988,000	$37,500,000	$41,135,000	$115
2,500	$979,668,000	$52,500,000	$60,493,000	$110

* Estimated $392K per TPD of capacity.
** Estimated $70-$85/ton O&M costs without debt payment or residual disposal costs.
*** 10-year bond issued at 2.1%
**** Includes sale of electricity at $0.04/kw-hr and recovery of ferrous and non-ferrous metals.

4.5.4 Critical Path

The critical path schedule assumes a decision is made to pursue a mass burn combustion WTE facility as part of the revised SWMP. It is expected that changes to the enabling legislation, design, permitting, procurement, construction and testing of a new mass burn facility could take 10-12 years.

5 Summary and Conclusions

This Study reviewed a large number of proven and emerging solid waste disposal technologies. The long-list suite of technologies was reduced to a short-list of those that are potentially suitable for the Corporation to initiate, permit, and construct over the next SWMP planning period (2020 to 2040). Suitable technologies were then further evaluated to identify specific benefits, drawbacks, costs, and critical paths for implementation.

Each technology has its own hurdles and critical paths/schedules. The Corporation is currently in an enviable position of having 14-16 years of capacity within the Phase VI landfill cells. That said, some of these alternatives and technologies may require 10-12 years to plan, design, permit and construct. It cannot be stressed enough that time is of the essence. The hope is that the Corporation will use the information included within this report and develop a 2-year plan to select and begin to implement the long-term solid waste strategy for the State of Rhode Island.

The Corporation should limit its focus to “proven” technologies. Proven technologies are considered solid waste processes and management methods that have a history of managing waste materials with similar characteristics and volume as the Corporation’s waste stream. Many emerging technologies, while operating well on highly processed waste materials at relatively low tonnages (<50 TPD), have not matured enough to offer a reliable solid waste solution for the Corporation and the State of Rhode Island. However, the Corporation should continue to monitor and explore these technologies as they develop.

Most modern solid waste management strategies include a combination of processing and disposal methods at a single location. This is sometimes called an “Eco-Park.” In a way, the Corporation can already be considered an Eco-Park. The Corporation continues to support municipal single stream recycling paired with its Material Recycling Facility (MRF) as well as utilizing aerobic windrow composting for leaf and yard wastes. With the expansion of these operations and installation of an anaerobic digestion (AD) facility to manage food wastes, the Corporation could increase diversion of recyclables and organic wastes. While each of these processes have residual waste materials that will require the continued use of the Central Landfill, or another landfill, the diversion of recyclable and organic wastes will reserve room in the landfill for other solid wastes.

At some point the Central Landfill will reach its ultimate capacity and by that time, an emerging technology may have proven itself at the capacity and reliability needed by the Corporation. If not, the Corporation will face the decision to develop a new landfill, haul waste to an out-of-state landfill, develop a modern waste-to-energy facility, or cap and close the landfill and allow the private sector to manage all of Rhode Island’s wastes.

Because some of these alternatives and technologies may require 10-12 years to plan, design, permit and construct, when the Central Landfill has 10-12 years of capacity remaining (in 2022-2024), the Corporation’s must make its first major decision regarding the future primary disposal technology for solid waste management in Rhode Island.

Table 5-1 provides a cost summary of all short-listed technologies.

Table 5-1: Cost Summary of Short-List Technologies

Short-Listed Technology	Assumed Tonnage (TPY)	Capital Cost ($)	Annual O&M Costs** ($)	Annual Debt Service ($)	Total Annual Cost ($)	Net Cost per Ton ($/Ton)*
LANDFILLING Central Landfill Expansion						
10-Year of Additional Capacity	750,000	$32,625,000	$22,500,000	$3,651,000	$26,151,000	$35
20-Year of Additional Capacity	750,000	$65,250,000	$22,500,000	$4,029,000	$26,529,000	$35
30-Year of Additional Capacity	750,000	$97,875,000	$22,500,000	$4,430,000	$26,930,000	$36
40-Year of Additional Capacity	750,000	$130,500,000	$22,500,000	$4,855,000	$27,354,000	$36
New Landfill						
10-Year of Additional Capacity	750,000	$47,700,000	$22,500,000	$5,338,000	$27,838,000	$37
20-Year of Additional Capacity	750,000	$95,400,000	$22,500,000	$5,891,000	$28,391,000	$38
30-Year of Additional Capacity	750,000	$143,100,000	$22,500,000	$6,478,000	$28,978,000	$39
40-Year of Additional Capacity	750,000	$190,800,000	$22,500,000	$7,098,000	$29,598,000	$39
TRANSFER STATION						
Rail Haul	300,000	$51,500,000	$24,180,000	$5,763,000	$29,943,000	$100
Rail Haul	750,000	$99,000,000	$58,032,000	$11,079,000	$69,111,000	$92
Rail Haul	1,150,000	$140,500,000	$87,048,000	$15,723,000	$102,771,000	$89
ORGANICS MANAGEMENT						
Expanded Composting/ Co-Composting	80,000	$500,000	$3,360,000	$56,000	$3,416,000	$19
Anaerobic Digester	46,500	$25,500,000	$2,790,000	$2,854,000	$5,643,000	$101
Anaerobic Digester	75,000	$40,000,000	$4,500,000	$4,476,000	$8,976,000	$90
MECHANICAL SEPARATION						
Mixed Waste Processing	300,000	$41,000,000	$16,066,000	$4,588,000	$20,654,000	$39
Mixed Waste Processing	750,000	$92,960,000	$40,164,000	$10,403,000	$50,567,000	$37
WASTE-to-ENERGY						
Mass-Burn/RDF	220,000	$274,307,000	$18,700,000	$16,938,000	$35,638,000	$115
Mass-Burn/RDF	300,000	$391,867,000	$24,000,000	$24,197,000	$48,197,000	$113
Mass-Burn/RDF	500,000	$666,174,000	$37,500,000	$41,135,000	$78,635,000	$115
Mass-Burn/RDF	750,000	$979,668,000	$52,500,000	$60,493,000	$112,993,000	$110

* Net Cost/Ton includes revenue from electric sales, compost sales, and recyclables sales; does not include potential revenues from tip fees.

** Costs do not account for cost of collection, potential pre-processing costs for separation, debt service or residual disposal.

See Appendix B for additional details and cost information.

6 Endnotes

1) Advanced Sustainable Materials Management: 2014 Fact Sheet, November 2016 https://www.epa.gov/sites/production/files/2016-11/documents/2014_smmfactsheet_508.pdf
2) Rhode Island Statewide Planning Program, Technical Paper 162, Rhode Island Population Projections 2010-2040, April 2013 http://www.planning.ri.gov/documents/census/tp162.pdf
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