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Municipal Solid Waste in New York City: An Economic and Environmental Analysis of Disposal Options

Executive Summary

Disposal methods for municipal solid waste (MSW) in New York City have evolved from ocean and street dumping to unregulated incineration, and current export and landfilling practices. At present, the majority of New York City's MSW is processed at private transfer stations predominantly located in outer-borough neighborhoods, and shipped on long-haul trucks to out-of-state landfills. Heavy reliance on trucking adversely affects air quality in neighborhoods around transfer stations and leads to traffic congestion, noise, smog, and significant greenhouse gas emissions. Rising fuel prices also threaten to make current disposal methods unaffordable in the future, and landfilling practices can be environmentally problematic, particularly with respect to greenhouse gas emissions.

Each day, the Department of Sanitation (DSNY) disposes of roughly 11,000 tons of waste, and the City is exploring ways to make its solid waste management practices more sustainable. The 2006 Comprehensive Solid Waste Management Plan (SWMP) outlined two major goals: the gradual elimination of long-haul truck transport of MSW (to be accomplished by expanding rail and barge transport infrastructure); and the improvement of neighborhood equity with respect to waste management (to be achieved by adding Manhattan transfer stations and reducing the amount of MSW processed in the outer boroughs). The infrastructure improvements required to implement this plan are extremely costly, and community opposition to new transfer stations has slowed the implementation process.

Additionally, the City has made efforts to explore new conversion technologies for waste disposal by soliciting and evaluating a series of proposals for in-city commercial facilities and commissioning feasibility studies. A range of technologies that could play a role in DSNY's waste disposal efforts are evaluated in this paper.

Waste-to-Energy (WTE) incineration is already used to process portions of New York City's waste at a commercial facility in Newark, New Jersey. This technology combusts MSW and uses the residual heat to generate electricity with net electric output efficiency of approximately 17% to 20%. WTE incineration is cost-competitive with landfilling, and stringent emission controls put in place in the 1990's have drastically improved the quality of air emissions, which once contained high quantities of dioxins and heavy metals. WTE incineration facilities can accommodate large throughputs of MSW, and this disposal option could potentially be expanded at one or more sites proximate to the city (in-city facilities are not currently being considered). One major environmental drawback of WTE incineration is the large number of truck trips required to deliver waste to out-of-city facilities.

Anaerobic digestion is a particularly promising conversion technology that has performed well in New York City evaluations. Through the controlled decomposition of organic material, this process produces a biogas that can be combusted to generate electricity. While proposed facilities can only handle modest portions of the City's MSW, the technology appears to be one of the most cost-effective disposal options available, and it has few environmental drawbacks. A 2010 feasibility study also concluded that an anaerobic digestion facility located near the Hunts Point Food Distribution Center would likely reduce truck traffic associated with waste disposal. This technology, which boasts an impressive energy conversion ratio of roughly 42%, appears ripe for development in New York City.

Thermal processing technologies such as gasification and pyrolysis are relatively young conversion methods that decompose organic waste in high temperature, oxygen-starved environments, and produce syngas (which can be used to generate electricity). These facilities can accommodate large quantities of MSW and produce significant amounts of electricity, however they are currently very expensive to build, operate, and maintain. Because thermal processing facilities generally require a base level of organic and plastic waste in their feedstock to run properly, some environmental groups have opposed the technologies on the grounds that they undermine recycling, composting, and waste reduction efforts.

Given the vast amount of waste managed by DSNY and the complex tradeoffs between various disposal options, a combination of methods will necessarily be needed for New York City's MSW disposal. A precise quantification of the truck travel required for various disposal options could potentially help guide the City's decision-making process, as local truck traffic is a primary source of both negative environmental impacts and neighborhood equity concerns. The calculus involved in this assessment will change as the DSNY truck fleet continues to modernize and incorporate more fuel-efficient vehicles.

As the City recalibrates the composition of future waste disposal contracts, efforts should be made to rapidly integrate desirable new options that have demonstrated feasibility, and ensure that all capital-intensive projects meet the long-term goals outlined in the SWMP. Anaerobic digestion technology appears to offer a promising disposal option, and given the City's stated interest in developing in-city disposal facilities, it may be desirable for the City to begin the siting and procurement processes for such a facility in the near future.

While the primary goals of the SWMP remain desirable, the City may want to re-evaluate the merits of certain capital-intensive infrastructure projects and explore re-directing resources to the accelerated modernization of the DSNY vehicle fleet or the construction of new in-city conversion facilities. These options could potentially achieve the goals of neighborhood equity and environmentally sound disposal in a more cost-effective way.

Solid Waste Disposal in New York City: A Brief History

Until the 1930's, much of New York City's waste was dumped into city streets or the ocean. In 1881, the City created the Department of Street Cleaning, a precursor to Department of Sanitation, in order to deal with pervasive waste in the streets and associated public health problems. For much of the twentieth century, thousands of apartment building incinerators and a small number of municipal incinerators burned large portions of the city's waste. While incineration offered a relatively convenient disposal option, the lack of emission controls meant that the city's air quality suffered. By mid-century, municipal incinerators no longer played a major role in MSW disposal, though apartment building incinerators were still in use through the 1970's.

In the twentieth century, portions of New York City's waste were also sent to 89 city-owned landfills. The largest of these was Fresh Kills Landfill in Staten Island. Initially opened in 1947, Fresh Kills was planned as a temporary solution until new municipal incinerators were built in each borough. It would later become the world's largest landfill.

In the 1990's, in-city incineration fully ceased, and New York City instituted recycling requirements for paper, metal, glass, and plastic. By the late 1990's all the solid waste collected by the City was transported to Fresh Kills, mostly via barge from a series of marine transfer stations. Due to local political pressure and environmental concerns, Fresh Kills was closed in 2001, though it was briefly re-opened as a disposal site for debris from the September 11, 2001 terrorist attacks. After the closure of Fresh Kills, private transfer stations – predominantly located in outer-borough neighborhoods – began processing most of New York City's solid waste for transport by rail and long-haul truck to out-of-state landfills.

In 2006, New York City released its Comprehensive Solid Waste Management Plan, which has two primary goals: increased borough equity with regard to MSW disposal (to remedy the heavy burden placed on neighborhoods that process waste generated in other boroughs), and the reduction of long-haul truck transport for waste export (to reduce both the environmental impacts of truck transport and the economic burden of rising fuel costs and landfill tipping fees). Full implementation of this plan requires significant capital costs, as infrastructure must be modified for MSW containerization to enable increased barge and rail export. The City is continuing to move forward with the process, though community opposition to new transfer stations and budget constraints have delayed the timeline for full implementation.

Quantifying New York City's Municipal Solid Waste

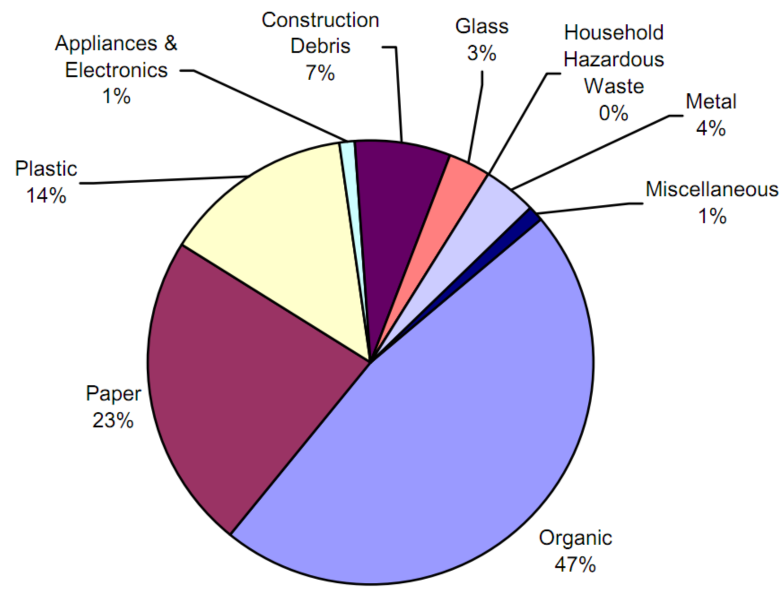
Each year, New York City generates approximately 14 million tons of waste and recyclables.[1] Nearly 50,000 tons of waste are collected per day, and the Department of Sanitation (DSNY) manages about 25% of this amount. The remaining 75% is generated by private businesses or

[1] City of New York, 2011. PlaNYC: A Greener, Greater New York – Solid Waste. April 2011 Update. http://nytelecom.vo.llnwd.net/o15/agencies/planyc2030/pdf/planyc_2011_solid_waste.pdf

construction activities and is privately managed.[2] Over 2,000 city-owned trucks and 4,000 private trucks are used for in-city collection.

The focus of this paper will be the solid waste managed by DSNY and the economic and environmental merits of various disposal options. Each day, DSNY disposes of approximately 11,000 tons of waste, and the agency spends roughly $1 billion annually on solid waste disposal.[3] While the City estimates that one third of the residential waste stream could be recycled through the current curbside collection program, the curbside and containerized recycling diversion rate in New York City was only 15.7% in fiscal year 2010.[4] The vast majority of remaining waste is hauled to out-of-state landfills.

DSNY-Collected Mixed MSW Composition by Material Group



Source: Alternative Resources, Inc., 2006

Current/Planned System of Disposal: Out-of-State Landfilling

The current method of disposal for nearly all of New York City's MSW involves long-haul transport to out-of-state landfills. After the closure of Fresh Kills, the City negotiated short-term contracts with various landfills outside of New York City. In recent years, landfill availability in the Northeast and Mid-Atlantic has become increasingly limited and disposal prices have risen sharply, forcing the City to look farther afield for landfill options.

Long-haul trucking is the primary method used to transport MSW from New York City transfer stations to landfills. Forty-five percent of city-collected waste is currently transported in this manner, while 32% of waste is transported by rail, and 23% travels shorter distances via City-collection trucks.[5] The portion of waste that is not brought to out-of-state landfills is currently processed at the Newark Resource Recovery Center, a Waste-to-Energy incineration plant.

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[2] New York City Department of Sanitation, 2006. Comprehensive Solid Waste Management Plan. http://www.nyc.gov/html/dsny/html/swmp/swmp-4oct.shtml

[3] City of New York, Mayor's Office of Operations, 2011. The Mayor's Management Report Preliminary Fiscal 2011, p. 105. http://www.nyc.gov/html/ops/html/data/mmr.shtml

[4] City of New York, Mayor's Office of Operations, 2011

[5] City of New York, 2011

The Comprehensive Solid Waste Management Plan: In 2006, New York City released its Comprehensive Solid Waste Management Plan (SWMP). This revised framework for waste management outlines ambitious recycling targets as well as plans to reorganize MSW disposal around two broad goals: borough self-sufficiency with respect to MSW disposal, and the eventual elimination of long-haul trucking in order to address rising transport costs and environmental impacts.

Transportation Modes for City-Collected Waste

MODE OF TRANSPORT FROM CITY	CURRENT	FUTURE
Rail	32%	41%
City collection truck	23%	12%
Long-haul truck	45%	0%
Barge	0%	47%

Source: NYC Dept. of Sanitation, NYC Mayor's Office

In order to transition away from long-haul trucking, the SWMP proposes major increases in rail and barge transport of MSW. Because containerization of waste at local transfer stations is a necessary step in this process, the City has formulated plans to build or retrofit a series of transfer stations and upgrade current infrastructure. Four marine transfer stations that became obsolete with the closure of Fresh Kills are slated for retrofitting to accommodate containerization and barge transport: Hamilton Avenue (Brooklyn), Southwest Brooklyn, East 91st Street (Manhattan), and North Shore (Queens).[6] In 2009-2010, initial construction commenced on the Hamilton Avenue and North Shore facilities,[7] while the Southwest Brooklyn and East 91st Street facilities are still in the permitting process. Budget shortfalls and opposition from communities surrounding many of these transfer station sites have significantly delayed the timeline for full implementation of the SWMP. For wastesheds that are not served by these four facilities, the SWMP proposes long-term contracts with private transfer stations for truck-to-rail or truck-to-barge disposal. To date, several of these contracts have been signed.[8] Under the SWMP, much of Manhattan's waste will continue to be processed at the Newark Resource Recovery WTE facility.

Another primary goal of the SWMP is increased borough and neighborhood equity with regard to MSW disposal. Transfer stations located in a small number of outer-borough neighborhoods currently process the vast majority of the city's waste: 70% percent of the city's MSW is processed at 14 waste transfer stations in the South Bronx, 15 in Williamsburg/Greenpoint, Brooklyn, and five in southeastern Queens.[9] The Bloomberg administration has proposed that each borough eventually process its own waste, and full SWMP implementation would create a more equitable distribution of transfer stations (largely due to new sites in Manhattan). However, the planned transfer station on East 91st and a new recycling facility on the Gansevoort Peninsula in Manhattan have already met with fierce community opposition, delaying the implementation of SWMP-inspired efforts to improve neighborhood equity.

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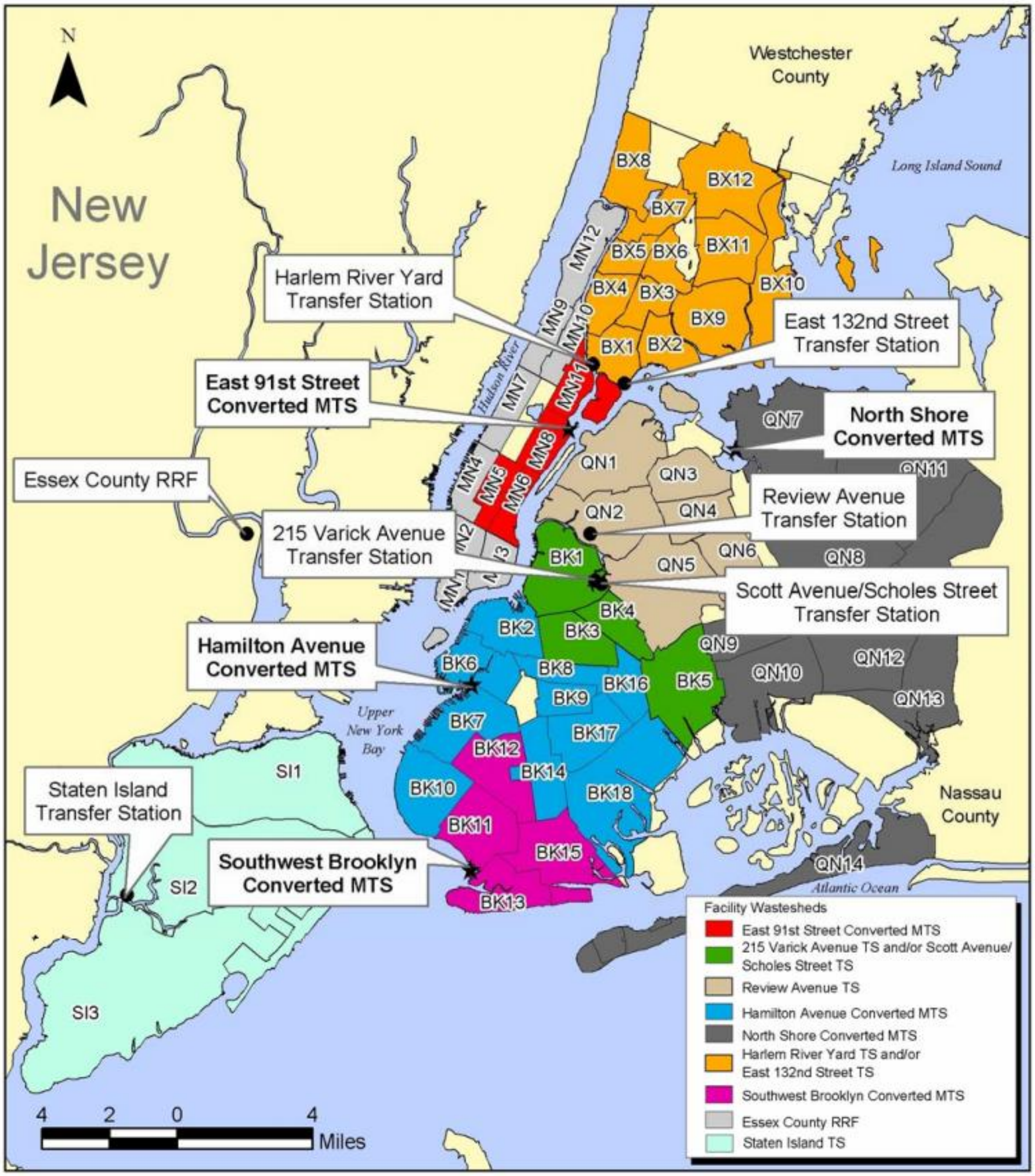
[6] New York City Department of Sanitation, 2006.
[7] New York City Department of Sanitation, 2010. DSNY Annual Report 2010. http://www.nyc.gov/html/dsny/downloads/pdf/pubinfo/annual/ar2010.pdf
[8] Ibid.
[9] Navarro, M., 2011. New York proposes delay for waste transfer stations. *The New York Times*. 25 March.

Locations of SWMP Long Term Export Facilities and Wastesheds



Source: New York City Department of Sanitation, 2006.

Economic Assessment

Transportation Costs: Waste disposal at out-of-state landfills entails significant transportation costs for New York City. Of the City's roughly $1 billion annual budget for solid waste management, approximately $300 million is currently spent to export 3.3 million tons of DSNY-collected waste.[10] Fuel costs and truck fleet maintenance are factored into the "tipping fees" the City must pay private transfer stations to process and transport MSW to distant landfills, and these costs are expected to rise significantly. As of July 2010, New York City was paying $90.97 per ton for waste disposal at the Harlem River Yards transfer station, under a contract with Waste Management, Inc. Between 1997 and 2007, tipping fees at New York City transfer stations increased between 50 and 60 percent.[11] During the recent recession, waste generation quantities have fallen significantly in the northeast, putting downward pressure on tipping fees. However, these fees have historically increased at a rate greater than general inflation. A 2010 study commissioned by the City used 4% average annual increases in tipping fees as its most reasonable projection and 3% as a conservative projection.[12]

Infrastructure Improvement Costs: The SWMP calls for hundreds of millions of dollars worth of waste infrastructure construction projects and retrofits in order to phase out long-haul trucking and move toward neighborhood equity, including:

- A marine transfer station on East 91st Street at the East River in Manhattan, with an estimated cost of $125 million.
- A marine transfer station along Gravesend Bay in southwest Brooklyn, with an estimated cost of $108 million.
- A recycling facility on the Gansevoort Peninsula in Manhattan at Pier 52 on the Hudson River, with an estimated cost of $80 million.
- Retrofits to the marine transfer station in Manhattan at Pier 99 at West 59th St. and the Hudson, with an estimated cost of $50 million.[13]

Capital costs for these and other projects could create a significant financial burden for the City, and full implementation of the SWMP is projected to increase overall costs for collection, transportation, and disposal of MSW by 14.7% over status quo long-haul trucking practices.[14] However, the new facilities would allow for additional barge and rail transport of MSW, protecting DSNY from some of the future tipping fee increases associated with fuel price inflation.

In fiscal year 2009, DSNY spent $228 per ton for municipal refuse collection, not including disposal costs.[15] Collection costs would be expected to drop in the future as additional transfer stations would limit City-collection truck travel by nearly 3 million miles.[16]

Environmental Assessment

Local Impacts from Transportation: New York City's current waste disposal practices lead to problematic local environmental and public health effects. Heavy reliance on truck transport

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[10] City of New York, 2011

[11] R.W. Beck, 2010. Hunts Point Anaerobic Digestion Feasibility Study. Preapred for the New York City Economic Development Corporation. July 2010.

[12] Ibid.

[13] Navarro, M., 2011.

[14] Overall cost projections before and after SWMP implementation can be found here: http://www.nyc.gov/html/dsny/downloads/pdf/swmp/swmp/swmp-4oct/attmnt11.pdf

[15] City of New York, Mayor's Office of Operations, 2011.

[16] City of New York, 2011

adversely affects air quality in communities around transfer stations. Studies have shown that asthma rates are higher in New York City neighborhoods where truck traffic is heavy.[17] The air quality threats associated with heavy truck traffic are likely the greatest local environmental hazard linked to MSW management, and in this respect the City's waste management practices have helped turn some New York City neighborhoods into environmental justice (EJ) communities.

Full implementation of the SWMP is expected to reduce City-collection truck travel by nearly 3 million miles and private long-haul truck travel on city streets by 2.8 million miles.[18] By reducing the amount of truck travel associated with MSW disposal, the City could lessen smog, noise, traffic congestion and air pollution.

As the DSNY trucking fleet is modernized, City-collection truck emissions may become less problematic. Portions of the DSNY fleet have recently shifted toward more efficient vehicle technologies powered by compressed natural gas, ethanol blends, biodiesel, and hybrid-electric engines. The current fleet has reduced particulate matter emissions by 80% and nitrogen oxide emissions by 50%, compared to the 2005 fleet.[19] Similar improvements in long-haul trucking technology are unlikely to occur in the near-term, and because long-haul trucks must initially travel within city limits, disposal options that rely heavily on long-haul trucking tend to have more problematic local environmental impacts.

Greenhouse Gas Emissions: New York City's solid waste system creates an estimated 1.66 million metric tons of greenhouse gas emissions annually, which is 3% of the city's total.[20] The current system has two main sources of greenhouse gas emissions: transportation emissions and methane in landfill gas.

New York City's reliance on long-haul trucking generates significant greenhouse gas emissions, as millions of tons of MSW are trucked to distant landfills each year, using one of the least fuel-efficient transportation technologies available. In addition to reducing truck travel on city streets by nearly 6 million miles, full implementation of the SWMP would eliminate 55 million miles of long-haul truck travel outside of the city. In total, this transition would reduce greenhouse gas emissions by approximately 38,000 metric tons per year.[21]

As MSW decomposes in a landfill, methane-rich landfill gas is generated. Methane is over twenty times more potent a greenhouse gas than carbon dioxide, and while many landfills now capture portions of their emitted gas, landfill emissions consistently rank as the largest or second largest source of anthropogenic methane emissions in the United States.[22] Modern landfill gas

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[17] Spira-Cohen, A., et al., 2011. Personal exposures to traffic-related air pollution and acute respiratory health among
Bronx schoolchildren with asthma. *Environmental Health Perspectives*, 119(4), p. 559-565.

[18] City of New York, 2011

[19] New York City Department of Sanitation, 2010. 2010 Annual Report on Alternative Fuel Vehicle Program. http://www.nyc.gov/html/dsny/downloads/pdf/pubinfo/annual/Hybrid/2010LL38%20Report_2011FINAL.pdf

[20] Ibid.

[21] Ibid.

[22] U.S. EPA, 2010. "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2008." U.S. EPA, Washington D.C., April 10, 2010 http://www.epa.gov/climatechange/emissions/usgginv_archive.html

collection methods are estimated to capture approximately 65 to 90 percent of emissions. As a point of reference, a 2009 study estimated that a Vancouver, BC landfill that captured approximately 80% of its landfill gas still emitted 382 kg of CO_2 equivalent per metric ton of MSW.[23]

In addition to direct greenhouse gas emissions and indirect emissions that are a consequence of MSW disposal (such as emissions from consumption of purchased electricity), New York City has estimated its "Scope 3" emissions, which encompass other indirect emissions that occur outside of City oversight. Annual Scope 3 fugitive methane emissions generated from the decomposition of exported MSW are estimated at approximately 2.7 million metric tons of CO_2 equivalent per year.[24]

New York City's Interest in New Conversion Technologies for MSW

New York City has made efforts to explore new technologies for waste conversion in recent years. In 2004, the City commissioned a multi-part evaluation of new and emerging solid waste management conversion technologies that could be commercially viable for implementation in New York City. Criteria for evaluated technologies included: readiness, size, reliability, environmental performance, beneficial use of waste, and residual waste.

Phase Two of the evaluation, commissioned in 2006, determined that thermal processing and anaerobic digestion were the most promising technologies for use in New York City. The Phase Two report submitted by Alternative Resources, Inc. included a thorough analysis of proposed in-city facilities for two anaerobic digestion technologies and four thermal processing technologies. Hydrolysis was also highlighted as a less developed but potentially viable technology.

The Mayor's Office of Long-Term Planning and Sustainability released an update of its *PlaNYC: A Greener, Greater New York* report in 2011. In a chapter on solid waste, the report details 13 initiatives meant to make the City's waste-related practices more sustainable. Building on the SWMP, these initiatives include enhanced recycling efforts and an exploration of pilot projects for conversion technologies such as anaerobic digestion and thermal processing.

New York City has shown a strong interest in exploring new beneficial use options for MSW disposal, and a range of potential conversion technologies could be worthy of consideration. Three of the most prominent options are detailed in the following sections of this briefing paper.

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[23] Ritchie, M. and Smith, C., 2009. Comparison of greenhouse gas emissions from waste-to-energy facilities and the Vancouver landfill. Technical Memorandum, prepared for the City of Vancouver. March 2009. http://vancouver.ca/engsvcs/solidwaste/landfill/pdf/greenhouse%20Emmissions.pdf

[24] City of New York, 2010. Inventory of New York City Greenhouse Gas Emissions, September 2010, by Jonathan Dickinson and Rishi Desai. Mayor's Office of Long-Term Planning and Sustainability, New York.

Waste-to-Energy Incineration

While Waste-to-Energy (WTE) incineration is currently used as a disposal method for a portion of New York City's MSW and the technology is often cited as a benchmark in discussions of new conversion technologies, there are no current plans to locate WTE facilities within New York City. Any expansion of WTE disposal would likely entail increased capacity at facilities proximate to the city.

Description of Technology: WTE incineration plants combust MSW and capture the residual heat in order to generate electricity, usually with steam boilers. Some WTE facilities also use the heat created in the incineration process to provide district heating.

In the United States, most WTE plants process between 500 and 3,000 tons of MSW per day. WTE plants generate an ash byproduct, in quantities roughly equivalent to 20% of the weight of MSW processed. In the United States, a portion of the ash from WTE facilities is commonly used for landfill cover, or in the production of concrete or cement. In Europe, "bottom ash" (about 85% of the ash) is used in road construction. All remaining ash must be landfilled.

The WTE facility in Newark, New Jersey that currently processes a portion of the City's waste is owned and operated by Covanta Energy. The facility was opened in 1990, and it combusts 2,800 tons per day of MSW, generating approximately 65 megawatts (MW) of electricity for sale.

A WTE facility processing one million metric tons of MSW per year requires a land footprint of about 100,000 square meters.[25]

Prevalence of WTE Facilities: Currently there are 89 WTE plants operating in the United States, cumulatively generating about 2500 MW per day. No new facilities were brought on-line between 1996 and 2007.[26] While the United States Department of Energy and 23 states classify WTE as a "renewable" source of energy, the lack of a cohesive ruling on this classification is one reason for limited expansion of WTE facilities. In 2007, 12.5% of total MSW in the United States was combusted to produce energy, while many European countries combusted over 30%, and Japan combusted over 60%.[27]

Economic Assessment

Energy Generation: Electricity generation at a typical WTE plant is in the range of 500 to 600 kilowatt hours (kWh) per ton of MSW. Standard WTE facilities in the United States use steam boilers to generate electricity, and net electric output efficiency is approximately 17% to 20%.[28] This is only about half the efficiency of fossil fuel plants, so WTE is only economically

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[25] Psomopoulos, C.S., Bourka, A., and Themelis, N.J., 2009. Waste-to-energy: A review of the status and benefits in
USA. *Waste Management* 29, 1718–172

[26] Ibid.

[27] Diamond, M., 2011. Wasting Energy: Waste-to-Energy's Struggle Highlights America's Failure to Incentivize Renewable Energy. *ABA Energy Committees Newsletter*, Vol. 8, No. 4, July 2011.

[28] Waste-To-Energy Research and Technology Council, 2011. Answers to Frequently Asked Questions Regarding Waste-to-Energy. http://www.seas.columbia.edu/earth/wtert/faq.html

competitive as a commercial energy source if the additional benefits of waste disposal and "renewable" status are accorded considerable value.

Many plants co-generate electricity and district heating (at roughly 1000 kWh per ton). Denmark's 28 WTE plants provide 35% of the country's district heating. New York City would be unlikely to benefit from this co-generation capacity because in-city siting of WTE facilities is not currently under consideration.

Tipping Fees: WTE plants earn revenue from both tipping fees and the sale of the excess electricity they produce. As of March 2011, the New Jersey Department of Environmental Protection listed a tipping fee of $92.33/ton for the Covanta WTE facility in Newark.[29] Truck transportation to and from the WTE facilities adds an additional cost burden for New York City.

Capital Costs and Other Economic Factors: While capital costs for new WTE plants can vary significantly depending on location, size, and other factors, the Waste-to-Energy Research and Technology Council estimates a rough guideline of $650 per annual ton of capacity. A typical 1,000-ton per day WTE plant employs about 60 staff members.[30]

Environmental Assessment

Pollutants and Greenhouse Gas Emissions: In the 1990's, WTE plants faced opposition from environmental groups because their air emissions often contained high levels of dioxins/furans and heavy metals. After the Environmental Protection Agency implemented the maximum available control technology (MACT) regulations in 1995, the United States WTE industry reduced dioxin and furan emissions by 99.9% and mercury/volatile metal emissions by 99%.[31] Most WTE plants in the United States now emit significantly less than the allowable amounts of major pollutants.

Average Emissions of WTE Facilities in the United States

Pollutant	Average emission	US EPA standard	Average emission (% of US EPA standard)	Unit
Dioxin/furan, TEQ basis	0.05	0.26	19.2%	ng/dscm
Particulate matter	4	24	16.7%	mg/dscm
Sulfur dioxide	6	30	20%	ppmv
Nitrogen oxides	170	180	94.4%	ppmv
Hydrogen chloride	10	25	40%	ppmv
Mercury	0.01	0.08	12.5%	mg/dscm
Cadmium	0.001	0.020	5%	mg/dscm
Lead	0.02	0.20	10%	mg/dscm
Carbon monoxide	33	100	33.3%	ppmv

dscm: dry standard cubic meter of stack gas.

Source: Psomopoulos et al., 2009

Combustion of solid waste produces fewer pounds of carbon dioxide and sulfur dioxide per megawatt hour than combustion of coal, oil, or natural gas. MSW combustion does emit more nitrogen oxide than oil and natural gas, and

[29] New Jersey Department of Environmental Protection, Facility Tipping Fees, March 2011: http://www.nj.gov/dep/dshw/swr/tipfee.htm
[30] Waste-To-Energy Research and Technology Council, 2011
[31] Psomopoulos et al., 2009

slightly less than coal.[32] WTE emissions of nitrogen oxide still comprise less than 1% of the United States' total.[33]

The city of Vancouver, British Columbia recently conducted a detailed study of how WTE greenhouse gas emissions compare with emissions from landfills. In the 2008 comparison, the WTE facility had lower emissions than the landfill (336 kg of CO_2 equivalent per metric ton of MSW, versus 382 from the landfill). However, as diversion rates are projected to increase and organics are increasingly removed from the waste stream, it is assumed that the percentage of plastic within Vancouver's MSW will rise from 8% to 11%. This plastic-rich MSW would raise WTE emissions to 460 kg of CO_2e/metric ton of MSW, while reduced organic content would lower landfill emissions to 243 kg of CO_2e/metric ton of MSW.[34] New York City's SWMP includes goals to increase recycling diversion rates, so similar future emission patterns from the City's waste stream could reasonably be expected.

WTE incineration facilities such as the Covanta facility in Newark emit a range from 0.4 to 1.5 metric tons of CO_2e per megawatt hour of electricity produced, while landfill gas to electricity facilities emit roughly 2.3 metric tons of CO_2e per megawatt hour.[35]

Transportation Impacts: The MSW that is currently processed through WTE incineration must be trucked to out-of-city facilities, requiring thousands of round-trips per year by collection trucks. While the portion of MSW shipped to landfills by rail or barge is expected to rise with implementation of the SWMP, current WTE facilities with City contracts cannot accommodate rail/barge delivery, therefore any increase in WTE disposal would likely result in additional truck travel and associated truck emissions. Newly built WTE facilities proximate to the City could conceivably accommodate barge and/or rail delivery.

Anaerobic Digestion

New York City has commissioned a series of studies of new conversion technologies for MSW management that could be viable for commercial implementation in the city, and in these studies anaerobic digestion repeatedly emerged as one of the most promising options. The City has also evaluated specific proposals for three in-city anaerobic digestion facilities: commercial proposals from ArrowBio and Valorga, and a feasibility study of a Hunts Point facility (with no specified vendor).

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[32] Diamond, M., 2011
[33] Psomopoulos, et al., 2009
[34] Ritchie, M. and Smith, C., 2009
[35] Covanta Energy Corporation, 2011. Verified petition of Covanta Energy Corporation requesting inclusion of energy from waste as an eligible technology in the main tier of New York's renewable portfolio standard program. Submitted to the State of New York Public Service Commission, February 11, 2011. http://documents.dps.state.ny.us/public/Common/ViewDoc.aspx?DocRefId={B182BB02-B717-47A5-BC00-50F3A556B377}

Description of Technology: Digestion is the controlled decomposition of organic materials by microbes, generating liquids and gasses. Anaerobic digestion occurs in the absence of oxygen. Organic portions of MSW (primarily food waste, yard waste, and paper) must first be separated from the waste stream through a pre-treatment process. Digestion then occurs within a contained chamber. This process produces a biogas (primarily methane and carbon dioxide), which can be combusted to produce electricity, as well as a solid byproduct: digestate. Through a post-treatment process, the digestate can be turned into compost.

Pre-treatment helps maximize recovery of recyclables beyond what is normally diverted. Separation methods for pre-treatment differ in various plans analyzed by New York City. Many involve typical sorting mechanisms such as magnets and screens, as well as size-reduction equipment such as shredders and pulpers. One technology analyzed by the City, ArrowBio, uses a water-based soaking method for separation, followed by wet digestion.

The digestion process can be wet or dry, and solids are retained in the digester for between 20 and 80 days. The biogas produced during digestion generally has methane quantities between 55% and 80%. Some technologies require an additional step to remove contaminants from biogas. Biogas is then commonly combusted to produce electricity, and any electricity not needed to power the process is sold to the grid.

Processing capacities for the proposed ArrowBio and Valorga facilities in New York City would be approximately 200,000 tons per year (slightly over 500 tons per day), significantly lower than throughput for proposed thermal processing facilities or WTE facilities. The ArrowBio facility would require eight acres of land, while the Valorga facility would have a 14-acre footprint. The Hunts Point facility discussed in the City's 2010 feasibility study would process only 60,000 tons of waste per year, and potential sites range from 3.2 to 7.23 acres.[36]

Global Prevalence: Existing facilities using a range of anaerobic digestion technologies are currently operating in Spain, Belgium, Finland, Israel, Australia, and elsewhere. Within the United States there are 151 operational anaerobic digestion systems, however most use livestock manure as an input rather than MSW.[37]

Economic Assessment

Energy Generation: New York City identified electricity production as the most economical use of biogas from anaerobic digestion (other options include vehicle fuel production and biomethane production).[38] Technologies reviewed by the City generated a range from 124-250 kilowatt-hours per ton of MSW processed. The proposed facilities that performed best in the City's analysis, ArrowBio and Valorga, have energy conversion efficiencies of approximately 42%.[39]

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[36] R.W. Beck, 2010

[37] Bracmort, K., 2010. Anaerobic Digestion: Greenhouse Gas Emission Reduction and Energy Generation. Congressional Research Service Report for Congress. May 4, 2010.

[38] R.W. Beck, 2010

[39] Alternative Resources, Inc., 2006. Focused Verification and Validation of Advanced Solid Waste Management Conversion Technologies, Phase 2 Study. Prepared for NYC Economic Development Council. March 2006.

The Hunts Point facility discussed in the City's 2010 feasibility study would produce about 1,500 kilowatts of electricity, net of on-site use.[40]

Projected Tipping Fees: Phase two of the City's evaluation of new conversion technologies included an economic analysis of anaerobic digestion and thermal processing facilities to determine estimated 2014 tipping fees for commercial-scale projects. Projected capital and operating costs were considered, along with estimated quantities of recovered energy, products (such as compost), and byproducts requiring landfill disposal.

Under a public ownership/financing model, tipping fees for anaerobic digestion facilities were projected to be between $43 and $65 per ton, depending on the technology used. Under a private ownership/financing model, fees are estimated at $56 to $80 per ton.[41] This is significantly less than both thermal processing and current landfilling practices.

Large-scale markets are not currently in place for compost produced from MSW digestate. If a market for composting could not be found, landfill disposal of digestate could push the cost to approximately $72 to $108 per ton under public ownership, and $72 to $108 under private ownership.

Tipping fees account for roughly 60% of an anaerobic digestion facility's revenue. The 2010 feasibility study concluded that new in-city facilities would be economically viable if they charged tipping fees of $80/ton, escalating from 2009 at an assumed inflation rate of 3%.[42]

Costs for MSW disposal at anaerobic digestion facilities, particularly with ArrowBio technology, are projected to be less expensive than current landfilling practices and most other disposal options. While the capacity of any single anaerobic digestion facility would accommodate only a modest portion of the City's MSW, this technology seems to present a cost-effective option that could play a role in future New York City disposal practices.

Environmental Assessment

Truck Transport: The City has identified Hunts Point as a potential site for an anaerobic digestion facility, in part because the Hunts Point Food Distribution Center produces large quantities of organic waste that is currently trucked to distant disposal facilities.[43] With the proposed new facility, this organic waste could be processed with little or no truck transportation. A facility on the site would be expected to process about 60,000 tons of waste annually, and approximately 18,000 tons of digestate byproduct would then need to be hauled away. This net reduction of 42,000 tons of material per year would save the City 2,800 truck trips annually (assuming the average truck holds about 15 tons).[44] This considerable reduction in truck transport would lessen traffic and air pollution in a neighborhood that is currently

[40] R.W. Beck, 2010
[41] Alternative Resources, Inc., 2006
[42] R.W. Beck, 2010
[43] DSM Environmental Services, 2005. Hunts Point Food Distribution Center, Organics Recovery Feasibility Study. Prepared for The NYC Economic Development Corporation. December 30, 2005.
[44] R.W. Beck, 2010

overburdened by truck traffic. A facility located near a large source of organic waste in another part of the city near could also be expected to reduce local truck traffic significantly.

Pollutants and Greenhouse Gas Emissions: Anaerobic digestion facilities tend to emit extremely low levels of most pollutants. Little or no dioxin and mercury emissions are reported. However, since the engines used to convert biogas to electricity in most digestion plants do not have nitrogen oxide emission controls, nitrogen oxide emissions are generally higher than those from WTE or thermal processing plants, contributing to smog.[45]

Since methane and other gasses are captured in the anaerobic digestion process, and facilities are powered by the renewable energy produced, greenhouse gas emissions are very low. By reducing the amount of waste sent to landfills, MSW disposal at anaerobic digestion facilities would almost certainly reduce New York City's carbon footprint.

Other Environmental Factors: Unlike WTE and thermal processing, anaerobic digestion requires no fresh water for typical processes, and there is little to no wastewater discharged.

The pre-processing of waste that is necessary before digestion occurs would also allow the City to recover a higher percentage of recyclable items from the waste stream.

Thermal Processing

A number of different thermal processing technologies decompose organic waste in high temperature, oxygen-starved environments. This differs from WTE incineration because the lack of oxygen prevents full combustion and oxidation. Thermal processing technologies include gasification, plasma gasification, pyrolysis, cracking, and depolymerization. Distinctions between these technologies center around the processing temperatures, the amount of oxygen present during processing, and the degree of decomposition of organic waste.

Description of Technologies: Thermal processing technologies generate temperatures of 800 to 8,000 degrees Fahrenheit inside a reaction vessel in order to convert organic materials into "syngas" (typically hydrogen, carbon monoxide, and carbon dioxide) or fuel gas. This gas is then combusted to produce energy. Supplemental fuels such as natural gas are sometimes added to improve gas quality.

Syngas is made of unoxidized or incompletely oxidized compounds. Thermal technologies tend to have lower air pollutant emissions than WTE incineration. More overall waste material is eliminated in thermal processing than in incineration, as the ash remaining after processing is only about 8% to 15% of the original volume.[46]

All carbon and hydrogen-based materials, including plastic, rubber, and textiles can potentially be converted into energy with thermal processing. Some technologies require minimal pre-

[45] Alternative Resources, Inc., 2006

[46] The Blue Ridge Environmental Defense League, 2009. Waste Gasification: Impacts on the Environment and Public Health. http://www.bredl.org/pdf/wastegasification.pdf

processing to remove large items. During processing, inorganic material is often turned into a glassy vitrified material or a solid char material. Portions of this material can have beneficial uses, but a range between 0% and 28% of the material generally requires landfill disposal.[47]

Air pollution controls are necessary on thermal processing facilities, and some technologies pre-clean syngas as well.

Throughputs are relatively high for most thermal processing facilities. Typical plants can process roughly one million tons per year. A single facility of this size in New York City could process roughly 25% of the waste managed by DSNY. Land footprints of the four commercial facilities analyzed for possible construction in New York City range from 11 to 36 acres.

Global Prevalence: Thermal processing technologies are relatively young, but both demonstration projects and commercial facilities have become more common in recent years, particularly in Asia. Japan disposes of about 40 million tons of MSW through thermal processing each year.[48] Plasma gasification plants are currently being constructed in Turkey and India, and a number of North American cities have pilot projects in place.[49] Ottawa's commercial scale thermal processing demonstration project began the process of seeking a license for permanent operation in 2011,[50] while other demonstration projects are in various stages of completion in Los Angeles,[51] Tallahassee,[52] and St. Lucie County, Florida.[53]

Economic Assessment

Energy Generation: Thermal processing facility operations are energy intensive, but the process also generates significant quantities of energy. Net electricity production is typically 380-530 kilowatt-hours per ton of MSW. Some technologies that add fossil fuels to the process can generate over 2,000 kilowatt-hours per ton of waste.[54]

Net electric output efficiencies for most thermal processing plants are approximately 15%, nearly equivalent to WTE technology. However, facilities such as Rigel's proposed plasma gasification plant use combined-cycle combustion turbines and add fossil fuels to syngas, achieving efficiencies of about 37%. Such technologies are therefore on par with base load fossil fuel plants in terms of efficiency, while simultaneously offering waste disposal.

Capital and Operating Costs: Thermal processing facilities are relatively expensive to build, operate, and maintain. Construction costs for the four potential facilities analyzed by the City range from $405 million to $876 million. Average costs for both construction and

47 Alternative Resources, Inc., 2006
48 Alternative Resources, Inc., 2006
49 Pourali, M., 2010. Application of Plasma Gasification Technology in Waste to Energy—Challenges and Opportunities. *IEEE Transactions on Sustainable Energy*, Vol. 1, No. 3, October 2010.
50 http://www.zerowasteottawa.com/docs/141-RT-3557_RevA_PTR%20Final%20Assessment%20Report%20FINAL.pdf
51 http://www.socalconversion.org/index.html
52 http://www.westinghouse-plasma.com/projects/projects-under-development
53 http://www.dep.state.fl.us/Air/emission/construction/geoplasma.htm
54 Alternative Resources, Inc., 2006

operations/maintenance were more than double those of anaerobic digestion facilities on a per-ton basis, according to New York City's analysis.

Projected Tipping Fees: After considering facility costs and potential energy revenues, New York City derived estimates for 2014 tipping fees at four proposed thermal processing facilities. Projected tipping fees range from $96 to $129 per ton under public ownership models and $103 to $165 under private ownership models. While anaerobic digestion tipping fee estimates were significantly lower, these projected fees are still reasonably competitive with estimated out-of-state landfill tipping fees, especially if public ownership/financing could be arranged.

As thermal processing facilities become more prevalent, construction and operation costs are expected to drop.[55] These technologies might therefore present a more cost-effective option for the City in the near future.

Environmental Assessment

Pollutant Emissions: Due to the limited number of commercial-scale thermal processing facilities currently operating, quantitative emissions figures are difficult to obtain. According to most measures, thermal processing is environmentally preferable to WTE incineration in terms of pollutant emissions. Carbon monoxide and nitrogen oxide emissions are lower, and acid gas emissions are far lower. Thermal processing plants also emit fewer dioxins and do not produce ash that requires landfilling.[56]

Greenhouse Gas Emissions: The Environmental Protection Agency identifies Waste-to-Energy disposal methods (including both thermal processing and WTE incineration) as net reducers of greenhouse gas emissions, due to their production of electricity from sources other than fossil fuels, as well as the avoidance of landfill emissions they provide. Because the electric output efficiencies of thermal processing facilities and WTE incineration plants are roughly comparable, their greenhouse gas emissions can be considered approximately equivalent.

Truck Transportation: If a thermal processing facility with a disposal capacity of roughly one million tons per year (this is the approximate size of the commercial facilities evaluated by the City) were built within New York City, approximately 25% of the MSW managed by DSNY could be processed locally, eliminating thousands of miles of long-haul truck transport (some of which occurs within city limits). A smaller-scale demonstration facility could accommodate roughly to 3% to 5% of DSNY-managed waste, contributing to a more modest but still significant reduction in long-haul truck miles traveled.

Total in-city truck traffic would be unlikely to rise appreciably with the adoption of an in-city thermal processing plant, as transport to a thermal processing facility would simply replace transport to a transfer station. Specific quantification of local truck transport changes would depend largely on which current disposal contracts were discontinued. Local truck traffic around the thermal processing facility could be heavy in the (largely industrial) neighborhoods being

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[55] Spoerri, A. et al., 2010. Technological change in Swiss thermal waste treatment: An expert-based socio-technical analysis. *Waste Management* 30 (2010) 1382–1394.

[56] Alternative Resources, Inc., 2006

discussed as potential sites. However, siting a large-scale waste processing facility within city limits would likely lead to a large net reduction in overall MSW truck transportation.

Thermal Processing, Recycling, and Waste Reduction: Thermal processing facilities generally need a base level of organic and plastic waste in their feedstock to run properly. Some environmental groups have opposed thermal processing (and other waste conversion technologies) on the grounds that such technologies undermine recycling, composting, and waste reduction efforts.[57] In most cases, the energy produced by thermally converting waste into syngas is less than that which could be saved by recycling waste and eliminating the need for production of new materials. However, these methods are not necessarily mutually exclusive. Some portion of the waste stream cannot be recycled or will fail to be diverted, and conversion technologies such as thermal processing still have a number of environmental benefits over other disposal methods.

Policy Recommendations

The primary goals of the SWMP – improved environmental justice through borough equity, and a shift toward more environmentally friendly, economical methods of waste transportation – remain highly desirable for New York City. However, in the five years since the release of the SWMP, technological developments and economic factors have created a changed landscape, and the City would benefit from a reevaluation of the best methods for achieving these goals.

Increased reliance on local disposal options could potentially allow the City to limit the capital expenditures proposed in the SWMP. In particular, the construction of some waste containerization facilities/marine transfer stations may prove to be unnecessary if environmental goals can be achieved by processing additional portions of MSW at in-city conversion facilities and nearby WTE plants. Speeding the adoption of improved emission control technology for the DSNY vehicle fleet could also reduce the environmental burdens on New York City neighborhoods.

Given the vast amount of waste managed by DSNY and the complex tradeoffs between various disposal options, a combination of methods will necessarily be needed for New York City's MSW disposal for years to come. Economic considerations, environmental factors, and neighborhood equity must be balanced as the City seeks to create a more sustainable waste management system. As the City recalibrates the composition of future waste disposal contracts, efforts should be made to rapidly integrate desirable new options that have demonstrated feasibility and ensure that all capital-intensive projects meet the long-term goals outlined in the SWMP. A table comparing various disposal options is included at the conclusion of this paper.

The Role of WTE Incineration: Given the cost-competitiveness, reasonable electricity generation efficiency, and high throughput capacity of WTE facilities, this disposal method appears to be superior to landfilling in many respects. WTE facilities proximate to the city also offer disposal sites that do not add environmental burdens to any city neighborhoods and would not spark siting controversies. As such, continuing or increasing out-of-city WTE incineration

[57] The Blue Ridge Environmental Defense League, 2009

practices would likely reduce the burden on New York City's Environmental Justice (EJ) communities.

Required truck transportation to out-of-city facilities remains as one of the major drawbacks of this disposal method. However, improvements in DSNY truck efficiency should eventually negate some of these problems. If the City does continue with full-scale development of containerization facilities for barge and rail MSW transport, it would also be advisable to solicit bids from WTE facilities that can accept waste through these more efficient transportation methods, and consider expanding the tonnage sent to WTE facilities in the future.

In-City Anaerobic Digestion: Based on the City's evaluations of proposed anaerobic digestion facilities, this technology appears to be economically preferable to most other disposal options and it entails few environmental drawbacks. The Hunts Point facility discussed in the City's 2010 feasibility study would also reduce truck travel in a neighborhood that is currently overburdened with traffic and pollution. While an anaerobic digestion facility could only handle a modest amount of the City's MSW, such a facility would likely help meet the overarching goals of the SWMP.

Given the City's stated interest in moving forward with pilot projects for beneficial use MSW conversion technologies, commencing the procurement process for a Hunts Point anaerobic digestion facility in the near term seems to be a worthy goal.

Securing an in-city site for any MSW conversion facility will be one of the greatest challenges facing the City in this process. Neighborhood equity concerns and Not-In-My-Backyard arguments traditionally hinder siting projects, as the communities around proposed sites would face real or perceived environmental burdens from the new facilities. Public outreach and education efforts about the actual effects of in-city conversion facilities should precede any siting efforts. Anaerobic digestion facilities have negligible emissions, and a facility near the Hunts Point Food Distribution Center would be expected to reduce overall neighborhood truck traffic by allowing large quantities of waste to be processed in the immediate vicinity rather than trucked out of the area. Three potential sites for an anaerobic digestion facility were already identified in the 2010 feasibility study. It may be necessary for the City to launch neighborhood environmental remediation or beautification projects in an effort to ease the siting process around the chosen location.

Given current budget issues, it would be advisable for the City to use a Private Ownership and Financing model for this project. The Design-Build-Own-Operate model of public-private partnerships tends to speed the financing process and lessen financial risk for the City.

Thermal Processing: While thermal processing facilities can accommodate large quantities of MSW, they are currently very expensive to build, operate, and maintain. It is unlikely that the City could reduce waste management costs by pursuing a thermal processing facility at the expense of currently planned waste infrastructure upgrades. It is also possible that the ambitious recycling targets proposed in the SWMP and PlaNYC could eventually create problems in ensuring appropriate MSW feedstocks for a thermal processing facility.

However, as new thermal processing facilities and demonstration projects move forward, it is very possible that the technology will mature and become more economically and environmentally viable in the near future.

Looking Ahead: The City should consider undertaking a cost-benefit analysis to evaluate the relative merits of continuing all planned waste infrastructure upgrades, versus adopting a slightly scaled-back plan with portions of available capital diverted to expand in-city disposal options (such as anaerobic digestion) and expedite the modernization of the DSNY truck fleet. As a part of this analysis, the City should attempt to precisely quantify necessary truck miles traveled for all possible disposal options. Truck transport emissions are a major source of local neighborhood pollution as well as greenhouse gasses. Rising fuel costs also make overreliance on truck transport economically risky for the City. As such, disposal plans that limit both local and long-haul trucking should be given initial priority. Because nearly all disposal options require local collection-truck travel, the accelerated modernization of the DSNY truck fleet could potentially offer the most cost-effective way to lessen local environmental impacts.

A wide range of technologies should continue to be considered for future disposal of New York City's MSW. Ideally, the City should conduct a Review of Improvements in MSW Technology approximately every five years, in order to remain on the forefront of developments that could play a role in New York City's waste management. In particular, thermal processing technologies are likely to become more affordable as new facilities are built and one or more of the available technologies emerges as the demonstrated leader in conversion efficiency. Hydrolosis technology will also likely soon advance beyond the demonstration phase in the United States, and should be seriously considered for future MSW disposal projects.

The overall scale of MSW disposal needs in New York City necessitates multiple, and continually evolving solutions. As current landfill contracts near their conclusions, additional in-city projects should continue to be explored.

	Long-Haul Trucking to Landfills	Rail/Barge Transport to Landfills	WTE Incineration	Anaerobic Digestion	Thermal Processing
Annual Throughput (tons per year)	3.3 million (through multiple export contracts)	3.3 million (through multiple export contracts)	1 million (capacity at a facility proximate to NYC)	200,000 (approx. capacity at a proposed in-city facility)	1 million (capacity at a facility proximate to NYC)
Facility Footprint	N/A	N/A	25 acres	8-14 acres	11-36 acres
Estimated Disposal Cost per ton in 2014 (Tipping Fee)[a]	$102.39	$117.45[b]	$103.92	$72 to $108	$103 to $165
Electricity Produced (per ton of MSW)	0	0	500-600 kWh	124-250 kWh	380-530 kWh (>2000 kWh with fossil fuel additives)
Net Electric Output Efficiency	N/A	N/A	17%-20%	42%	15% (approx) (37% with fossil fuel additives)
Long-Haul Truck Miles Traveled per year	55 million	0	0	0	0
Local Truck Travel	BASE CASE needed for collection and local processing	BASE CASE	Approx. 67,000 truck trips[c]	2,800 fewer truck trips than BASE CASE[d]	Up to 2,800 fewer truck trips than BASE CASE
Greenhouse Gas Emissions	382 kg of CO_2e per metric ton of MSW from landfill emissions, plus transport emissions	38,000 fewer metric tons of CO_2e than long-haul trucking scenario	336 kg of CO_2e per metric ton of MSW, plus transport emissions	Significantly lower than landfilling or WTE Incineration	Comparable to WTE Incineration

[a] Long-Haul Trucking and WTE incineration figures represent 2010 tipping fees of $90.97 and $92.33 respectively, with 3% annual inflation. Anaerobic digestion and thermal processing fees come from City projections for 2014, under private ownership/financing (assuming a market for compost cannot be found for anaerobic digestion).
[b] The rail/barge tipping fee estimate represents a 14.7% increase over the long-haul trucking estimate because costs for collection, transportation, and disposal of MSW are projected to be 14.7% higher than costs for long-haul trucking disposal practices after full implementation of the SWMP.
(See http://www.nyc.gov/html/dsny/downloads/pdf/swmp/swmp-4oct/attmnt11.pdf). This tipping fee estimate therefore represents a 14.7% increase over the long-haul trucking cost projection.
[c] Assuming each truck holds 15 tons, nearly 67,000 trips would be necessary to deliver 1 million tons of waste to WTE facililties.
[d] Based on estimates from 2010 Hunts Point Anaerobic Digestion feasibility study.