Memorandum

Date: November 22, 2024

To: Honorable Chairman Anthony Rodriguez
and Members, Board of County Commissioners

From: Daniella Levine Cava
Mayor

Subject: Update on the Site Selection for the Sustainable Solid Waste Campus – Directive No. 241676

Executive Summary

This report is in response to Directive No. 241676, sponsored by Commissioner Gilbert and adopted by the Board of County Commissioners (Board) on September 13, 2024, to conduct an analysis of all the proposed sites for the location of a Sustainable Solid Waste Campus (Campus), specifically evaluate the viability of the Medley land-swap option, meet with the City of Doral (City or Doral) to discuss the City's financial contribution, and bring a final site recommendation to the December 3, 2024, Board Meeting. After careful consideration of all available site options, and particularly given the additional spiraling capital costs and annual operating and maintenance expenses generated by relocation of the Campus, I am recommending the existing Resource Recovery Facility (RRF) site as the location for the Campus. All factors considered, the RRF is the most responsible decision. The Department of Solid Waste Management (DSWM) and the Administration have thoroughly explored and evaluated all viable site options, including reconfiguring the footprint of structures on NW 58th Street. This report provides cost comparisons for six different sites: Doral, NW 58th Street, Airport West, Medley, Eitlejorge, and Okeechobee. A map of the sites can be found attached as Exhibit A.

Timeline

Deciding the Waste-to-Energy (WTE) facility location is important to ensure access to potentially significant insurance proceeds towards the cost of the Campus. The County negotiated an extension with the RRF's insurers, extending the two-year deadline to February 12, 2026. This additional time allows the County to secure a contract to replace the facility. If the deadline is not met, the County will receive insurance proceeds based on the actual cash value of the property, which could be over 40 percent less than the replacement cost. Selecting a site by early December will represent significant progress towards the construction of the facility and increases the likelihood that the County can obtain another extension from the insurers in light of such progress.

Recommendation

Through this process, I learned that there is no perfect site for the Sustainable Solid Waste Campus. As Mayor, my objective is to always deliver critical, quality services to our residents in a financially and environmentally responsible and efficient way. In this case, my priority is to build a safe, environmentally sustainable plant that can integrate seamlessly into the community as part of a broader Zero Waste strategy. Just as importantly, this plant and this Campus should not create an undue burden to any of our ratepayers. I take my role as the environmental and fiscal steward of the public's tax dollars very seriously, and at my direction, County staff has spent countless hours analyzing the financial and environmental costs and benefits to each potential site. On August 18, 2023, I recommended the Airport West site, which was subsequently discussed at the September 6, 2023, Board meeting. My recommendation for the Airport West site was consistent with our Solid Waste Master Plan vision due to its large footprint, which would accommodate

additional facilities for the comprehensive Sustainable Solid Waste Campus. After the Board earlier this year directed us to determine the full extent of the cost differential between building on the RRF site and each of the other sites in connection with a potential MOU with the City of Doral, we drilled down to determine the magnitude of the additional costs that would be incurred by our household and municipal solid waste customers by any relocation of the RRF site.

In consultation with our professional advisors, we identified additional soaring costs, including $65 million in wetlands mitigation and $108 million in hauling costs due to the 1.5-year additional construction time, at the Airport West site, making it less fiscally responsible than originally suggested. In order to leave no stone unturned, staff continued trying to find other alternatives and studied a total of six different locations. Each of the alternative sites generate significant additional capital and/or annual operating and maintenance costs compared to simply building the WTE facility back at the RRF site. Although we have done our due diligence and feel comfortable with the environmental aspects of the Airport West site, the escalating costs thereof make the RRF site the most fiscally responsible decision.

I firmly believe it is in the best interest of the residents of Miami-Dade County to locate the Campus on the RRF site. This location, with added capacity for other Zero Waste components on the County-owned NW 58th Street properties, will allow us to construct a state-of-the-art WTE plant that meets the latest Environmental Protection Agency (EPA) and Department of Environmental Protection (DEP) regulatory standards; this will be a significant improvement over the old RRF facility around which the City of Doral incorporated and grew and where their residents and businesses chose to reside and conduct business. Just as importantly, it will save our residents over $800 million over 20 years which DSWM would otherwise incur by relocating the WTE facility outside of Doral.

City of Doral Negotiations

During discussions, the Board made clear that the City of Doral would need to bear a majority or the entirety of the cost of moving the WTE plant. On November 4, 2024, the City of Doral held a Special Meeting[1]. As a result of that meeting, the City Council passed two resolutions:

(1) The City Council agreed to pay the County an aggregate of $40 million over 30-35 years if the WTE facility is relocated from Doral. However, the Council did not provide any direction regarding whether the City would pay the County if the WTE were moved to Medley or the 58th Street sites.

(2) The City Council authorized the City Attorney to begin conflict resolution under Florida Stat. Ch. 164 if the Board elects to build the Campus in Doral. This requires conflict resolution between governmental entities prior to litigation.

As explained above, moving the WTE site from Doral would cost up to $800 million over 20 years. If Doral is only able to pay $40 million, ratepayers from other parts of the County would be forced to bear the cost. It is also unfair to ask the residents of Doral to take on such a major financial burden that could seriously hinder the city's finances for years to come.

[1] https://legistar1.granicus.com/Doral/meetings/2024/11/1463_A_Special_Council_Meeting_24-11-04_Meeting_Agenda.pdf

Significant Incremental Costs Related to Moving from Doral

The DSWM, in collaboration with Arcadis U.S., Inc. (Arcadis), the Department's bond engineer, compared all costs associated with relocating the WTE facility from Doral. The analysis for the incremental costs for all sites was based on 65 acres per site to ensure consistent comparisons. All estimated development schedules are subject to change depending on detailed site investigation, permitting, protracted litigation, etc. Below are cost comparisons[2] between the six different sites. They have been ranked from least costly to most costly. The cost comparisons include the actual construction cost of the WTE facility, any additional capital costs to be incurred with respect to that site, and total 20-year[3] operating and maintenance (O&M) costs. A more detailed Site Cost Analysis Matrix and a Site Selection Factors Summary Matrix is attached hereto as Exhibit B.

(1) Doral:

- **Estimated construction cost**: $1.5 billion.
- **Additional capital costs**: None.
- **Estimated development schedule**: seven years, nine months.
- **Total annual O&M costs**: $59.3 million. The total annual O&M costs include chemicals, utilities, and ash disposal.

(2) NW 58th Street: To ensure all possible avenues were considered, the NW 58th Street County-owned property was evaluated. This site option proposes moving DSWM Administrative Offices for Collections Operations, Internal Services Department Fleet Shop, and Mosquito Control to the existing RRF site and developing a soccer complex at the closed landfill portion of the site.

- **Estimated construction cost**: $1.4 billion.
- **Additional capital costs**: approximately $322 million. This includes deep dynamic compaction to improve the stability and suitability of the old landfill site for, gas controls, etc.; relocation costs; and waste hauling due to the longer construction period.
- **Estimated development schedule**: ten years, three months.
- **Total annual O&M costs**: $62 million. The annual O&M costs include chemicals, the purchase of potable water and sanitary sewer services, and ash disposal. **We estimate that the 58th Street site will cost an additional $25 million in debt service payments and O&M costs per year with CPI increases over the 20-year period. This translates to an additional $10.29 per ton to the tipping fee and an increase of $35.04 to each household in the waste collection service area in the base year, relative to the Doral site**.

(3) Airport West:

- **Estimated construction cost**: $1.6 billion.
- **Additional capital costs**: approximately $269 million. This includes roadway improvements, wetlands mitigation, and costs for waste hauling due to the longer construction period.
- **Estimated development schedule**: nine years, three months.
- **Total annual O&M costs**: $81 million. The annual O&M costs include chemicals, the purchase of potable water and sanitary sewer services, O&M of a new transfer station, annual rent payments to the Miami-Dade Aviation Department, and ash disposal. **We estimate the Airport West site will cost an additional $40 million in debt service payments and O&M costs per year with CPI increases over the 20-year period. This translates to an additional**

[2] *All cost estimates are presented in 2033 dollars and all sites are considered with a footprint of 65 acres, (Exhibit B). The additional incremental costs use the Doral site as the base.*

[3] *Twenty years represent the useful life of the WTE.*

$16.66 per ton to the tipping fee and an increase of $56.72 to each household in the waste collection service area in the base year, relative to the Doral site.

(4) Medley:

- **Estimated construction cost**: $1.5 billion.
- **Additional capital costs**: approximately $428 million. This includes land acquisition and additional costs for waste hauling due to the longer construction period. Based on discussions with the property owner, the cost to fill the lake areas would be borne by the property owner. The property owner has provided verbal cost estimates to fill the lake. However, that number is substantially lower than what County experts estimate is necessary for a buildable site.
- **Estimated development schedule**: 10 years, 6 months (additional time for lake filling).
- **Total annual O&M costs**: $75 million. The annual O&M costs include the costs for chemicals, the purchase of potable water and sanitary sewer services, annual host fee of $2.6 million to the Town of Medley, host fee of $11 million to the property owner, and ash disposal. **We estimate that the Medley site will cost an additional $46 million in debt service payments and O&M costs with CPI increases over the 20-year period. This translates to an additional $19.02 per ton to the tipping fee and an increase of $64.74 to each household in the waste collection service area in the base year, relative to the Doral site**.
- The Medley owner has proposed that, in lieu of selling us the land, he would swap the land in exchange for land at Airport West. Given the comparative property values, this would result in the transfer of approximately 75% of the acreage of Airport West to the Medley owner, thereby precluding any future use for aviation or an inland port. Furthermore, the intended use of the site for rock mining could prove to be problematic.

(5) Okeechobee:

- **Estimated construction cost**: $1.6 billion.
- **Additional capital costs**: approximately $300 million. This includes roadway improvements, wetlands mitigation, relocation costs for DSWM, DTPW, and ISD Facilities, and additional costs for waste hauling due to the longer construction period.
- **Estimated development schedule**: ten years, four months.
- **Total annual O&M costs**: $77 million. This includes chemicals, the purchase of potable water and sanitary sewer services, O&M of a new transfer station, and ash disposal. **We estimate that the Okeechobee site will cost an additional $47 million in debt service payments and O&M costs per year with CPI increases over the 20-year period. This translates to an additional $19.32 per ton to the tipping fee and an increase of $65.76 to each household in the waste collection service area in the base year, relative to the Doral site.**

(6) Eitlejorge**:** This proposal was received recently and is located on Okeechobee Road, north of the Florida Turnpike. Because this proposal came in later in the process, we did not have ample time to do outreach to any of the cities that might be impacted, e.g. Hialeah and Hialeah Gardens.

- **Estimated construction cost**: $1.6 billion.
- **Additional capital costs**: approximately $200 million. This includes land acquisition and additional costs for waste hauling due to the longer construction period.
- **Estimated development schedule**: nine years, three months.
- **Total annual O&M costs**: $87 million. The annual O&M costs include chemicals, the purchase of potable water and sanitary sewer services, O&M of a new transfer station, revenue sharing of $9.8 million to the property owner, and ash disposal. **We estimate that the Eitlejorge site will cost an additional $48 million in debt service payments and O&M costs per year with CPI increases over the 20-year period. This translates to an additional**

$19.67 per ton to the tipping fee and an increase of $66.97 to each household in the waste collection service area in the base year, relative to the Doral site.

The Facts About Waste to Energy

In addition to cost, staff and third-party experts have thoroughly analyzed any possible environmental and health impacts from a state-of-the-art WTE plant. Miami-Dade County generates over five million tons of waste each year, more than twice the national average per capita, making it essential to have a robust infrastructure to manage this growth sustainably. Under my leadership, the County seeks to develop a Campus that leverages Zero Waste strategies and advanced technologies to protect both our community and the environment. An important part of the Campus will be a WTE facility that will enable us to manage waste sustainably and efficiently in the medium term, as we work toward our goal of becoming a Zero Waste County. WTE is a proven technology that has successfully processed large volumes of waste worldwide. As the County's landfills reach capacity, transporting waste over long distances is neither sustainable nor cost-effective. The Campus will enable us to divert waste away from perpetual landfilling.

Our proposed WTE facility will divert significant amounts of waste from landfills, converting it into clean energy, all while adhering to strict environmental and air quality standards to safeguard our community. A team from the County toured WTE facilities in London and Dublin. They witnessed how many of these facilities are seamlessly integrated within their local communities. Closer to home, the Solid Waste Authority of Palm Beach County (SWA) constructed a mass burn WTE facility in 2015, which has been visited by many County Commissioners and staff. Recently, SWA had a workshop to discuss the replacement of an older WTE plant originally commissioned in 1989. If approved, the new mass burn plant will process 3,000 tons of waste daily and is projected to cost $1.5 billion. The existing two WTE plants have enabled them to divert most of their waste from landfills and exceed the state's 75% Recycling Goal for the last three years.

Despite concerns that WTE could delay a Zero Waste Master Plan (ZWMP), it, in fact, supports this goal by diverting waste from landfills, generating renewable energy as defined by Florida law and the U.S. Environmental Protection Agency (EPA), and handling residual waste that cannot be recycled or composted. Integrating WTE into a ZWMP promotes a circular economy and moves us closer to Zero Waste. There are misconceptions around landfill emissions, incineration, and WTE, which causes confusion among residents and environmental communities. This report seeks to provide clarification surrounding these topics, addresses health concerns, and highlights why WTE is a crucial component in making Miami-Dade County a Zero Waste County.

Concerns about health risks, especially related to emissions and air quality, are understandable when discussing WTE. However, modern WTE plants are equipped with state-of-the-art pollution control systems, such as scrubbers and baghouses, that meet or exceed strict EPA air quality standards. These plants not only reduce waste volume, but also mitigate the health risks associated with landfill methane, odors, and groundwater contamination. Many of the claims raised by opponents may have been true in the past when regulations were lax or non-existent and technology was not as advanced. As detailed below, stronger regulations and the latest technology, all of which will be implemented in our WTE facility, now mean that the operation of these facilities pose minimal risks well below applicable EPA standards for humans, fauna and flora.

Health Concerns

My goal is to ensure the waste facilities servicing our community are safe. At the direction of the Board, the Administration has conducted air modeling and health risk assessments for the

potential WTE sites. Air emissions and human health impacts were not evaluated for the Okeechobee or Eitlejorge Sites; however, due to their proximity to the Airport West site, we do not anticipate significant differences. Preliminary findings from Arcadis[4], DSWM's bond engineer, demonstrate that health risks at all three sites are well below EPA's lifetime cancer risk threshold for common pollutants like benzene. The report also found that health risks related to drinking untreated water near a WTE facility are over one million times lower than the EPA's cancer risk standard. The report also found impacts on flora or fauna below applicable standards.

The EPA enforces strict regulations on all waste management facilities, including WTE plants and landfills, to minimize public health and environmental risks. In countries with weak regulations, hazardous pollutants from waste facilities can contaminate air and water. In contrast, the EPA and Florida Department of Environmental Protection (FDEP) ensure that U.S. facilities meet the stringent standards. The EPA recently proposed stricter emission standards for WTE plants, and we certainly intend to comply with such standards at our facility (Exhibit C).

Myth Busting and Waste Management FAQs

Below are several key misconceptions about WTE, along with corresponding facts that clarify and address each one. Detailed information on these topics, including supporting studies and data, can be found in the attachments to this memorandum (Exhibit D).

Myth #1: WTE facilities have higher greenhouse gas emissions than landfills.
Reality: WTE facilities have a lower GHG impact than landfills (Attachment 1). Electricity generated therefrom reduces reliance on power from the grid, thus avoiding additional emissions.

Myth #2: WTE facilities emit dangerous levels of air pollutants.
Reality: Modern WTE facilities are equipped with state-of-the-art pollution control systems that meet or exceed EPA standards for emissions. An EPA Database[5] illustrates that emissions from WTE facilities are much lower than those from older incineration methods or industrial processes such as cement manufacturing and coal fired power plants.

Myth #3: Recycling and composting are enough to achieve Zero Waste goals.
Reality: While recycling and composting are vital to a ZWMP, they cannot handle all waste streams. WTE offers a solution for waste that cannot be economically recycled or composted.

Myth 4: WTE facilities spread polyfluoroalkyls (PFAS).
Reality: EPA has indicated that the temperature and residence time in WTE technology may be sufficient to neutralize certain PFAS compounds (Attachment 2). Ongoing studies by the EPA aim to assess the effectiveness of WTE technology in the neutralization of PFAS.

Myth #5: WTE is the number one generator of Mercury.
Reality: According to the EPA's own website[6], "the burning of municipal and medical waste was once a major source of mercury emissions. A reduction in the use of mercury along with state and federal regulations, however, has led to a decrease in emissions from this source by over 95%.

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[4] https://documents.miamidade.gov/mayor/memos/04.19.2024-Report-Regarding-the-Three-Alternate-Waste-To-Energy-Facility-Sites-Preliminary-Permit-and-Regulatory-Review.pdf
[5] https://www.epa.gov/air-emissions-inventories/2020-national-emissions-inventory-nei-data
[6] https://www.epa.gov/mercury/basic-information-about-mercury

WTE and Zero Waste

The ultimate goal of a ZWMP is to maximize beneficial use of waste and promote sustainable waste management practices like recycling and composting. However, WTE is often overlooked as an integral part of this strategy, due to a misconception that it competes with recycling efforts or delays Zero Waste goals. WTE can complement these efforts and accelerate the path to achieving Zero Waste by diverting non-recyclable and non-compostable waste from landfills, significantly reducing landfill emissions and extending the life of existing landfill sites.

Miami-Dade County has consistently demonstrated commitment to waste diversion and the beneficial reuse of materials. The county initiated its residential recycling program in 1990 and is working hard to improve our recycling rates. In addition, DSWM continues to expand its used oil collection program, provides e-waste and white goods recycling, and began a mulching pilot program. As part of its plans to integrate a WTE facility into the Sustainable Solid Waste Campus, Miami-Dade County will continue to prioritize waste diversion over disposal.

The WTE facility will have the capacity to process 4,000 tons of waste per day, or approximately 1,330,000 tons annually. Table 1, below, reflects the projected total waste managed by DSWM from FY 2024 to FY 2053. Currently, DSWM manages more than 2,000,000 tons of waste per year, approximately only 40% of the 5 million tons that is generated in Miami-Dade County; by FY 2035, this figure is expected to exceed 2,500,000 tons due to population growth. This projection provides DSWM with the opportunity to divert over 500,000 tons of waste for beneficial reuse. If the County is successful in diverting waste that enters our system, we can then require that the other waste generated in the County enter our system, as provided by Florida law[7]. This affords the opportunity to achieve Zero Waste long term for the entire County waste stream.

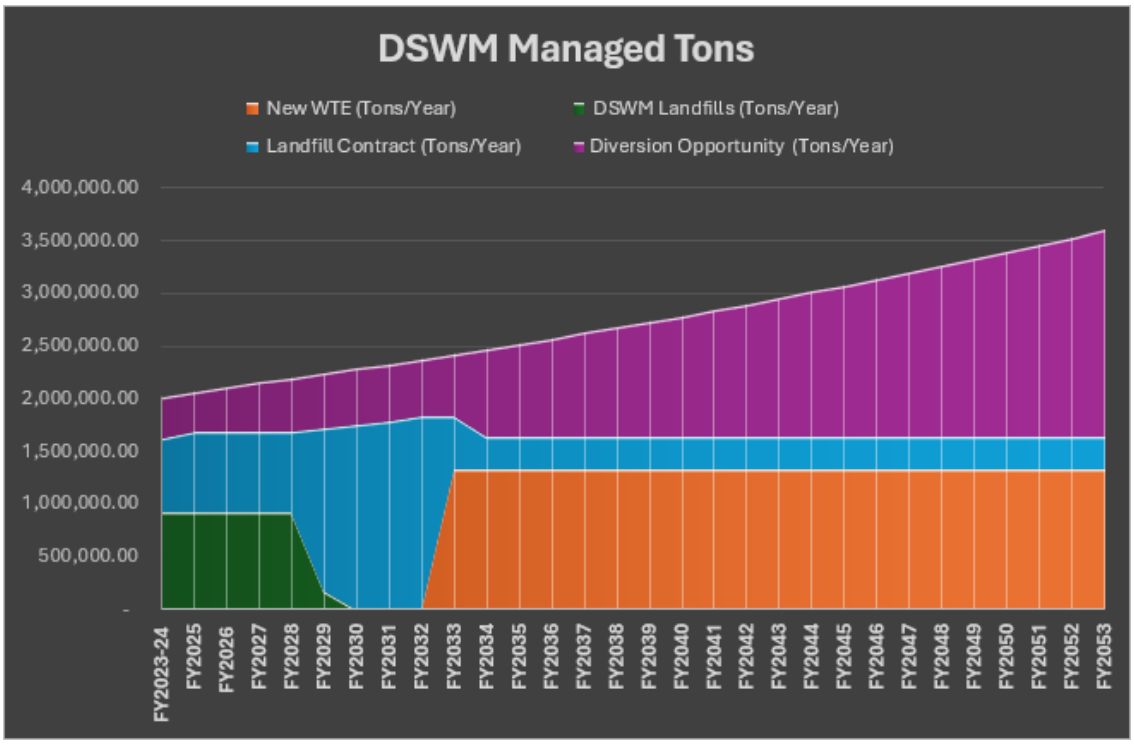

Table 1: Comprehensive Review of Total Anticipated Waste Managed by DSWM.

[7] http://www.leg.state.fl.us/statutes/index.cfm?App_mode=Display_Statute&URL=0400-0499/0403/Sections/0403.713.html#:~:text=(2)%20Any%20local%20government%20which,waste%20generated%20within%20its%20jurisdiction.

Generating Renewable Energy: Electricity generated from WTE reduces the need for fossil fuels. Additionally, the State of Florida (Statute 366.91) and EPA consider electricity generated from WTE facilities as a renewable energy source; this is crucial for jurisdictions like Miami-Dade County that are working towards lowering their carbon footprint.

Reliance on Landfills: Environmentally, landfill operations are less sustainable than alternatives like WTE facilities. Landfills emit methane, which the EPA calls a "climate super-pollutant," that is far more potent than carbon dioxide and is believed to be responsible for one-third of the warming from greenhouse gases. Heavy reliance on trucking and rail also contributes to a bigger carbon footprint through the long-haul transport of waste. Long term dependence on landfill disposal is not sustainable financially nor environmentally.

Handling Residual Waste: Even with robust recycling and composting programs, there are still residual waste streams that cannot currently be easily diverted. WTE helps manage this residual waste, ensuring it does not end up in landfills, where it may otherwise generate methane and other pollutants. Furthermore, it can help promote a circular economy by recovering valuable resources such as metals from the combustion process, which can be recycled back into production systems.

Conclusion

Forty years ago, the RRF was built in a remote location in NW Dade, far from residential areas. Since then, significant development has occurred around the site, and after the 2023 fire, many residents near the facility called for its relocation. After an extensive analysis of hundreds of properties by County staff and expert consultants, it is evident that no site for the Campus is without controversy. The Airport West site was considered a potential alternative but would cost $269 million more to build and over $21 million more annually to operate than the RRF site. Over 20 years, this would amount to an additional $800 million in costs. The other sites are even more expensive. Given these additional costs, and the undue burden they would create on ratepayers, I cannot justify relocating the Campus away from the RRF site.

Visits by Commissioners and myself to WTE facilities in Japan, Europe, and the U.S. show that with the right technology and regulations, these facilities can be successfully integrated into communities. In Japan, WTE powers community centers for nearby residents. This reinforced my belief that a modern WTE facility at the RRF site can be compatible with its surroundings and provide significant improvements over the outdated facility that preceded it.

As the County moves forward with sustainable waste management, building a Sustainable Solid Waste Campus incorporating WTE will help contribute to the County's Zero Waste goals. Site selection is a crucial first step towards these goals. I am confident that building the Campus at the RRF site is the most responsible choice for the surrounding community and Miami-Dade County residents at large. We will also incorporate additional Zero Waste facilities across the street at NW 58th Street to drive us towards a zero-waste future. This modern facility will adhere to strict EPA and DEP standards and will be designed to fit seamlessly within the community, potentially including educational components to promote Zero Waste practices.

Attachment
Exhibit A – Site Location Map
Exhibit B – Site Selection Matrix
Exhibit C – EPA Regulated Emissions
Exhibit D – Myth Busting WTE Misconceptions

c: Geri Bonzon-Keenan, County Attorney
Gerald Sanchez, First Assistant County Attorney
Jess McCarty, Executive Assistant County Attorney
Office of the Mayor Senior Staff
Aneisha Daniel, PhD, Director, Department of Solid Waste Management
Yinka Majekodunmi, Commission Auditor
Theresa Therilus, Interim Chief, Office of Policy and Budgetary Affairs
Basia Pruna, Director, Clerk of the Board
Eugene Love, Agenda Coordinator

EXHIBIT A

Site Location Map

EXHIBIT A

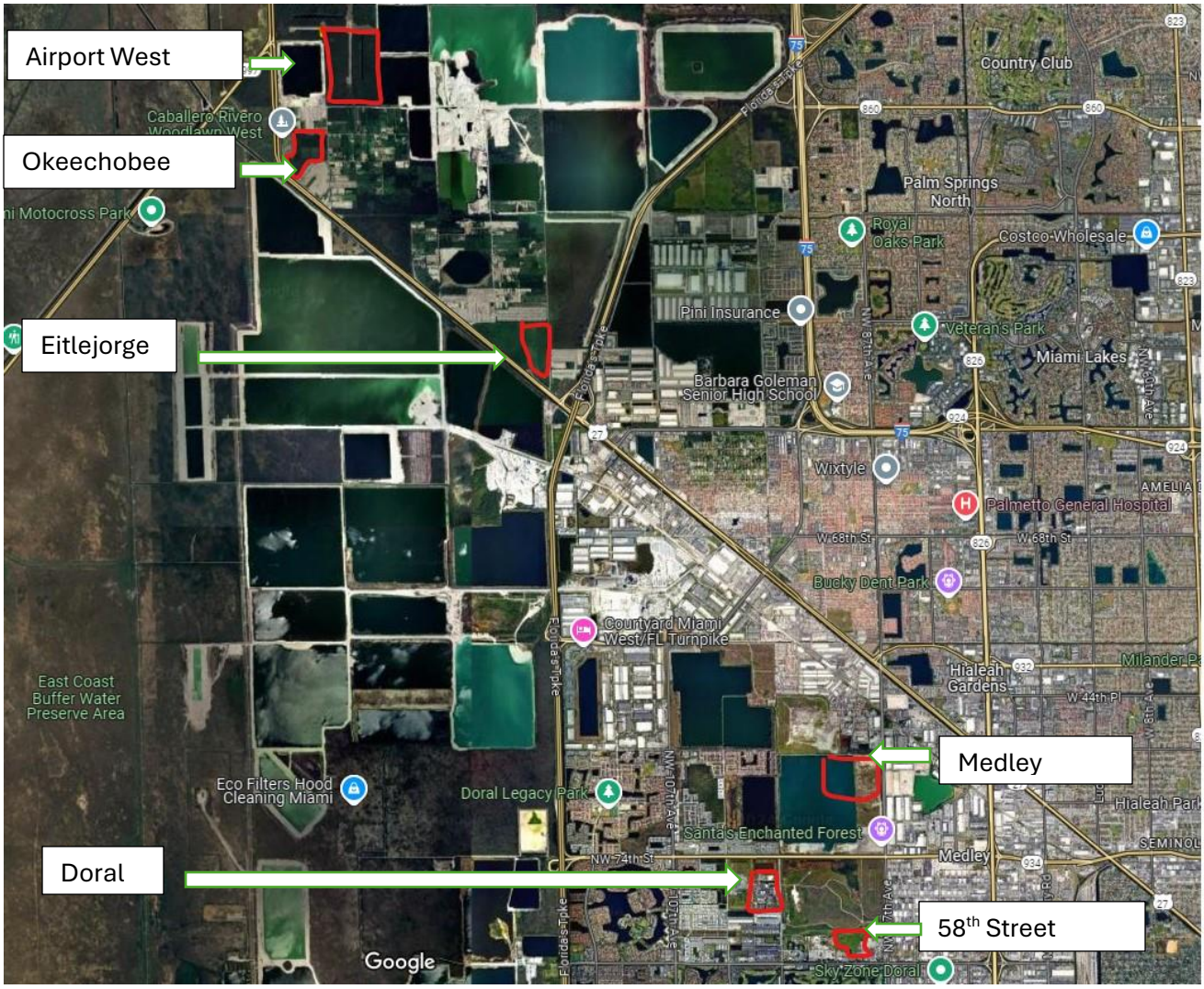
Airport West
Okeechobee
Eitlejorge
Doral
Medley
58th Street
Caballero Rivero Woodlawn West
Country Club
Palm Springs North
Royal Oaks Park
Costco Wholesale
Pini Insurance
Veteran's Park
Miami Lakes
Barbara Goleman Senior High School
Wixtyle
Palmetto General Hospital
Bucky Dent Park
Courtyard Miami West/FL Turnpike
East Coast Buffer Water Preserve Area
Hialeah Gardens
Eco Filters Hood Cleaning Miami
Doral Legacy Park
Santa's Enchanted Forest
Hialeah Park
Sky Zone Doral
Google

EXHIBIT B

Site Selection Matrix
&
WTE Site Selection Summary Comparison

Miami-Dade County Department of Solid Waste Management

Exhibit B

Comparing Proposed WTE Sites

All costs in 2033 dollars

	Doral RRF Site	58th St. Option (Move DSWM, ISD & MC to RRF, Soccer Complex to 58th St LF, DTPW Stays)	Airport West	Medley Site	Okeechobee	Eitlejorge
Capital Costs-Non Recurring Costs						
WTE Capital Cost	$1,488,886,000	$1,488,886,000	$1,582,443,592	$1,498,497,272	$1,593,591,461	$1,575,256,849
Original Estimated Development Schedule	7 years, 9 months	8 years, 9 months	9 years, 3 months	9 years, 9 months	10 years, 4 months	9 years, 3 months
Schedule Adjustments	None	+1 year, 6 months	None	+9 months	None	None
Revised Estimated Development Schedule	7 years, 9 months	10 years, 3 months	9 years, 3 months	10 years, 6 months	10 years, 4 months	9 years, 3 months
White Rock contribution					($35,000,000)	
Estimated Land Acquisition	$0	$0	$0	$220,507,000	$0	$93,192,000
Estimated Cost to Fill Lake Areas	$0	$0	$0	TBD	$0	$0
Additional Site Costs for WTE	$0	$23,027,000	$0	$0	$0	$0
Estimated Roadway Improvements	$0	$0	$1,918,000	TBD	$1,644,000	$0
Additional Wetlands Mitigation	$0	$0	$65,250,000	$0	$15,750,000	$0
Relocation Costs	$0	$147,718,000	$0	$0	$224,401,901	$0
TOTAL Estimated Capital Cost	$1,488,886,000	$1,659,631,000	$1,649,611,592	$1,719,004,272	$1,800,387,362	$1,668,448,849
LESS DTPW and MC Funding Amounts	$0	$28,593,003	$0	$0	$82,988,300	$0
TOTAL DSWM Bond Amount	$1,488,886,000	$1,631,037,997	$1,649,611,592	$1,719,004,272	$1,717,399,061	$1,668,448,849
Additional costs due to WTE development schedule extension	$0	$180,086,000	$108,051,000	$198,094,000	$186,089,000	$108,051,000
Total Non-Recurring	$1,488,886,000	$1,811,123,997	$1,757,662,592	$1,917,098,272	$1,903,488,061	$1,776,499,849
Variance btw Doral and Proposed Site		**$322,237,997**	**$268,776,592**	**$428,212,272**	**$414,602,061**	**$287,613,849**
Annual Operating Costs- Recurring Costs (2033 costs)						
O&M Fee	$42,018,000	$42,018,000	$42,018,000	$42,018,000	$42,018,000	$42,018,000
Consumables - Pebble Lime	$4,520,000	$4,520,000	$4,520,000	$4,520,000	$4,520,000	$4,520,000
Consumables - Ammonium Hydroxide	$453,000	$453,000	$453,000	$453,000	$453,000	$453,000
Consumables - Carbon	$480,000	$480,000	$480,000	$480,000	$480,000	$480,000
Utilities Pass-Through - Potable Water	$0	$2,293,000	$2,293,000	$2,293,000	$2,293,000	$2,293,000
Utilities Pass-Through - Sanitary Sewer	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000
Utilities Pass-Through - Natural Gas	$0	$0	$0	$0	$0	$0
New Transfer Station O&M	$0	$0	$15,396,000	$0	$15,396,000	$15,396,000
Annual Fee to Medley	$0	$0	$0	$2,610,000	$0	$0
Annual Revenue Share	$0	$0	$0	$11,099,000	$0	$9,794,000
Annual Rent-MDAD	$0	$0	$3,816,000	$0	$0	$0
Ash Disposal - Rail Haul	$11,825,000	$11,825,000	$11,825,000	$11,825,000	$11,825,000	$11,825,000
Total Annual O&M Costs	$59,299,000	$61,592,000	$80,804,000	$75,301,000	$76,988,000	$86,782,000
Variance btw Doral and Proposed Site		**$2,293,000**	**$21,505,000**	**$16,002,000**	**$17,689,000**	**$27,483,000**
Total O&M Costs (20-yr)	$1,593,386,334	$1,655,000,102	$2,171,233,737	$2,023,366,066	$2,068,696,388	$2,331,864,836
Operating Cost Per Ton- Proposed WTE Sites	***$44.47***	***$46.19***	***$60.60***	***$56.48***	***$57.74***	***$65.09***

Notes

1 All site areas adjusted to 65 acres

2 Airport West has 180 acres available to DSWM.

All costs in 2033 dollars

		58th St. Option (Move DSWM, ISD & MC to RRF, Soccer Complex to 58th St	Airport West	Medley Site	Okeechobee	Eitlejorge
Capital Costs-Non Recurring Costs						
WTE Capital Cost	$1,488,886,000	$1,488,886,000	$1,582,443,592	$1,498,497,272	$1,593,591,461	$1,575,256,849
Original Estimated Development Schedule	7 years, 9 months	8 years, 9 months	9 years, 3 months	9 years, 9 months	10 years, 4 months	9 years, 3 months
Schedule Adjustments	None	+1 year, 6 months	None	+9 months	None	None
Revised Estimated Development Schedule	7 years, 9 months	10 years, 3 months	9 years, 3 months	10 years, 6 months	10 years, 4 months	9 years, 3 months
White Rock contribution					($35,000,000)	
Estimated Land Acquisition	$0	$0	$0	$220,507,000	$0	$93,192,000
Estimated Cost to Fill Lake Areas	$0	$0	$0	TBD	$0	$0
Additional Site Costs for WTE	$0	$23,027,000	$0	$0	$0	$0
Estimated Roadway Improvements	$0	$0	$1,918,000	TBD	$1,644,000	$0
Additional Wetlands Mitigation	$0	$0	$65,250,000	$0	$15,750,000	$0
Relocation Costs	$0	$147,718,000	$0	$0	$224,401,901	$0
TOTAL Estimated Capital Cost	$1,488,886,000	$1,659,631,000	$1,649,611,592	$1,719,004,272	$1,800,387,362	$1,668,448,849
LESS DTPW and MC Funding Amounts	$0	$28,593,003	$0	$0	$82,988,300	$0
TOTAL DSWM Bond Amount	$1,488,886,000	$1,631,037,997	$1,649,611,592	$1,719,004,272	$1,717,399,061	$1,668,448,849
Additional costs due to WTE development schedule extension	$0	$180,086,000	$108,051,000	$198,094,000	$186,089,000	$108,051,000
Total Non-Recurring	$1,488,886,000	$1,811,123,997	$1,757,662,592	$1,917,098,272	$1,903,488,061	$1,776,499,849
Variance btw Doral and Proposed Site		**$322,237,997**	**$268,776,592**	**$428,212,272**	**$414,602,061**	**$287,613,849**
Annual Operating Costs- Recurring Costs (2033 costs)						
O&M Fee	$42,018,000	$42,018,000	$42,018,000	$42,018,000	$42,018,000	$42,018,000
Consumables - Pebble Lime	$4,520,000	$4,520,000	$4,520,000	$4,520,000	$4,520,000	$4,520,000
Consumables - Ammonium Hydroxide	$453,000	$453,000	$453,000	$453,000	$453,000	$453,000
Consumables - Carbon	$480,000	$480,000	$480,000	$480,000	$480,000	$480,000
Utilities Pass-Through - Potable Water	$0	$2,293,000	$2,293,000	$2,293,000	$2,293,000	$2,293,000
Utilities Pass-Through - Sanitary Sewer	$3,000	$3,000	$3,000	$3,000	$3,000	$3,000
Utilities Pass-Through - Natural Gas	$0	$0	$0	$0	$0	$0
New Transfer Station O&M	$0	$0	$15,396,000	$0	$15,396,000	$15,396,000
Annual Fee to Medley	$0	$0	$0	$2,610,000	$0	$0
Annual Revenue Share	$0	$0	$0	$11,099,000	$0	$9,794,000
Annual Rent-MDAD	$0	$0	$3,816,000	$0	$0	$0
Ash Disposal - Rail Haul	$11,825,000	$11,825,000	$11,825,000	$11,825,000	$11,825,000	$11,825,000
Total Annual O&M Costs	$59,299,000	$61,592,000	$80,804,000	$75,301,000	$76,988,000	$86,782,000
Variance btw Doral and Proposed Site		**$2,293,000**	**$21,505,000**	**$16,002,000**	**$17,689,000**	**$27,483,000**
Total O&M Costs (20-yr)	$1,593,386,334	$1,655,000,102	$2,171,233,737	$2,023,366,066	$2,068,696,388	$2,331,864,836
Operating Cost Per Ton- Proposed WTE Sites	***$44.47***	***$46.19***	***$60.60***	***$56.48***	***$57.74***	***$65.09***

Debt Service @ 20 years 3.5%	$0	$22,673,012	$18,911,410	$30,129,477	$29,171,847	$20,236,820
Operating Costs will increase with CPI	$0	$2,293,000	$21,505,000	$16,002,000	$17,689,000	$27,483,000
		$24,966,012	**$40,416,410**	**$46,131,477**	**$46,860,847**	**$47,719,820**
Fiscal Impact to Solid Waste Customers - assuming 50% of tons are from SW Customers based on the estimated number of households (369,220) in FY 2033 at 0.5% Growth						
FY 2033 - Estimated Number of Households	369,200					
Collection Rate is 96.5% **(B)**	356,278					
Fiscal Impact to SW Customer- Half of Cost **(C) = ((A) multiplied by 50%)**		$12,483,006	$20,208,205	$23,065,738	$23,430,424	$23,859,910
Annual Fiscal Impact of Capital per household		$31.82	$26.54	$42.28	$40.94	$28.40
Annual Fiscal Impact of Operating (recurring costs) per household		$3.22	$30.18	$22.46	$24.82	$38.57

WTE SITE SELECTION FACTORS SUMMARY COMPARISON

Factors	Effect	Doral	Medley	Airport West	Okeechobee	Eitlejorge	58th Street
Site Size		65-acre developable area.	Of 65 acres offered for development of a WTE, would require lakefilling of approximately 31 acre area reported as 45 feet deep.	Total property size is 416 acres, MDAD has agreed to lease up to 180 acres to DSWM for the development of a solid waste campus.	Approximately 65-ac site offered by Terra group in swap for 65 acre area of existing DTPW, DSWM and Park (Soccer Complex) property at 58th Street Landfill site. Sufficiently sized for WTE, but smaller site in floodplain may involve more technical challenges with stormwater retention and discharge.	Approximately 72-ac site offered by Lowell Dunn	58th Street Landfill Site includes an approximately 38-ac area for DSWM Collections, ISD Shop & Fueliing Facilities, Mosquito Control, Home Chemical Collection, and Stericycle facilities, and an approximately 47.4-ac area for the Parks future Soccer Complex.
Residential Receptors		<0.1 mile to nearest residential zoning	Adjacent to residential zoning	0.5 miles from Miramar < 0.5 mile from nearest MDC residential/ag zoning	1.5 miles from Miramar < 0.5 mile from nearest MDC residential/ag zoning	3.0 miles from Miramar >1.0 miles to nearest MDC residential zoning	Approx. 0.50 mile to nearest residential zoning
Inside Urban Development Boundary (UDB)	Cost/time	Yes	Yes	No	No	No	Yes
Land Purchase Cost[1]	Cost	No land purchase cost.	Purchase price of $2.6 Mil per acre assumed based on Owner's second proposal, Owner responsible for lake filling at no additional costs.	No land purchase cost.	No land purchase cost: Swap for 65 acre 58th Street parcel plus $35M. Does not include costs for relocating existing DSWM, Mosquito Control, Stericycle, ISD and DTPW facilities.	72 acres offered for $992,000 per acre, totaling $71.4M (2024 Dollars).	No land purchase cost.
Existing Utilities (water/sewer/natural gas/electric)	Cost/time	Yes, all utilities available on site.	Potable water and sanitary sewer utilities available at site. Electric and natural gas utilities would have to be extended to the site.	No, all utilities would have to be extended to the site.	No, all utilities would have to be extended to the site.	No, all utilities would have to be extended to the site.	Yes, all utilities available at site. Electric substation for RRF located on west side of 58th Street landfill property.
Site Geotechnical	Cost/time	Yes	No - existing soils not well suited for WTE. Additional site preparation required.	No - existing soils not well suited for WTE. Additional site preparation required.	Per swap proposal, the $35M allocation could be directed towards making the site "pad ready".	No - existing soils not well suited for WTE. Additional site preparation required.	Former landfill site - existing site areas assumed to need Deep Dynamic Compaction prior to redevelopment and all structures assumed to be on pile foundations with gas controls.

WTE SITE SELECTION FACTORS SUMMARY COMPARISON

Factors	Effect	Doral	Medley	Airport West	Okeechobee	Eitlejorge	58th Street
Air Permitting	Time	Air permitting will be challenging, site is closest to Everglades National Park. Preliminary air dispersion modeling results were favorable.	Air permitting will be most challenging due to other large emitters, made more complex with two additional emissions sources for proposed Medley LF horizontal expansion.	Air permitting will be challenging but site is furthest from Everglades National Park. Most favorable preliminary air dispersion modeling results of the sites evaluated.	Not evaluated, but do not anticipate significant variation from Airport West results. Slightly closer to Everglades National Park.	Not evaluated, but do not anticipate significant variation from Airport West results. Slightly closer to Everglades National Park.	Not evaluated, but do not anticipate significant variation from RRF Site results. Slightly further from Everglades National Park. <4mi from MIA - Maximum stack elevation 310ft above MSL.
Site Located in Floodplain	Cost/time	No	No	Yes	Yes	Yes	No
Wetlands and Endangered Species Mitigation	Cost/time	No	No	Yes	Yes	No wetlands appear on NWI, endangered species not evaluated but issues expected to be similar to Okeechobee and Airport West sites.	None
Comprehensive Everglades Restoration Plan (CERP) Review	Cost/time	No	No	Yes - within North Lake Belt CERP Area	No	Yes - within North Lake Belt CERP Area	No
Estimated Construction Cost (Including land Acquisition Cost, 2033 Dollars)	Cost	$1,488,886,000	$1,719,004,272	$1,649,611,592	$1,800,387,362 Does not include value of land being swapped.	$1,668,448,849	$1,659,631,000 External funding for ISD and Mosquito Control faciliteis will reduce total DSWM bond amount.
Estimated Modern Transfer Station Capital Construction Cost (included in Capital costs above)	Cost	N/A	N/A	$50,000,000	$50,000,000	$50,000,000	N/A
Sea Level Rise requirements in Western C-9 Canal Basin, Rule 40E-41.063	Cost/time	N/A	N/A	Yes	Yes	Yes	TBD
Estimated Annual Operating Costs (WTE O&M, WTE Consumables, Utilities, Ash Disposal, Etc.)	Cost	$59,299,000	$59,299,000	$59,299,000	$59,299,000	$59,299,000	$59,299,000
Additional Operating Costs (fleet, drivers, transfer station operation, host fees, etc.)	Cost	N/A	$2.3M for potable water purchase (boiler feedwater) $11.1M Revenue Share and $2.6M Medley Host Fee Total Estimate $16.0M Per Year	$2.3M for potable water purchase (boiler feedwater) New TS Operations $15.4M MDAD Rent $3.8M Total Estimate $21.5M Per Year	$2.3M for potable water purchase (boiler feedwater) New TS Operations $15.4M Total Estimate $17.7M Per Year	$2.3M for potable water purchase (boiler feedwater) New TS Operations $15.4M Revenue Share $9.8M Total Estimate $27.5M Per Year	$2.3M for potable water purchase (boiler feedwater)
Estimated Total Annual Operating Costs	Cost	$59,299,000	$75,301,000	$80,804,000	$76,988,000	$86,782,000	$61,592,000

WTE SITE SELECTION FACTORS SUMMARY COMPARISON

Factors	Effect	Doral	Medley	Airport West	Okeechobee	Eitlejorge	58th Street
Estimated Annual Capital Debt Service Costs (Assumes 20yr Term, 3.5% Rate)	Cost	$104,759,622	$120,950,992	$116,068,448	$126,677,193	$110,836,768	$112,603,686
Estimated Incremental Collection Fee Increase	Cost	N/A - Base	$64.74	$56.72	$65.76	$66.97	$35.04
Estimated Incremental Disposal Tipping Fee Increase	Cost	N/A - Base	$19.02	$16.66	$19.32	$19.67	$10.29
Estimated Project Duration	Cost/Time	7 years 9 months	10 years 6 months	9 years 3 months	10 years 4 months	9 years 3 months	10 years, 3 months
Estimated Additional Transfer and Disposal Costs Due to Schedule Extension	Cost	N/A - Base	$198,094,000	$108,051,000	$186,089,000	$108,051,000	$180,086,000

Notes

[1] For all sites, demolition of existing RRF building foundations, pits, underground infrastructure, and site remediation to be completed under separate project and not included in WTE development costs.

EXHIBIT C

EPA Regulated Emissions

REGULATED EMISSIONS FOR RRF COMPARED TO ANTICIPATED REGULATIONS

EPA's Regulated Air Pollutant	EPA Limits for RRF (ug/dscm)	Current NSPS Limit (Applies to WTE facilities built after 1994)	Proposed NSPS Limits (Applies to any new WTE facility)
Cadmium	35	71% Reduction	97% Reduction
Lead	400	65% Reduction	97% Reduction
Particulate Matter	25[1]	20% Reduction	80% Reduction
Mercury	50	0% Reduction	88% Reduction
Dioxin/Furans	30[2]	57% Reduction	94% Reduction
Hydrochloric Acid	29[3]	14% Reduction	73% Reduction
Sulfur Dioxide	29[3]	3% Increase	52% Reduction
Nitrogen Oxides	250[3]	40% Reduction	80% Reduction
Carbon Monoxide	100[3]	0% Reduction	84% Reduction

[1]unit of measurement is mg/dscm
[2]unit of measurement is ng/dscm
[3]unit of measurement is ppmdv

REGULATED EMISSIONS FOR RRF COMPARED TO ANTICIPATED REGULATIONS

EPA's Regulated Air Pollutant	Current Limit NSPS (Applies to WTE facilities built after 1994)	Proposed NSPS Limits (Applies to all new WTE facilities)
Cadmium	71% Reduction	97% Reduction
Lead	65% Reduction	97% Reduction
Particulate Matter	20% Reduction	80% Reduction
Mercury	0% Reduction	88% Reduction
Dioxin/Furans	57% Reduction	94% Reduction
Hydrochloric Acid	14% Reduction	73% Reduction
Sulfur Dioxide	3% Increase	52% Reduction
Nitrogen Oxides	40% Reduction	80% Reduction
Carbon Monoxide	0% Reduction	84% Reduction

EXHIBIT D

Myth Busting & Waste Management FAQS

Attachment 1 - GHG Emissions Study

Attachment 2 - PFAS Fate & Transport in WTE Facilities (SWANA)

Myth Busting and Waste Management FAQs

1. Myth: WTE facilities have higher greenhouse gas (GHG) emissions than landfills
   Reality: The Department of Solid Waste Management (DSWM) engaged Arcadis to determine the climate impact of various post solid waste collection methods. The analysis quantified the GHG impact of WTE facilities, landfills, composting facilities, anaerobic digesters, material recovery facilities (MRFs), and other facilities. Arcadis' report (Exhibit C) concluded that WTE facilities have a lower greenhouse gas impact than landfills. The report used the Environmental Protection Agency (EPA's) Emission Factors for Greenhouse Gas Inventories to make this determination.

   Arcadis also included electrical generation from the WTE facility as part of its analysis—since the WTE facility is generating electricity that would otherwise be generated as part of the electrical grid, the WTE facility is helping avoid emissions from the grid. These emissions are avoided since electricity generated from WTE facilities have a lower carbon intensity than natural gas which is the predominant source of electricity in Florida. The report used carbon intensity of electricity generation from data published by the U.S. Energy Information Administration (EIA).

2. Myth: WTE facilities emit dangerous levels of air pollutants
   Reality: Modern WTE facilities are equipped with state-of-the-art pollution control systems that meet or exceed EPA standards for emissions. The EPA and FDEP closely regulate these power plants to ensure that emissions of harmful pollutants like mercury, dioxins, and particulates are kept at safe levels. An EPA Database[1] illustrates that emissions from WTE facilities are much lower than those from older incineration methods or industrial processes such as cement manufacturing and coal fired power plants.

3. Myth: Recycling and composting are enough to achieve zero waste
   Reality: While recycling and composting are vital to a Zero Waste Master Plan (ZWMP), they alone cannot handle all waste streams. WTE offers a solution for the residual waste that cannot currently be economically recycled or composted. By converting this waste into energy, WTE plays an essential role in diverting waste from landfills and reducing overall waste volumes.

4. Myth: WTE facilities spread PFAS
   Reality: Disposal facilities must contend with the implications of handling waste streams contaminated with per- and polyfluoroalkyl substances (PFAS), commonly referred to as "forever chemicals." These substances have been utilized in the manufacturing processes of a wide range of materials since the 1940s. PFAS are persistent in the environment, as they do not naturally break down, and the conditions required for their neutralization are still under investigation by the EPA and other federal and international agencies. The lack of regulation

[1] *https://www.epa.gov/air-emissions-inventories/2020-national-emissions-inventory-nei-data*

surrounding PFAS has led to their detection in waste disposal facilities, such as wastewater treatment plants and landfills, as well as in waterways and soils worldwide.

Although research on PFAS neutralization is limited, the EPA has indicated that the temperature and residence time in WTE technology may be sufficient to neutralize certain PFAS compounds. Ongoing studies by the EPA aim to assess the effectiveness of WTE technology in the neutralization of PFAS.

Additionally, according to a 2021 PFAS Solid Waste Association of North America (SWANA) Applied Research Foundation study (Attachment 1) – Fate and Transport in WTE interim guidance document concludes that "SWANA is cautiously optimistic regarding the role that WTE facilities can play in the destruction of PFAS in MSW. The thermal destruction of PFAS in high-temperature combustion systems such as WTE facilities may represent one of the few commercially proven options available to society for destroying these problematic, forever chemical compounds."

5. Myth: WTE is the number one generator of Mercury
   Reality: As the federal regulatory body that sets standards for emissions, the EPA is tasked with the responsibility of periodically updating emission standards and regulating waste. Notably, the EPA enacted the "Mercury-Containing and Rechargeable Battery Management Act of 1996", prohibiting the use of mercury in batteries. This act, coupled with enhanced emissions standards, has significantly contributed to the reduction of mercury emissions from WTE facilities. The EPA has also proposed new Maximum Achievable Control Technologies (MACT) standards for WTE facilities. The preliminary air modeling and human health risk assessment report did not include these stricter standards at the time of assessment. With the implementation of more stringent air emissions regulations, the human health risk and the environment are expected to be lower than the existing report results.

   Further, according to the EPA[2], "the burning of municipal and medical waste was once a major source of mercury emissions. A reduction in the use of mercury along with state and federal regulations, however, has led to a decrease in emissions from this source by over 95%."

[2] *https://www.epa.gov/mercury/basic-information-about-mercury*

Exhibit D - Attachment 1

Miami-Dade County Department of Solid Waste Management

Greenhouse Gas Emissions Study

October 14, 2024

Greenhouse Gas Emissions Study

October 14, 2024

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Appendix A

A GHG Emission Calculations

Acronyms and Abbreviations

CH_4	Methane
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalents
DSWM	Department of Solid Waste Management
GHG	Greenhouse Gas
IPCC	Intergovernmental Panel on Climate Change
MSW	Municipal Solid Waste
MT	Metric Tons
N_2O	Nitrous Oxide
TAP	Turned Aerated Pile
tpy	tons per year
WTE	Waste-to-Energy
USEPA	United States Environmental Protection Agency

Executive Summary

The Miami-Dade County Department of Solid Waste Management (Department) requested Arcadis, the County's Solid Waste Bond Engineer, to prepare estimates of GHG emissions for several of the Department's facilities and operations, and certain contract disposal facilities or other potential disposal alternatives, to inform County staff and for use in future public meetings and in decisions on how waste will be handled.

Greenhouse gas (GHG) emissions were estimated for landfills and several solid waste processing facilities that may be considered as a disposal alternative by Miami-Dade DSWM in the future. A list of these facilities is provided below:

- Class I Landfill
- Class III Landfill
- Mass-Burn Waste-to-Energy (WTE) Facility
- Gasification Facility
- Turned Aerated Pile (TAP) Composting Facility
- Mixed Waste Processing Facility
- Anaerobic Digestion Facility

Additionally, GHG emissions from the following waste transfer operations were also estimated.

- Curbside Residential Collection (2 times/week)
- Curbside Recycling Collection (2 times/month)
- Waste transfer to intermodal facility from transfer stations (Northeast Transfer Station (18701 NE 6th Avenue), West Transfer Station (2900 SW 72nd Avenue), and South Dade Landfill (23707 SW 97th Avenue))
- Waste transfer by rail - WM/FEC Intermodal Facility (7300 NW 69th Avenue, Miami, Florida)

The initial scope of this task was to use reported GHG emissions data from the United States Environmental Protection Agency (USEPA) for the landfills that are currently owned by or operated under contract with Miami-Dade County. Data obtained from the USEPA database showed that landfills produced fewer GHG emissions compared to waste processing facilities which contradicts the available research evidence. This discrepancy could be due to several factors such as differences in data collection, inaccuracies in reporting, or differences in inputs used to estimate emissions. As a result, relying solely on the USEPA database could lead to misleading conclusions about the environmental impacts of landfills versus other waste processing methods. Therefore, GHG emissions estimates for landfills were based on published USEPA emissions factors instead of reported data.

The emission calculations are provided in Appendix A and show that the highest GHG emissions rates are associated with Class I landfills (0.58 MT of CO_{2e} per ton of waste disposed), followed by WTE and other solid waste processing technologies.

1 Emissions Estimation

GHG emission calculation methodologies for the solid waste management facilities and the waste transfer operations are described below. GHG emissions are reported in units of CO_2equivalents (CO_2e). Wherever applicable, emissions of CO_2, CH_4, and N_2O are converted to CO_2e by multiplying by their global warming potential provided in IPCC, Fifth Assessment Report (AR5), 2013. The emission calculation tables are provided in Appendix A.

1.1 Landfills

GHG emissions were estimated for Class I and Class III landfills using the landfilling emission factor from Table 9 of the USEPA's *Emission Factors for Greenhouse Gas Inventories,* and the estimated maximum waste disposed to the landfills. The emission factor for mixed municipal solid waste (MSW) was used for the Class I landfill. Average emission factor values for several construction materials and yard trimmings were used for the Class III landfill. GHG emissions from Landfilling are provided in Table 2 of Appendix A.

1.2 Transfer Stations

GHG annual emissions due to waste transfer by trucks to the intermodal facility located at 7300 NW 69th Avenue, Miami, Florida from the following transfer stations was estimated. Emission calculations are provided in Table 3 of Appendix A.

- Northeast Transfer Station (18701 NE 6th Avenue)
- South Dade Landfill (23707 SW 97th Avenue)
- West Transfer Station (2900 SW 72nd Avenue)

Applicable emission factors for CO_2, CH_4, and N_2O provided in USEPA's *Emission Factors for Greenhouse Gas Inventories, Tables 4 and 8* were used. The emission factors are based on vehicle miles travelled. The vehicle miles traveled by the truck is estimated using the truck trips per year and the roundtrip distance to the intermodal facility. The truck trips are estimated based on 550,000 tons per year waste transferred from the three transfer stations to the intermodal facility at 28 tons per truck load (approximately 6,548 truck trips from each transfer station). The annual total CO_2e due to waste transfer from the transfer stations to the intermodal facility was estimated to be 1,006 Metric Tons per year (MT/yr).

1.3 Intermodal Facility

GHG annual emissions due to waste transfer by rail from the WM/FEC Intermodal Facility located at 7300 NW 69th Avenue, Miami, Florida to the Okeechobee landfill were estimated. Emission calculations are provided in Table 4 of Appendix A.

Applicable diesel mobile combustion emission factors for CO_2, CH_4, and N_2O provided in USEPA's *Emission Factors for Greenhouse Gas Inventories, Tables 2 and 5* were used. Vehicle miles per year were estimated based on two round trips per week at 52 weeks per year and trip distance. Diesel usage was estimated based on a 0.09 miles per gallon (472 ton-miles per gallon fuel efficiency for the rail haul and 5,300 tons per trip). The total CO_2e for the intermodal facility is 2,857 MT/yr.

1.4 Curbside Residential/Recycling Collection

GHG annual emissions for curbside residential and recycling collection were based on diesel usage from 2023 usage records received from the County. Vehicle miles were estimated based on an assumed 3 miles per gallon fuel efficiency of the garbage truck. Mobile diesel combustion emission factors for CO_2, CH_4, and N_2O provided in USEPA's *Emission Factors for Greenhouse Gas Inventories, Tables 2 and 5* were used. The total CO_2e for curbside collection is 17,827 MT/yr. Emission calculations are provided in Table 5 of Appendix A.

1.5 Conceptual Facilities

GHG annual emissions were calculated for the following conceptual facilities.

1.5.1 Mass Burn Waste-to-Energy (WTE) Facility

GHG annual emissions for the mass burn WTE facility were estimated using the mixed MSW combustion emission factor provided in USEPA's *Emission Factors for Greenhouse Gas Inventories, Table 9.* Emissions were calculated assuming a 4,000 tons per day throughput for the facility and a 91% typical facility availability. The emissions estimated using the USEPA factor do not include avoided emissions associated with displaced electric utility generation or avoided GHG emissions due to the recovery and recycling of ferrous metals at the combustor. The emissions include transport to the WTE facility and combustion-related non-biogenic CO_2 and N_2O. The USEPA Emission factors for WTE facilities do not factor in biogenic emissions; as such, they are not included in these calculations. The total CO_2e for the mass burn WTE is estimated to be 571,298 MT/yr (Appendix A, Table 6).

1.5.2 Gasification Facility

There is no emission factor for the gasification process provided by USEPA. Based on our understanding of the process and professional knowledge, GHG emissions for gasification facilities would be comparable and on par with GHG emissions from a WTE Facility with the same carbon content of fuel. Therefore, GHG annual emissions for the gasification facility were estimated using the mixed MSW combustion emission factor provided in USEPA's *Emission Factors for Greenhouse Gas Inventories, Table 9.* Emissions were calculated assuming a 4,000 tons per day throughput for the facility and an 85% typical facility availability. The emissions include transport of waste to the facility and combustion-related non-biogenic CO_2 and N_2O. The total CO_2e for gasification facility is estimated to be 533,630 MT/yr (Appendix A, Table 7).

1.5.3 Turned Aerated Pile (TAP) Composting Facility

GHG annual emissions for the TAP composting facility were estimated using the maximum composting emission factor for yard waste, food waste, and organics provided in USEPA's *Emission Factors for Greenhouse Gas Inventories, Table 9.* Annual emissions were calculated for a maximum waste throughput of 1,350 tons per day and 365 days a year. The emissions estimated using the USEPA factor do not include avoided emissions associated with fertilizer offset or soil carbon storage. Composting emissions include transport to the compost facility, equipment use at the compost facility, and CH_4 and N_2O emissions during composting. The total CO_2e for composting is estimated to be 68,985 MT/yr (Appendix A, Table 8).

1.5.4 Mixed Waste Processing Facility

GHG annual emissions for the mixed waste processing facility were estimated using the maximum recycling emission factor for yard waste, food waste, and organics provided in USEPA's *Emission Factors for Greenhouse Gas Inventories, Table 9.* Annual emissions were calculated for a maximum waste throughput of 4,000 tons per day and 365 days a year. The emissions estimated using the USEPA factor do not include avoided emissions associated with process energy, transportation energy, process non-energy, or forest carbon storage. The emissions include transport to the recycling facility and sorting of recycled materials at the material recovery facility. The total CO_2e for mixed waste processing facility is estimated to be 335,800 MT/yr (Appendix A, Table 9).

1.5.5 Anaerobic Digestion Facility

GHG annual emissions for the anaerobic digestion facility were estimated using the anaerobic digestion emission factor for food waste provided in USEPA's *Emission Factors for Greenhouse Gas Inventories, Table 9.* Emissions were calculated for a maximum throughput of 1,000 tons per day of food waste and organics. The emissions estimated using the USEPA factor do not include avoided emissions associated with displaced electric utility generation, soil carbon storage, or avoided fertilizer application. Emissions include transport to the anaerobic digester facility, equipment use at the anaerobic digester facility, biogas leakage at the digester, emissions released during the curing and land application process, and fugitive emissions during the curing and after land application. The total CO_2e for anaerobic digestion facility is estimated to be 40,150 MT/yr (Appendix A, Table 10).

2 Findings

GHG emissions were estimated for the Class I and Class III landfills and solid waste processing facilities that may be considered as a disposal alternative in the future. Table 1 of Appendix A provides summary of the annual CO_2e emissions. Table 1 also provides the metric tons of CO_2e emitted per ton of waste disposed or processed for landfills and other waste processing facilities. Based on CO_2e emitted per ton of waste disposed or processed, it is evident that Class III landfills that handle bulk MSW generate more GHG than waste processing facilities, primarily because decomposition of organic waste in landfills produces significant amounts of methane. Waste processing facilities tend to have lower greenhouse gases due to more efficient waste management practices and potential to recover energy and materials.

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Appendix A

GHG Emissions Calculations

Table 1: Greenhouse Gas (GHG) Annual Emissions Summary

Miami-Dade County, DSWM

Source		CO_2e (MT/yr)[1]	Maximum waste disposed (tons/yr)	CO_2e (MT/ton waste disposed)[1]	Avoided CO_2e emissions (MT/ton waste disposed)[7]
Landfills[2]	Class I Landfill	464,000	800,000	0.58	--
	Class III Landfill	8,017	130,000	0.06	--
Transfer Stations[3]	Northeast Transfer Station (18701 NE 6th Avenue, Miami, FL)	1,006	--	--	--
	South Dade Landfill (23707 SW 97th Avenue, Miami, FL)		--	--	--
	West Transfer Station (2900 SW 72nd Avenue, Miami, FL)		--	--	--
Intermodal Facility[4]	WM/FEC Intermodal Facility (7300 NW 69th Avenue, Miami, FL)	2,857	--	--	--
Curbside Collection[5]	Curbside Residential Collection (2x/week)	17,827	--	--	--
	Curbside Recycling Collection (2x/month)		--	--	--
Total		**493,706**	--	--	--

Conceptual Facilities[6]	CO_2e (MT/yr)[1]	Maximum waste processed (tons/yr)	CO_2e (MT/ton waste processed)[1]	Avoided CO_2e emissions (MT/ton waste processed)[7]
Mass-Burn Waste-to-Energy (WTE) Facility	571,298	1,328,600	0.43	0.18
Gasification Facility	533,630	1,241,000	0.43	0.20
Turned Aerated Pile Composting Facility	68,985	492,750	0.14	--
Mixed Waste Processing Facility	335,800	1,460,000	0.23	--
Anaerobic Digestion Facility	40,150	1,460,000	0.11	--

Notes:

1. GHG emissions reported as carbon dioxide equivalent (CO_2e).
2. Emission calculations are provided in Table 2.
3. Emission calculations are provided in Table 3
4. Emission calculations are provided in Table 4
5. Emission calculations are provided in Table 5
6. Emission calculations are provided in Tables 6 through 10.
7. Avoided emissions associated with displaced electric utility generation. The biogas produced is collected and can be combusted to produce heat and electricity. The recovery of heat and electricity from the combusted biogas offsets the combustion of other fossil fuel inputs. Avoided emissions are estimated using non-baseload factors of CO_2, CH_4 and N_2O provided in Emission Factors for Greenhouse Gas Inventories,Version 2023, Table 6, and anticipated electricity capacity of 515,870 MW.

Table 2 : GHG Annual Emissions from Landfills

Miami-Dade County, DSWM

Facility	Maximum waste disposed (tons/yr)[5]	CO_2e (MT/ Short Ton Material)[2]	Updated CO_2e (MT/yr)[3]
Class I Landfill	800,000	0.58	464,000
Class III Landfill	130,000	0.06	8,017

Notes:

1. Estimated maximum waste to be disposed to the landfill

2. Emission Factors for Greenhouse Gas Inventories, Version 2023, Table 9, EF for Landfilling (Class I based on Mixed MSW and Class III based on average EF for construction related waste). Landfilling emissions do not include avoided emissions associated with energy recovery or landfill carbon sequestration. Landfilling emissions include transport to landfill, equipment use at landfill, and landfill CH4 emissions from anaerobic decomposition of biogenic carbon compounds. Landfill CH4 is based on typical landfill gas collection practices, average landfill moisture conditions, and U.S.-average non-baseload electricity grid mix.

3. Sample calculation provided below. GHG emissions are reported in units of CO2e.

Sample Calculation:

CO_2e (MT/yr) = Max. Waste Disposed (tons/yr) x Emission Factor (MT CO_2e / short ton material)

Table 3 : GHG Annual Emissions due to Truck Traffic between Transfer Stations and the Intermodal Facility

Miami-Dade County, DSWM

Transfer Station	Truck Trips (#/yr)[1,2]	Roundtrip distance to Intermodal facility (miles/round trip)	Vehicle Miles Travelled (miles/yr)	Emissions (MT/yr)[5]		
				CO_2	CH_4	N_2O
Northeast Transfer Station (18701 NE 6th Avenue)	6,548	36	235,728	321	0.002	0.010
South Dade Landfill (23707 SW 97th Avenue)	6,548	54	353,592	481	0.003	0.015
West Transfer Station (2900 SW 72nd Avenue)	6,548	22	144,056	196	0.001	0.006
		CO_2e (MT/yr)[3]		**1,006**		

Emission Factors[4]

Pollutant	Value[4]	Units	Basis
CO_2	1.360	kg/vehicle-mile	USEPA, Table 8, Scope 3 Category 4: Upstream Transportation and Distribution and Category 9: Downstream Transportation and Distribution
CH_4	0.0095	g/vehicle-mile	USEPA, Table 4, Mobile Combustion for On-Road Diesel and Alternative Fuel Vehicles
N_2O	0.0431	g/vehicle-mile	USEPA, Table 4, Mobile Combustion for On-Road Diesel and Alternative Fuel Vehicles

Notes:

1. 550,000 tons/year transferred from 3 transfer stations to intermodal facility
2. 28 tons/truck load
3. GHG emissions are reported in units of CO_2e. Gases are converted to CO_2e by multiplying by their global warming potential.
4. Emission Factors for Greenhouse Gas Inventories, Version 2023, Table 8, CO_2 Emission Factor for Transportation and Distribution, and Table 4, CH_4 and N_2O emission factor for Mobile Combustion for On-Road Diesel and Alternative Fuel Vehicles.
5. See sample calculation below

Sample Calculation:

CO_2 (MT/yr) = (Vehicle Miles Travelled/yr) x Emission Factor (Kg/vehicle-mile) x 0.001 MT/kg

CH_4/N_2O (MT/yr) = (Vehicle Miles Travelled/yr) x Emission Factor (g/vehicle-mile) x 0.000001 MT/g

Table 4 : GHG Annual Emissions due to Waste Transfer by Rail from Intermodal Facility to Okechobee Landfill

Miami-Dade County, DSWM

Intermodal Facility	Roundtrip distance from Intermodal facility to Okeechobee Landfill (miles/trip)	Vehicle Miles (mile/yr)[1]	Diesel Usage (gal/yr)[2]	Emissions (MT/yr)[3]		
				CO_2	CH_4	N_2O
WM/FEC Intermodal Facility (7300 NW 69th Avenue, Miami, Florida)	240	24,960	277,333	2832	0.221	0.071
		CO_2e (MT/yr)[4]		**2,857**		

Emission Factors[5]

Pollutant	Value[5]	Units	Basis
CO_2	10.21	kg/gal	USEPA, Table 2, Diesel Mobile Combustion
CH_4	0.80	g/gal	USEPA, Table 5, Diesel Mobile Combustion Locomotives
N_2O	0.26	g/gal	

Notes:

1. Estimated based on 2 round trips per week to okeechobee landfill and 52 weeks per year.

2. Based on 0.09 miles/gallon fuel efficiency for the rail haul.Fuel efficiency estimated based on 472 ton-miles per gallon fuel efficiency of the rail based on online research. 550,000 tons waste moved per year; 5,300 tons/trip based on 104 trips per year (2 round trips /week)

3. See sample calculation below

4. GHG emissions are reported in units of CO_2e. Gases are converted to CO_2e by multiplying by their global warming potential.

5. Emission Factors for Greenhouse Gas Inventories,Version 2023, Table 2, CO_2 Emission Factor for Mobile Combustion (diesel), and Table 5, CH_4 and N_2O emission factor for Mobile Combustion (diesel) for locomotives.

Sample Calculation:

CO_2 (MT/yr) = Diesel usage (gal/yr) x Emission Factor (Kg/gal) x 0.001 MT/kg

CH_4/N_2O (MT/yr) = Diesel usage (gal/yr) x Emission Factor (g/gal) x 0.000001 MT/g

Table 5 : GHG Annual Emissions from Curbside Residential Collection

Miami-Dade County, DSWM

Curbside Collection	Diesel Usage (gal/yr)[1]	Vehicle Miles (miles/yr)[2]	Emissions (MT/yr)[3]		
			CO_2	CH_4	N_2O
Curbside Residential Collection (2x/week)	1,740,088	5,220,264	17,766	0.05	0.22
Curbside Recycling Collection (2x/month)					
		CO_2e (MT/yr)[4]	**17,827**		

Emission Factors[5]

Pollutant	Value[5]	Units	Basis
CO_2	10.21	kg/gal	USEPA, Table 2, Diesel Mobile Combustion
CH_4	0.0095	g/vehicle-mile	USEPA, Table 4, Diesel Mobile Combustion Medium- and Heavy-Duty Vehicles
N_2O	0.0431	g/vehicle-mile	

Notes:

1. Based on 2023 usage records
2. Based on 3 miles/gallon fuel efficiency of the garbage truck
3. See sample calculation below
4. GHG emissions are reported in units of CO_2e. Gases are converted to CO_2e by multiplying by their global warming potential.
5. Emission Factors for Greenhouse Gas Inventories,Version 2023, Table 2, CO_2 Emission Factor for Mobile Combustion (diesel), and and Table 4, CH_4 and N_2O emission factor for Mobile Combustion for On-Road Diesel and Alternative Fuel Vehicles.

Sample Calculation:

CO_2 (MT/yr) = Diesel usage (gal/yr) x Emission Factor (Kg/gal) x 0.001 MT/kg

CH_4/N_2O (MT/yr) = (Vehicle Miles Travelled/yr) x Emission Factor (g/vehicle-mile) x 0.000001 MT/g

Table 6 : GHG Annual Emissions for Mass-Burn Waste-to-Energy (WTE) Facility

Miami-Dade County, DSWM

Facility Throughput (tons/day)[1]	Facility Throughput (tons/yr)[2]	Emissions[3] CO_2e (MT/yr)
4,000	1,328,600	571,298

Emission Factors[4]

Pollutant	Value[4]	Units	Basis
CO_2e	0.43	MT CO_2e / Short Ton Material	USEPA, Table 9, Mixed MSW combustion EF

Notes:

1. Based on 4,000 tons per day design throughput for the facility
2. Estimated based on 91% typical facility availability
3. Sample calculation provided below. GHG emissions are reported in units of CO2e.
4. Emission Factors for Greenhouse Gas Inventories,Version 2023, Table 9, EF for Mixed MSW combustion. Combustion emissions do not include avoided emissions associated with displaced electric utility generation or avoided GHG emissions due to the recovery and recycling of ferrous metals at the combustor. Combustion emissions include transport to waste-to-energy facility and combustion-related non-biogenic CO_2 and N_2O. Biogenic emissions are not included.

Sample Calculation:

CO_2e (MT/yr) = Throughput (tons/yr) x Emission Factor (MT CO_2e / short ton material)

Table 7 : GHG Annual Emissions for Gasification Facility
Miami-Dade County, DSWM

Facility Throughput (tons/day)[1]	Facility Throughput (tons/yr)[2]	Emissions[3] CO_2e (MT/yr)
4,000	1,241,000	533,630

Emission Factors[4]

Pollutant	Value[4]	Units	Basis
CO_2e	0.43	MT CO_2e / Short Ton Material	USEPA, Table 9, Mixed MSW combustion EF

Notes:

1. Based on 4,000 tons per day design throughput for the facility
2. Estimated based on 85% typical facility availability
3. Sample calculation provided below. GHG emissions are reported in units of CO_2e.
4. Based on our understanding of the process and professional knowledge, GHG emissions for gasification facilities would be comparable and on par with GHG emissions from a WTE Facility with the same carbon content of fuel. Therefore, emission factor used for waste-to-energy facility is used. The emisison factor for WTE includes transport of waste to facility and combustion-related non-biogenic CO_2 and N_2O. Biogenic emissions are not included.

Sample Calculation:

CO_2e (MT/yr) = Throughput (tons/yr) x Emission Factor (MT CO_2e / short ton material)

Table 8: GHG Annual Emissions - Turned Aerated Pile Composting Facility

Miami-Dade County, DSWM

Facility Throughput (tons/day)[1]	Facility Throughput (tons/yr)[2]	Emissions[3] CO_2e (MT/yr)
1,350	492,750	68,985

Emission Factors[4]

Pollutant	Value[4]	Units	Basis
CO_2e	0.14	MT CO_2e / Short Ton Material	USEPA, Table 9, max of food waste/yard waste/organics composted EF

Notes:

1. Design throughput - 1,350 tons/day of yard waste, food waste, and organics
2. Estimated based on 365 days of operation
3. Sample calculation provided below. GHG emissions are reported in units of CO_2e.

4. Emission Factors for Greenhouse Gas Inventories, Version 2023, Table 9, Maximum of composting emission factors for food waste/yard waste/organics. Composting emissions do not include avoided emissions associated with fertilizer offset or soil carbon storage. Composting emissions include transport to compost facility, equipment use at compost facility, and CH_4 and N_2O emissions during composting.

Sample Calculation:

CO_2e (MT/yr) = Throughput (tons/yr) x Emission Factor (MT CO_2e / short ton material)

Table 9: GHG Annual Emissions - Mixed Waste Processing Facility
Miami-Dade County, DSWM

Facility Throughput (tons/day)[1]	Facility Throughput (tons/yr)[2]	Emissions[3]
		CO_2e (MT/yr)
4,000	1,460,000	335,800

Emission Factors[4]

Pollutant	Value	Units	Basis
CO_2e	0.23	MT CO_2e / Short Ton Material	USEPA, Table 9, max food waste/yard waste/organics recycling EF

Notes:

1. Design throughput - 4,000 tons/day of yard waste, food waste, and organics
2. Estimated based on 365 days of operation
3. Sample calculation provided below. GHG emissions are reported in units of CO_2e.

4. Emission Factors for Greenhouse Gas Inventories,Version 2023, Table 9, Maximum of recycling emission factors for food waste/yard waste/organics. Recycling emissions do not include avoided emissions associated with process energy, transportation energy, process non-energy, or forest carbon storage. Recycling emissions include transport to recycling facility and sorting of recycled materials at material recovery facility.

Sample Calculation:

CO_2e (MT/yr) = Throughput (tons/yr) x Emission Factor (MT CO_2e / short ton material)

Table 10: GHG Annual Emissions - Anaerobic Digestion Facility

Miami-Dade County, DSWM

Facility Throughput (tons/day)[1]	Facility Throughput (tons/yr)[2]	Emissions[3] CO_2e (MT/yr)
1,000	365,000	40,150

Emission Factors[4]

Pollutant	Value[4]	Units	Basis
CO_2e	0.11	MT CO_2e / Short Ton Material	USEPA, Table 9, Max EF from anerobic digestion of food waste

Notes:

1. Design throughput - 1,000 tons/day of food waste and organics
2. Estimated based on 365 days of operation
3. Sample calculation provided below. GHG emissions are reported in units of CO_2e.

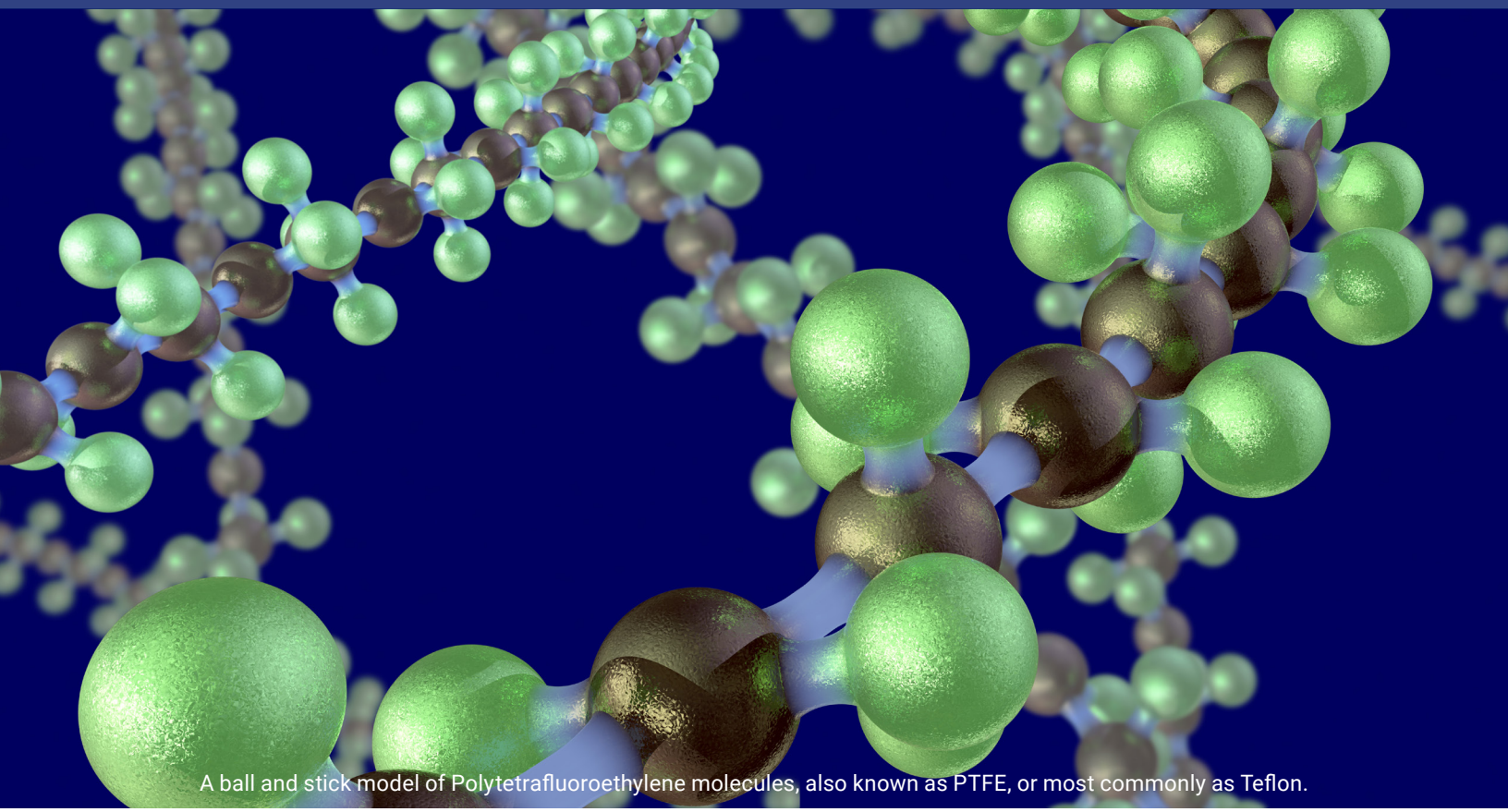
4. Emission Factors for Greenhouse Gas Inventories,Version 2023, Table 9, Maximum emission factor of food waste/organics from anaerobic digestion (wet digestate with curing). Anaerobically Digested (Dry and Wet Digestate with Curing) emissions do not include avoided emissions associated with displaced electric utility generation, soil carbon storage, or avoided fertilizer application. Emissions include transport to the anaerobic digester facility, equipment use at the anaerobic digester facility, biogas leakage at the digester, emissions released during the curing and land application process, and fugitive emissions during the curing and after land application.

Sample Calculation:

CO_2e (MT/yr) = Throughput (tons/yr) x Emission Factor (MT CO_2e / short ton material)

June 2021

PFAS FATE AND TRANSPORT IN WASTE-TO-ENERGY FACILITIES



A ball and stick model of Polytetrafluoroethylene molecules, also known as PTFE, or most commonly as Teflon.

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Prepared for:
SWANA Applied Research Foundation
Waste Conversion and Energy Recovery (WCER) Group Subscribers

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INTRODUCTION

In Fiscal Year (FY) 2019, the SWANA Applied Research Foundation's (ARF) Waste Conversion and Energy Recovery (WCER) Group selected the topic of "PFAS Fate and Transport in Waste-to-Energy Facilities" for investigation. This topic was described as follows:

> *"Per and polyfluoroalkyl substances (PFAS) have been receiving significant amount of attention as widespread and persistent contaminants. PFAS is a long-chain compound prized for its ability to resist heat and breakdown. Preliminary studies have shown that there may be negative health impacts and possible cancer links. PFAS is of particular interest to solid waste professionals in terms of its fate and transport to landfills and presence in landfill leachate.*
>
> *Initial studies performed in Europe and Japan have indicated that thermal treatment through traditional combustion may reduce PFAS in the waste, in both the ash residue and air emissions. Several universities and the EPA have ongoing research on PFAS in waste.*
>
> *I recommend that the SWANA WCER ARF perform a study to determine the impact that thermal treatments have on PFAS compounds, with a relative comparison of the health impacts between the current solid waste management options. At a minimum, a comparison of PFAS levels in leachate between WTE ash monofills versus traditional MSW landfills should be performed."*

Twelve organizations subscribed to the SWANA ARF's WCER Group in FY2021, each of which made a funding commitment to support the conduct of collective applied research in the waste-to-energy (WTE) area.[1] A listing of the WCER Group subscribers and their contacts is provided in Table 1-1.

The research findings presented in this report are based on a comprehensive review of the literature and an analysis of the findings of laboratory, pilot-scale, and full-scale investigations of the PFAS emissions from WTE facilities and similar thermal combustion plants and processes. This report was prepared by SWANA staff with input and draft report reviews provided by the WCER Group.

This report has been independently reviewed by Dr. Marco J. Castaldi, Professor, Chemical Engineering Department, and Director, Earth Engineering Center (EEC|CCNY) at The City College of New York, City University of New York. Dr. Castaldi is in agreement with its findings and conclusions.

[1] *If the jurisdiction or organization was already an ARF subscriber and had made about a penny ($0.011) per-ton funding commitment to another group, the funding rate for the WTE group was reduced to $0.0055 per ton.*

Table 1-1: SWANA ARF FY2021 Waste Conversion and Energy Recovery Group Subscribers

Tony Hill
Environmental Resources Director
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John "Doc" Holladay
Executive Director
Solid Waste Disposal
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Randy Kiser
Operations and Compliance
Manager
Hennepin County, MN

Manuel Lanuevo, PE
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Joe Levine, PE
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New River Resource Authority, VA

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Adam Ortiz
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Montgomery County, MD

Dan Pellowitz
Executive Director
Solid Waste Authority of
Palm Beach County, FL

John Snarr
Metropolitan Washington COG
I-95 Landfill Owners Group, VA

Dave Vollero
Executive Director
York County Solid Waste
Authority, PA

Hamid Zaman, PhD, Peng.
General Supervisor, Technical
Services, Waste Services
City of Edmonton, Alberta, CN

PERFLUOROALKYL AND POLYFLUOROALKYL SUBSTANCES (PFAS)

Perfluoroalkyl and polyfluoroalkyl substances (PFAS) are a group of synthetic chemicals that have been used in industrial processes and consumer products throughout the world since the 1950s[2] (See Figure 2-1). PFAS, which do not occur naturally and are wholly man-made, are widespread in the environment and are found in humans, wildlife, and fish all over the world. Some PFAS do not break down easily in the environment. On average, PFAS can remain in the body between two and nine years.[3]

PFAS may be in drinking water, food and food wraps, indoor dust, some consumer products, and workplaces. Although certain types of PFAS are no longer used, some products, including the following, may still contain PFAS:

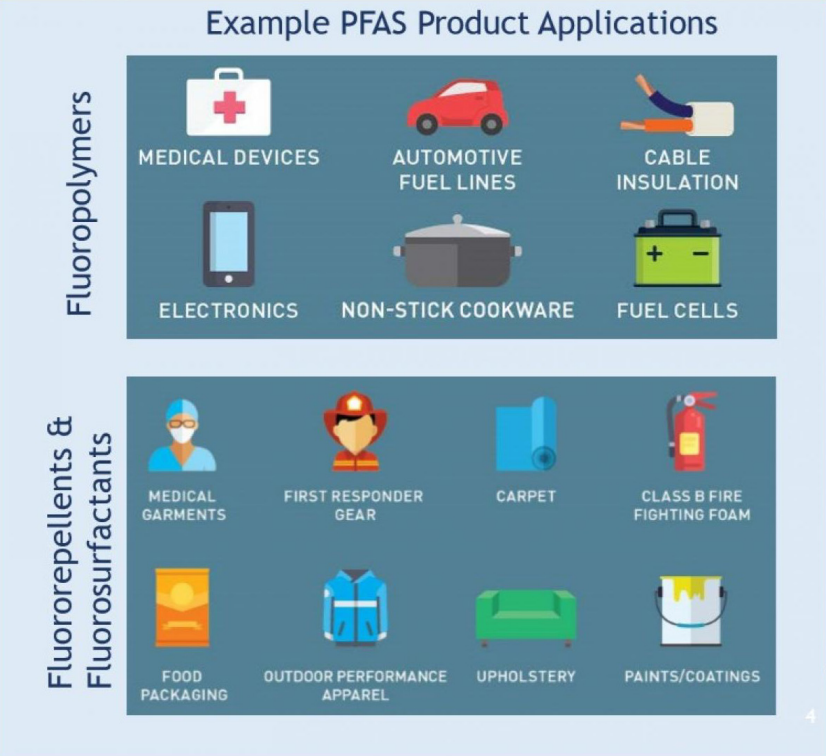
- Food packaging materials
- Nonstick cookware
- Stain resistant carpet treatments
- Water resistant clothing
- Cleaning products
- Paints, varnishes, and sealants
- Firefighting foam
- Cosmetics[4]

The Agency for Toxic Substances and Disease Registry (ATSDR) states that ingestion of PFAS is the primary exposure pathway for the general US population. Major ingestion sources include:

- Eating foods like fish and shellfish grown or raised with PFAS contaminated water or soil
- Eating food packaged in materials containing PFAS (e.g., popcorn bags, fast food containers, pizza boxes)
- Drinking contaminated water[5]

[2] *Agency for Toxic Substances and Disease Registry.* Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS): Frequently Asked Questions. https://www.atsdr.cdc.gov/pfas/resources/pfas-faqs.html.
[3] *Florida Department of Health.* Per- and Polyfluoroalkyl Substances (PFAS). *Updated January 4, 2021.*
[4] *Agency for Toxic Substances and Disease Registry.* Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS): Frequently Asked Questions.
[5] *ASTDR.* PFAS: An Overview of the Science and Guidance for Clinicians on Per- and Polyfluoroalkyl Substances (PFAS). *(Revised December 6, 2019). Some long-chain PFAS such as PFOS and PFOA were phased out of food packaging by the FDA in 2016. New shorter chain PFAS may have replaced those phased out in food packaging.*

Figure 2-1: Public Information Brief: PFAS



SOURCE: https://www.oaklodgewaterservices.org/surface-water/page/public-information-brief-pfas.

Scientists and others are conducting research and learning about the health effects of exposures to mixtures of PFAS.[6] Within the group of chemicals commonly referred to as PFAS, perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS) have become chemicals of emerging concern to the public's health.[7] Of the thousands of PFAS compounds, these two species have been the most widely studied. (See Figure 2-2).[8]

Figure 2-2: The Chemical Composition and Tail and Head Structures of PFOS and PFOA

Perfluorooctane sulfonate (PFOS)

Perfluorooctane carboxylate (PFOA)

SOURCE: ITRC. Naming Conventions and Physical and Chemical Properties of Per- and Polyfluoroalkyl Substances (PFAS). https://pfas-1.itrcweb.org/fact_sheets_page/PFAS_Fact_Sheet_Naming_Conventions_April2020.pdf.

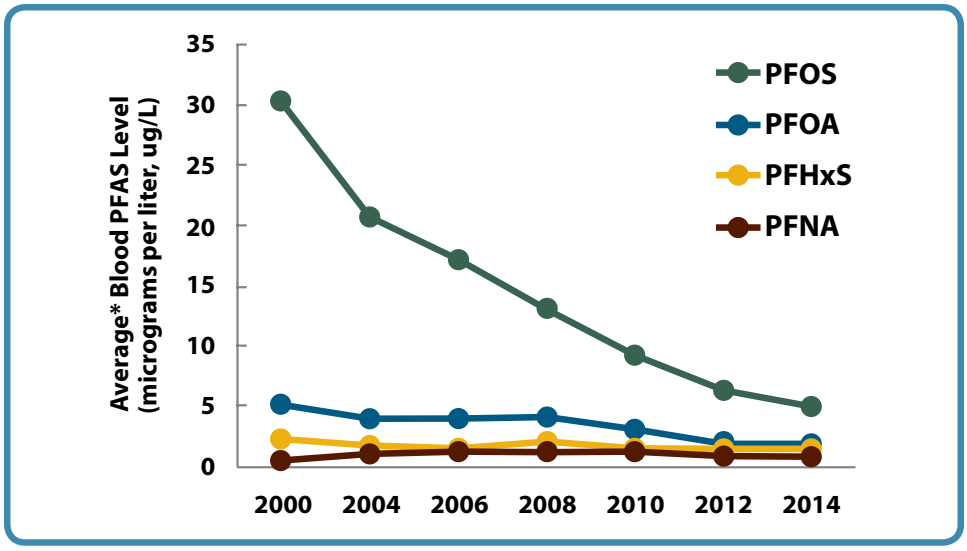
[6] *ASTDR. "What are the health effects of PFAS?"* https://www.atsdr.cdc.gov/pfas/health-effects/index.html.
[7] *Zahra, A. "PFAS: Chemicals of Emerging Concern."* Fullerton Observer, *Feb. 4, 2020.*
[8] *It is noteworthy that PFOS was phased out of production and use in 2002, and US manufacturers eliminated PFOA emissions and product content at the end of 2015.* https://ntp.niehs.nih.gov/whatwestudy/assessments/noncancer/completed/pfoa/index.html.

Some scientific studies suggest that certain PFAS may affect different systems in the body. The ATSDR is working with various partners to better understand how exposure to PFAS might affect people's health, especially how exposure to PFAS in water and food may be harmful. Although more research is needed, research involving humans suggests that high levels of certain PFAS may lead to the following:

- Increased cholesterol levels
- Changes in liver enzymes
- Small decreases in infant birth weights
- Decreased vaccine response in children
- Increased risk of high blood pressure or preeclampsia in pregnant women
- Increase risk of kidney or testicular cancer[9]

Blood levels of the most common PFAS in people in the US have decreased significantly since 3M began phasing out the production of PFOS, PFOA, and PFOS-related products in 2000. For example, as indicated in Figure 2-3, they have decreased by over 66 percent from 2000 to 2014.

Figure 2-3: Blood Levels of the Most Common PFAS in People in the US from 2000–2014



SOURCE: https://www.atsdr.cdc.gov/pfas/health-effects/us-population.html. Note: average = geometric mean.

A listing and description of the PFAS chemicals referred to in this report is provided in Table 2-1.

[9] *Agency for Toxic Substances and Disease Registry.* Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS): Frequently Asked Questions. https://www.atsdr.cdc.gov/pfas/resources/pfas-faqs.html.

Table 2-1: PFAS Chemicals: Abbreviations and Descriptions

Chemical	Abbreviation	Description
Fluorocarbons, Fluorotelomers, Oligomers, Telomers, Polymers, Mers		Fluorocarbons, sometimes referred to as perfluorocarbons, or PFCs, are organic compounds that are comprised of carbon and fluorine atoms. Fluorocarbons are structurally similar to hydrocarbons; however, fluorine atoms are substituted for hydrogen atoms in their chemical makeup. Fluorotelomers are fluorocarbon-based oligomers synthesized by telomerization. An oligomer is a polymer whose molecules consist of relatively few repeating units. A telomer is an extremely small polymer that generally has between two and five units. A "mer" refers to a repeating unit in chemistry. Polymer means multiple mers or units.
Fluorotelomer-Based Products	FTBP	Fluorotelomer-based products are commercial products that utilize fluorotelomers to repel water, oil, and stains. FTBPs include fire-fighting foams, grease-resistant food packaging, leather protectants, stain-resistant carpeting, and textiles.
Fluorotelomer carboxylic acid	FTCA	FTCAs are shorter chain (3-5 carbon) fluorinated organic compounds (FOC) used to replace PFCA.
Fluorotelomer Alcohol	FTOH	FTOHs are volatile precursos to PFCAs such as PFOA and perfluorononanoic acid (PFNA).
Perfluoroalkyl Acid	PFAA	PFAAs are a family of perfluorinated chemicals that consist of a carbon backbone (typically 4–14 carbons in length) and a charged functional group (primarily carboxylate, sulfonate, or phosphonate). The two most widely known PFAAs contain an eight-carbon backbone and include perfluorooctanoic acid (PFOA) and perfluorooctane sulfate (PFOS).
Perfluoroalkyl and polyfluoroalkyl substances	PFAS	PFAS are a large group (over 4,600) of man-made chemicals that have been used in industrial processes and consumer products throughout the world since the 1950s.
Perfluorobutanesulfonic Acid	PFBS	PFBS is a 4-carbon chain fluorocarbon with a sulfonic acid functional group. PFBS has been used by 3M as a replacement for PFOS in Scotchguard stain repellents since 2003.
Perfluorinated Carboxylic Acid	PFCA	PFCAs are longer chain perfluorinated carboxylic acids (e.g. with 5–9 carbons) are useful fluorosurfactants and emulsifiers used in the production of Teflon and related fluoropolymers.

Table 2-1: PFAS Chemicals: Abbreviations and Descriptions

Chemical	Abbreviation	Description
Perfluorooctanoic Acid	PFOA	PFOA is an 8-carbon fluorocarbon with a carboxylic acid functional group. PFOA is used for several industrial applications, including carpeting, upholstery, apparel, floor wax, textiles, fire-fighting foam, and sealants. Along with PFOS, it is one of the two most widely studied PFAS due to public health concerns.
Perfluorooctane Sulfonate	PFOS	PFOS is an 8-carbon fluorocarbon with a sulfonic acid functional group. PFOS is one of the two most widely studied PFAS due to public health concerns. PFOS was the key ingredient in Scotchgard and numerous stain repellents. 3M phased out the production of PFOS, PFOA and PFOS-related products starting in 2000.
Polytetrafluoroethylene	PFTE	PFTE is a fluorocarbon solid with a high molecular weight that consists wholly of carbon and fluorine. PTFE is used as a non-stick coating for pans and other cookware. The brand name of PTFE-based formulas is Teflon.

SOURCE: Wikipedia and the Interstate Technology and Regulatory Council. https://pfas-1.itrcweb.org/fact-sheets/.

PFAS IN MUNICIPAL SOLID WASTE

The PFAS content of MSW is reported to vary widely. One reason for this variance is that there is no standard methodology for obtaining representative MSW samples and establishing their PFAS content. PFAS concentrations for individual solid waste fractions have been found to range from 0 to more than 1,000 nanograms per gram of sample (ng/g). A value of 10 ng/g (0.01 parts per million or ppm) is considered a representative figure characterizing the overall MSW PFAS content.[10]

This value compares well with the findings of a study conducted by Sanborn Head and Associates, Inc. for the New England Waste Services of Vermont, Inc.,[11] which estimated that 23 grams per day of PFAS is included in the approximately 2,025 tons per day received at the Coventry Landfill.[12] This amount is equivalent to 12.5 ng/g or 0.0125 ppm. While these findings agree, it should be noted that the PFAS samples were taken from specific waste streams that included sludges from municipal wastewater treatment plants (WWTPs) and other industrial sources, sewer grit, contaminated soil, textiles from bulky wastes, carpeting and other construction and demolition (C&D) waste, and targeted wastes from commercial customers (such as food packaging). MSW from residential sources was not included in the sampling program.

Another method that can be used to estimate the PFAS content of MSW is to multiply the PFAS content of certain types of MSW (carpet for instance) by their reported PFAS concentrations. As an example, the EPA reported that carpets and rugs represented 1.7 percent of the MSW disposed in 2018.[13] Assuming that 40 percent of the weight of the carpet consisted of carpet fibers, carpet fibers would therefore represent 0.7 percent of the MSW disposed that year.[14]

A 2009 peer-reviewed study prepared by EPA researchers reported PFOA literature values of 200–600 nanograms per gram (or ppb) of fiber for pre-treated carpeting.[15] Multiplying these percentages by the carpet fiber fraction of MSW indicates that if all disposed carpet were pre-treated with PFOA, the PFOA content of MSW from carpet would be 0.001–0.004 ppm. (See Table 3-1).[16] These numbers are 10–40 percent of the MSW PFAS content reported above and therefore appear to support the MSW PFAS estimate of 0.01 ppm.

[10] *Kremen, A. "Leachate is the Driving Force for PFAS Sequestration in Landfills",* WasteAdvantage Magazine*, Nov 2, 2020.*
[11] *Sanborn Head and Associate, Inc.* PFAS Waste Source Testing Report: New England Waste Services of Vermont, Inc.*, October 2019.*
[12] *Email from Samuel Nicolai of Casella Waste Systems, Inc. to Jeremy O'Brien, SWANA's Director of Applied Research, February 4,2021.*
[13] *US EPA.* Advancing Sustainable Materials Management: 2016 and 2017 Tables and Figures*, November 2019.*
[14] *To determine the face weight (carpet fiber weight) of the total weight of the carpet, the total weight should be divided by 2.5. Some manufacturers, Mohawk for example, list both the face weight and total weight on the display cards. For example, 22 oz. nylon Mainstreet type commercial carpet equals 54.08–55.28 oz. total weight.*
[15] *Guo, Z. et al.* Perfluorocarboxylic Acid Content in 116 Articles of Commerce*. (EPA/600/R-09/033) (March 2009). The PFOA content range found in the study for pre-treated carpeting was ND (non-detect) to 462 nanograms per gram of carpet fiber).*
[16] *This estimate assumes that all the carpet being disposed has been pre-treated. While it is not unreasonable to assume that a majority of carpet has been pretreated for stain resistance, the percentage of pre-treated carpet to total disposed carpet was not estimated for this study.*

Table 3-1: Estimated PFOA Concentration in MSW from Carpet Fibers

Parameter	Units	Low Estimate	High Estimate
Carpet Disposed	% MSW	1.7%	1.7%
Carpet Fiber Disposed	% Carpet Weight	40%	40%
Carpet Fiber Disposed	% MSW	0.7%	0.7%
Carpet Fiber PFOA Content	ppb	200	600
PFOA in MSW from Carpet Fiber	ppm	0.001	0.004
	lbs/ton MSW	0.000003	0.000008

Based on quantities typically found in homes, professional carpet-care liquids, pre-treated carpeting, treated floor waxes and sealants, and treated home textile products and upholstery are likely to be the most important sources of perfluorocarboxylic acid (PFCA) sources in non-occupational indoor environments. The disposal of these products—along with nonstick cookware, food packaging materials, paints, varnishes, sealants, and cleaning products—are likely sources of PFAS in the residential MSW stream.[17]

[17] *Guo, Z. et al.* Perfluorocarboxylic Acid Content in 116 Articles of Commerce. *(EPA/600/R-09/033) (March 2009).*

ENVIRONMENTAL PROTECTION AGENCY PFAS INITIATIVES

Introduction

Within the last two years, the EPA has issued two important documents relating to the management of PFAS wastes:

1. Technical Brief. *Per- and Polyfluoroalkyl Substances (PFAS): Incineration to Manage PFAS Waste Streams.* (August 2019).
2. *Interim Guidance on the Destruction and Disposal of Perfluoroalkyl and Polyfluoroalkyl Substances and Materials Containing Perfluoroalkyl and Polyfluoroalkyl Substances.* (December 2020).

In addition, the EPA's Office of Research and Development (ORD) established a PFAS Innovative Treatment Team (PITT) in the spring of 2020. These recent EPA documents and initiative are summarized below.

EPA Technical Brief: Incineration of PFAS Waste Streams

About 16 months prior to the issuance of its interim guidance in December 2020, EPA issued a technical brief on the use of incineration to manage PFAS waste streams.[18]

In the brief, EPA states that one potential disposal method for PFAS waste is through high temperature chemical breakdown, or incineration. Incineration has been used as a method of destroying related halogenated organic chemicals such as polychlorinated biphenyls (PCBs) and ozone-depleting substances (ODSs), where sufficiently high temperatures and long residence times break the carbon-halogen bond, after which the halogen can be scrubbed from the flue gas, typically as an alkali-halogen.

The technical brief states the incineration of halogenated organic compounds occurs via unimolecular decomposition and radical reaction. For unimolecular decomposition, fluorinated organic compounds require temperatures above 1,000˚C to achieve 99.99 percent destruction with one second residence time. It is noteworthy that this temperature and residence time is required for US WTE facilities. (See Table 4-1). The most difficult fluorinated organic compound to decompose is carbon tetrafluoride (CF_4), requiring temperatures over 1,400°C.

EPA also notes that the extent to which PFAS-containing waste material in the United States is incinerated is not fully documented or understood. One reason for this is PFAS compounds are not listed as hazardous wastes under the Resource Conservation and Recovery Act (RCRA), nor as hazardous air pollutants under Clean Air Act regulations, so they are not subject to the tracking systems associated with these regulations.

EPA concludes the technical brief by stating that the agency is considering multiple disposal techniques, including incineration, to effectively treat and dispose of PFAS wastes. EPA researchers are currently studying PFAS incineration, sampling and analytical methods development, and industrial field sampling. Research on thermal stability of PFAS compounds, the ability to fully capture and identify PFAS compounds and their thermal decomposition byproducts, and the efficacy of emission control technologies are areas of targeted research. These efforts, in cooperation with states and industries, are aimed at proper disposal of PFAS-containing wastes without media-to-media transfer or environmental release.

[18] *EPA Technical Brief.* Per- and Polyfluoroalkyl Substances (PFAS): Incineration to Manage PFAS Waste Streams. *August, 2019.*

EPA PFAS Innovative Treatment Team (PITT)

The PFAS Innovative Treatment Team (PITT) was established by the EPA ORD in the spring of 2020. The PITT brought together multi-disciplined research staff from EPA over a six-month period on a full-time basis to focus their efforts and expertise on a single problem: namely, the disposal and/or destruction of PFAS-contaminated media and waste. The PITT operated in a work environment designed to break down administrative and procedural barriers in an effort to facilitate faster results.

The PITT researchers identified four innovative technologies as promising for destroying PFAS in liquid or solid waste streams:

- Electrochemical Oxidation
- Mechanochemical Degradation
- Pyrolysis and Gasification
- Supercritical Water Oxidation

The team developed a series of Research Briefs that provide an overview of the four innovative technologies as well as the research that is underway at the EPA ORD to further explore these technologies.[19]

EPA Interim Guidance

Overview

On December 18, 2020, the US EPA issued a publication entitled "Interim Guidance on the Destruction and Disposal of Perfluoroalkyl and Polyfluoroalkyl Substances and Materials Containing Perfluoroalkyl and Polyfluoroalkyl Substances".[20] The interim guidance presents currently available information on PFAS destruction and disposal along with information on the current state of the science and the uncertainties associated with current commercially available disposal or destruction technologies.

In the interim guidance, EPA identified three technological solutions that are commercially available and potentially have the capability to destroy PFAS or manage the migration of PFAS in PFAS-containing materials. These technologies are:

- Thermal treatment
- Landfilling
- Underground injection control

It is noteworthy that two of these technologies are the primary methods that are used to treat and dispose of MSW in the US. EPA noted that incineration is an effective and approved method for destroying a number of halogenated organic chemicals including chlorinated solvents, polychlorinated biphenyls (PCBs), dioxin-laden wastes, brominated flame retardants, refrigerants, and ozone-depleting substances (ODSs). Since fluorine, like chlorine and bromine, is a halogen, PFAS fall into the category of halogenated chemicals.

[19] https://www.epa.gov/chemical-research/pfas-innovative-treatment-team-pitt.

[20] *US EPA. Interim Guidance on the Destruction and Disposal of Perfluoroalkyl and Polyfluoroalkyl Substances and Materials Containing Perfluoroalkyl and Polyfluoroalkyl Substances. December 18, 2020. EPA accepted public comments on the interim guidance through February 22, 2021. https://www.epa.gov/pfas/interim-guidance-destroying-and-disposing-certain-pfas-and-pfas-containing-materials-are-not. SWANA submitted comments on the Interim Guidance in February 2021.*

PFAS are difficult to destroy due to the strength of the carbon-fluorine bond, which is caused by fluorine's electro-negativity and the chemical stability of fluorinated compounds. The incomplete destruction of PFAS compounds during the incineration process or the recombination of reactive intermediate reaction products can potentially result in the formation of new PFAS or other products of incomplete combustion (PICs), issues that are of concern to the EPA.[21]

For the interim guidance, it is noteworthy EPA defined PFAS destruction as the complete severing of all carbon-fluorine bonds in a PFAS molecule. Severing all carbon-fluorine bonds would result in conversion of PFAS to carbon dioxide, hydrogen fluoride (HF), and other compounds.[22] EPA noted HF and some of the other products of combustion can be removed in pollution control devices.

PFAS Destruction in Municipal Waste Combustors (MWCs)

The interim guidance states there were 193 municipal waste combustor (MWC) units operating in the United States.[23] Three main classes of technologies are used to combust MSW: mass burn (78 percent), refuse-derived fuel (17 percent), and modular combustors (five percent).

EPA noted that, with mass burn units, MSW is combusted without any preprocessing other than removal of items too large to go through the feed system or hazardous materials, such as pressurized containers. In a typical mass burn combustor, refuse is placed on a grate that moves the waste through the combustor. The grates typically have three sections. On the initial grate section, referred to as the drying grate, the moisture content of the waste is reduced before ignition. The second grate section, referred to as the burning grate, is where most of the active burning takes place. The third grate section, referred to as the burnout or finishing grate, is where remaining combustibles in the waste are burned. Typical combustion temperatures for mass burn units can range from 800–1,100°C (1,472–2,012°F).[24]

Residence times of gases within MWCs vary from unit to unit, depending on design and operational factors such as furnace volume, excess combustion air percentage, whether flue gas recirculation is employed, and combustor operating load parameters. Overall combustion air residence times have been calculated in the 7–10 second range for a small sampling of MWC design loads, with an approximate residence time at temperature above 980°C (1,800°F) of about two seconds at full combustor load.[25] MWCs typically achieve combustion gas temperatures of greater than 1,500°F for residence times of greater than two seconds.[26] Finally, studies suggest that combustion temperatures necessary to completely destroy PFAS may be reduced if certain catalysts, such as calcium hydroxide, are present in thermal treatment system.[27]

[21] *Typical values for C–F bonds are around 100 kcal/mol, while for C–Cl bonds are around 80 kcal/mol; C–Cl bonds are therefore weaker.*

[22] *EPA has stated that complete combustion of PFAS is almost impossible to achieve due to kinetic and transport limitations which are related to the "three Ts" of combustion (time, temperature and turbulence.) See Linak, W. and Lee, C.W.* Incineration 101 and issues related to PFAS destruction. *(US EPA/ORD, Research Triangle Park, NC).*

[23] *The EPA is apparently defining an MWC unit as a single boiler train in a WTE facility. Most WTE facilities in the US have two or more boiler trains. The Energy Recovery Council reported that there were 75 WTE facilities in the US in 2018. (Michaels, T. and Krishnan, K. Energy Recovery Council:* 2018 Directory of Waste-to-Energy Facilities*).*

[24] *US EPA.* Interim Guidance on the Destruction and Disposal of Perfluoroalkyl and Polyfluoroalkyl Substances and Materials Containing Perfluoroalkyl and Polyfluoroalkyl Substances*. December 18, 2020.*

[25] *Ibid.*

[26] *Linak, Bill and C. Lee.* Incineration 101 and issues related to PFAS destruction. *EPA Region 5/State Directors Teleconference Call (February 12, 2020).*

[27] *Wang, F. Lu, X., Li, X. and Shih, K. Effectiveness and Mechanisms of Defluorination of Perfluorinated Alkyl Substances by Calcium Compounds during Waste Thermal Treatment. Environ. Sci. Technol. 2015, 49, 9, 5672–5680 (April 7, 2015).* https://doi.org/10.1021/es506234b.

The temperatures and residence times typically achieved and/or required for the thermal treatment of non-hazardous and hazardous waste in the US and Europe are presented in Table 4-1.

Table 4-1: Temperature and Residence Times for the Thermal Treatment of Non-Hazardous and Hazardous Solid Waste

Waste Type	Location	Temperature		Residence Time
		Centigrade	Fahrenheit	Seconds
Non-Hazardous (MSW)	US[1]	800–1,100	1,472–2,012	2s[2]
	Europe[3]	850	1,562	2s
Hazardous Waste[4]	Europe	1,100	2,012	2s

[1] *Typical combustion temperatures for mass burn units. (US EPA. Interim Guidance on the Destruction and Disposal of Perfluoroalkyl and Polyfluoroalkyl Substances and Materials Containing Perfluoroalkyl and Polyfluoroalkyl Substances. December 18, 2020.)*
[2] *Approximate residence time at temperature above 980°C (1,800°F) of about 2 seconds at full combustor load. (Ibid).*
[3] *Waste incineration plants shall be designed, equipped, built and operated in such a way that the gas resulting from the incineration of waste is raised, after the last injection of combustion air, in a controlled and homogeneous fashion and even under the most unfavorable conditions, to a temperature of at least 850 °C for at least two seconds." (Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control).*
[4] *If hazardous waste with a content of more than 1 percent of halogenated organic substances, expressed as chlorine, is incinerated or co-incinerated, the temperature required to comply with the first and second subparagraphs shall be at least 1 100 °C." (Ibid).*

Based on its review, EPA concluded the effectiveness of incineration to destroy PFAS compounds and the tendency for formation of fluorinated or mixed halogenated organic byproducts is not well understood, as few experiments have been conducted under the oxidative and temperature conditions representative of field-scale incineration. Emission studies, particularly for PICs, have been incomplete due to lack of necessary measurement methods suitable for the comprehensive characterization of fluorinated and mixed halogenated organic compounds.[28]

Need for Additional Research

EPA believes it is important to determine whether thermal treatment units and their associated post-combustion control devices are adequately controlling PICs, especially fluorinated PICs. In light of the uncertainties and unknowns, continued research is needed to better understand the effectiveness of PFAS destruction through high temperature combustion of waste. After sufficient research has been completed to address the related knowledge and data gaps, EPA can make a more informed recommendation on disposal of PFAS compounds and PFAS-containing substances using incineration. Unfortunately, an investigation planned for August 2020 at the Union County Resource Recovery Facility in Rahway, NJ was canceled due to public opposition.[29, 30]

[28] *US EPA* . Technical Brief. Per- and Polyfluoroalkyl Substances (PFAS): Incineration to Manage PFAS Waste Streams. *August 2019.*
[29] *Crunden, E.A.,"PFAS test at Covanta-operated incinerator scrapped following public outcry."* Waste Dive, *August 26, 2020.*
[30] *Warren, M. Proposed Rahway incinerator study could help US deal with toxic chemicals. Activists wonder if it's safe. NJ.com. Auguste 22, 2020. No PFAS would have been burned during the Rahway experiment. Instead, the EPA planned to inject two non-toxic compounds — carbon tetraflouride (CF4) and hexafluoroethane (C2F6) into the incinerator. Scientists hoped that studying how the two compounds break down in the incinerator will give a glimpse into how PFAS acts in the same situation because their chemical structures are similar to PFAS. The EPA said the experiment would have been conducted over a three-day period, and the two substitute compounds would have been burned for "a few hours" each day. During the study, Covanta would have operated the incinerator as normal. As part of the study, EPA researchers would have also analyzed samples collected from the incinerator to see if PFAS were being emitted through the burning of everyday trash.*

UNITED STATES RESEARCH

Introduction

As indicated above, EPA has concerns regarding the efficacy of high-temperature combustion in completely destroying PFAS and whether fluorinated or mixed halogenated organic byproducts are formed during the process.

The purpose of this section of the report is to present the findings and conclusions of reported PFAS thermal treatment studies conducted with the temperature and residence time conditions that reflect typical combustion temperatures for mass burn units (800–1,100°C) and residence times (about two seconds at temperature above 980°C at full combustor load). As discussed above, the effectiveness of PFAS destruction in WTE facilities is for the most part dependent on these two parameters.

The findings and conclusions of PFAS research projects targeted toward European Union WTE temperature and residence time requirements (850°C: two-second residence time) are presented in the next section. SWANA hopes the findings and conclusions of both sets of research projects can shed light on the concerns identified by the EPA. The studies summarized in this section were all based on laboratory or pilot-scale investigations.

Investigation of waste incineration of fluorotelomer-based polymers as a potential source of PFOA in the environment (2014)

Fluorotelomer-based polymers (FTBPs) are a group of PFAS that are topically applied to textiles and paper to provide unique surface properties such as oil and water repellency for textiles and oil and grease penetration prevention for paper used in food packaging. A global inventory of the sources of PFOA emissions to the environment identified the waste incineration of FTBP products as a potential source of PFOA.

A comprehensive laboratory-scale study was conducted at the University of Dayton Research Institute in 2013 to provide data requested by EPA to determine whether municipal and/or medical waste incineration of commercial FTBPs at end of life is a potential source of PFOA that may contribute to environmental and human exposures.[31]

The study was divided into two phases (I and II) and was conducted in accordance with EPA Good Laboratory Practices (GLPs) as described in the quality assurance project plan (QAPP) for each phase. The thermal reactor system used in the study was a non-flame, batch-charged, continuous flow reactor system. Phase I testing determined that the PFOA transport efficiency across the thermal reactor system to be used in Phase II was greater than 90 percent.

Phase II testing involved operating the reactor system at 1000°C for two seconds residence time with 3.2–6.6 milligrams per dry standard cubic meter (mg/dscm) of hydrogen fluoride (HF), corrected to seven percent oxygen (O_2), and continuously monitored exhaust oxygen of 13 percent. The FTBP composites processed under these conditions in this thermal reactor system yielded results demonstrating that waste incineration of fluorotelomer-based polymers does not result in the formation of detectable levels of PFOA under conditions representative of typical MWC and medical waste incinerator operations in the US.

Based on these findings, the study's authors concluded waste incineration of these polymers should not be expected to be a source of PFOA in the environment.

[31] *Taylor, P.H. et al. Investigation of waste incineration of fluorotelomer-based polymers as a potential source of PFOA in the environment. Chemosphere 110 (2014) 17–22.*

Emissions of fluorinated compounds from the combustion of carpeting (2007)

One of the waste streams that is typically disposed of in combustors is carpet, due to its high heating value and combustibility. Some of the stain-resistant coatings that carpeting is treated with contain perfluorinated compounds (PFCs) such as perfluorooctanoic acid (PFOA) and their corresponding homologues (C6–C14 acids) as well as fluorotelomer alcohols and fluoropolymers. PFOA has recently been implicated as a chemical of concern due to its toxicity. It is unknown as to whether PFCs can be released from combustion or formed as by-products in combustors.[32]

EPA conducted a study in 2007 in a 0.73 kW pilot-scale rotary kiln incinerator simulator (RKIS) to qualitatively and, where applicable, quantitatively assess the potential for emissions of fluorinated compounds from combustion devices.[33] The primary goal of the study was to assess whether PFCs can be released from combustion facilities burning carpeting.

During the test, the RKIS was operated under "mild" combustor conditions at temperatures of less than 1,000°C and with the secondary combustion chamber off. Testing was performed using two different types of carpeting: one type that contained no stain-resistant treatment and one type treated with a stain resistant material that contains PFCs.

The PFOA emission results across six runs were either non-quantifiable or at trace (<0.000464 ppm) levels.[34] Based on these results, EPA concluded there was no statistically significant difference between PFOA emission levels while burning only natural gas and while burning treated or doped carpet, suggesting effective destruction via combustion of FTBPs used in carpet applications even under "mild" combustion conditions. EPA also noted that trace PFOA emission levels were likely due to the historical use of fluoropolymers in pilot combustor duct sampling or to the use of fluoropolymers in analytical laboratories.

Thermal degradation of fluorotelomer treated articles and related materials (2005)

The Yamada, et al. study represents the first known attempt to investigate thermal degradation of fabric treated with a fluorotelomer-based acrylic polymer (FTBP) under laboratory conditions, conservatively representing typical combustion conditions of time, temperature, and excess air level in an MWC.[35] When textiles and paper treated with FTBPs are processed in MWCs, the potential emissions of PFOAs as thermal degradation products of FTBP combustion is of significant interest.

In the study, a polyester/cellulose fabric substrate (''article'') treated with a fluorotelomer-based acrylic polymer was processed under laboratory conditions, conservatively representing typical combustion conditions of time, temperature, and excess air level in a municipal incinerator, with an average temperature of 1000°C or greater over approximately two seconds residence time.[36] The results demonstrate the article was destroyed and no detectable amount of PFOA was formed.

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[32] *Lemieux, P., Strynar, M., Tabor, D., Wood, J., Cooke, M., Rayfield, B., Kariher, P.* Emissions of fluorinated compounds from the combustion of carpeting. *In: International Conference on Incineration and Thermal Treatment Technologies (IT3) Conference, Phoenix, AZ, May 14–18, 2007.*

[33] *https://cfpub.epa.gov/si/si_public_record_report.cfm?Lab=NHSRC&dirEntryId=166464.*

[34] *One natural gas only combustion blank; two untreated carpet; two fluorotelomer-treated carpet with reported fluorine level of 0.3 percent by mass; one fluorotelomer-doped carpet. Taylor, P.H. et al. Investigation of waste incineration of fluorotelomer-based polymers as a potential source of PFOA in the environment.* Chemosphere 110 *(2014) 17–22.*

[35] *Yamada, T. et. al. "Thermal degradation of fluorotelomer treated articles and related materials."* Chemosphere 61 *(2005) 974-984.Elsevier Ltd. All rights reserved.*

[36] *The test substrate was a fabric comprised of a blend of polyester (ethylene glycol, terephthalic acid) and cellulose fibers. The substrate was chosen to be representative of both synthetic and natural fibers that are used in textiles and cellulosic fibers (cotton, wood pulp) used in paper.*

Based on these results, the researchers concluded textiles and/or paper treated with such a fluorotelomer-based acrylic polymer that are processed in MWCs can be expected to be destroyed and not be a significant source of PFOA in the environment. However, the researchers noted there are other breakdown products of PFAS besides PFOA, and that the absence of PFOA does not imply the absence of other PFAS species in the flue gases.

EUROPEAN UNION RESEARCH

Introduction

The findings and conclusions of PFAS research projects targeted toward European Union (EU) WTE temperature and residence time requirements (850°C: 2s residence time) are presented in this section. In contrast to the laboratory studies reviewed above for US PFAS research, it is noteworthy that the projects reviewed below include one pilot-scale and three full-scale investigations of PFAS emissions from WTE facilities.

Studies

Destruction of Persistent Organic Compounds in Combustion Systems (2014)

EU regulations on persistent organic pollutants (POPs) prohibit or limit the use of 22 substances considered to be particularly problematic due to their health and environmental hazard.[31]

In 2014, Dr. Lisa Lundin and Dr. Stina Jansson of the Department of Chemistry at Umeå University in Sweden conducted a study for the Swedish Environmental Protection Agency to document and summarize the current state of knowledge regarding the destruction of POPs in combustion systems.[32] Another objective of this research was to determine if more research funding was needed to determine the degradation efficiency in "Advanced Solid Waste Incinerators" (ASWIs) by answering the following question:

> *"Regarding emission of persistent organic pollutants, is there a need for more rigorous control of what waste is being burned in municipal 850°C waste incinerators—so called advanced solid waste incinerators (ASWIs)—with regard to emissions of persistent organic pollutants (POPs)?"*[33]

The POPs targeted in the study are:

- Polybrominated diphenyl ethers (PBDE)
- Hexabromocyclododecane (HBCD)
- Polychlorinated dibenzo-p-dioxins (PCDD)
- Polychlorinated dibenzofurans (PCDF)
- Perfluorooctane sulfonic acid (PFOS)

The study reported that more than 90 percent of the MSW incineration in Sweden is done in grate-fired mass burn combustors. In a mass burn combustor, the fuel is fed onto grates (sometimes movable) and air is introduced in excess from below the grate. Combustion temperatures of 850°C and a gas residence time of two seconds are required for ASWIs in the EU. Grate-fired incinerators are highly tolerant of variations in the quality of the fuel, which is probably one of the main reasons for their extensive use in the industry.

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[31] *EU Regulation 850/2004 on Persistent Organic Pollutants (POPs), hereinafter referred to as the POPs Regulation. The POPs Regulation is the EU's tool for implementing the Stockholm Convention.*

[32] *L. Lundin, and S. Jansson.* Destruction of Persistent Organic Compounds in Combustion Systems. *Norway Umea University (2017). Dr. Lundin and Dr. Jansson both have long and extensive experience of research on formation, transformation, and degradation of POPs in waste incineration and other thermal processes with high potential for generating POPs.*

[33] *Advanced Solid Waste Incinerators (ASWIs) is a term used in Europe to refer to WTE facilities that meet the temperature (850°C) and residence times (two seconds) required for European WTE facilities. (See Table 4-1.)*

The study authors reported that knowledge on how PFOS behaves in combustion processes is scarce, but consensus in the limited scientific literature is that degradation of PFOS occurs at temperatures above 500°C. Complete combustion of PFOS/PFAS should result in the formation of CO_2, H_2O, SO_2, and HF; however, as with all other combustion processes, this puts quite high demands on the process conditions. The strong C-F bonds in the PFAS molecules require high energy input to break the bonds.

According to the United Nations Environment Program (UNEP), the most appropriate way to handle waste containing PFOS is combustion in plants equipped to handle halogenated waste streams. Combustion is also recommended as a disposal method for activated carbon filters used in PFAS water purification, and firefighting foams using PFAS (in hazardous waste incinerators). The requirements imposed are the same as for the incineration of hazardous waste, i.e., at least 1,100°C and two seconds residence time.

Regarding PFOS, the literature indicates that PFOS is destroyed in the combustion zone and is not reformed in the post-combustion zone. However, the number of studies and published scientific articles in peer-reviewed journals are limited. Based on this study, the authors concluded that the statement that PFOS are destroyed in ASWIs can only be made with a low level of confidence. After consulting with other experts in the field, the authors opined that any PFOS that survive intact from the combustion zone would be captured in the air pollution control devices, and would not be emitted to the atmosphere.

Pilot Scale Investigations

Waste incineration of Polytetrafluoroethylene (PTFE) to evaluate potential formation of Per- and Poly-Fluorinated Alkyl Substances (PFAS) in flue gas (2019)

In 2018, the Karlsruhe Institute of Technology (KIT) in Karlsruhe, Germany tested the combustion of polytetrafluoroethylene (PTFE) at its pilot plant under typical waste incineration conditions.[34] The purpose of the test was to determine the degree to which PTFE was transformed into fluorine species (F) (as hydrofluoric acid (HF)), and to study the possible generation of low molecular weight per- and polyfluorinated alkyl substances during the combustion process.[35]

The Institute for Technical Chemistry at KIT operates a rotary kiln test facility equipped with a boiler for heat recovery and a flue gas cleaning system that complies with German emission regulations. The pilot plant, called BRENDA (German acronym for "Brennkammer mit Dampfkessel"), provides scalable combustion research opportunities such as the thermal behavior of end-of-life technical and consumer products. BRENDA has an overall thermal power rating of 2.5MW, where 1.5MW are from the rotary kiln and 1MW from the post-combustion chamber. For this study, PTFE and wood pellets were weighed and fed to the rotary kiln, while natural gas was supplied to the kiln and to the post-combustion chamber.

Of the 31 types of PFAS studied, only 11 were detected in the flue gases. For the 11 compounds detected, no difference from baseline/control levels could be distinguished when paired t-testing was used to evaluate the significance of the measured quantities.[36] Based on the PFAS levels detected and the randomness of their occurrence throughout the study, it was concluded that the likely source of these detected compounds was contamination of the samples from the environment and not the combustion of the PTFE. In light of the test

[34] *The commonly known brand name of PTFE-based formulas is Teflon.*

[35] *Aleksandrov, K. et al. "Waste incineration of Polytetrafluoroethylene (PTFE) to evaluate potential formation of per- and Poly-Fluorinated Alkyl Substances (PFAS) in flue gas."* Chemosphere *(April 4, 2019). https://doi.org/10.1016/j.chemosphere.2019.03.191.*

[36] *The paired sample t-test, sometimes called the dependent sample t-test, is a statistical procedure used to determine whether the mean difference between two sets of observations is zero. In a paired sample t-test, each subject or entity is measured twice, resulting in pairs of observations. https://www.statisticssolutions.com/manova-analysis-paired-sample-t-test/.*

quantitation limits of 0.3 to 24 mg/Nm^3 (depending on the compound and volume captured), the study found the 31 PFAS species studied were not created during the incineration of PTFE. As a result, the study concluded municipal incineration of PTFE using best available technology is not a significant source of the studied PFAS and should be considered an acceptable form of waste treatment.[37]

Full Scale Investigations

Long-term sampling emission of PFOS and PFOA of a Waste-to-Energy incinerator (2018)

In 2011 a "state of the art" waste-to-energy facility called the Restoffen Energie Centrale (REC) began operations in Harlingen, Netherlands.[38] This facility was required to comply with a stringent permit for dioxin emissions of 0.01 ng TEQ/Nm^3.[39]

In 2013, the non-governmental organization ToxicoWatch found high concentrations of dioxins and PCBs in the eggs of backyard chickens near the incinerator. To determine whether the REC was a source of these pollutants, a long-term sampling program of flue gases for halogenated unintentional persistent organic pollutants (UPOPs) was conducted from August 2015 through February 2017.

During the sampling program, the UPOPs in the flue gas of the REC were measured using the AMESA (Adsorption MEthod for SAmpling of dioxins) continuous sampling method. While the major focus of the sampling program was on dioxins and PCBs, a side research effort was conducted that involved the collection of six samples over 3,942 hours of measurements of brominated and fluorinated compounds, with the fluorinated compounds being PFOS and PFOA.

The results of the PFOS and PFAS sampling effort are presented in Figure 6-1. As shown, PFOS was only detected during one shutdown event at a level of 8.23 pg/Nm^3. PFOA was detectable in all six long-term sampling periods (433–794 hours). PFOS/PFOA emissions ranged from 0.004–0.0134 ng/Nm^3, while average emissions were 0.002 ng/Nm^3, which resulted in a yearly load estimate of 40.1 mg for PFOA and 4.9 mg PFOS.[40]

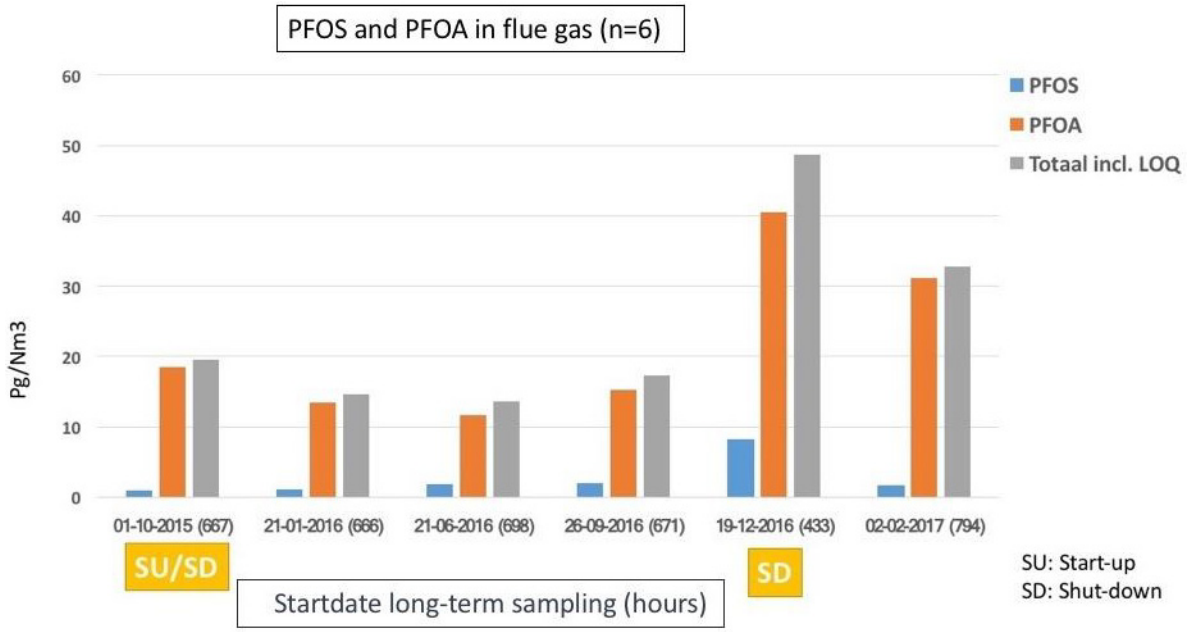
[37] *The PFAS and other chemicals studied included: Perfluorobutanoic acid (PFBA); Perfluoropentanoic acid (PFPeA): Perfluorohexanoic acid (PFHxA); Perfluoroheptanoic acid (PFHpA); Perfluorooctanoic acid (PFOA); Perfluorononanoic acid (PFNA); Perfluorodecanoic acid (PFDA); Perfluoroundecanoic acid (PFUdA); Perfluorododecanoic acid (PFDoA); Perfluoro-tridecanoic acid PFTrDA ; Perfluorotetradecanoic acid (PFTeDA):Perfluorobutanesulfonic acid (PFBS); Perfluorohexanesulfonic acid (PFHxS); Perfluoroheptanesulfonic acid (PFHpS); Perfluorooctanesulfonic acid (PFOS); Perfluordecanesulfonic acid (PFDS); Perfluorooctanesulfonamide (PFOSA); N-Methyl-Perfluorooctanesulfonamide (N-Me-FOSA); N-Ethyl- Perfluorooctanesulfonamide (N-Et-FOSA); N-Methyl-Perfluorooctane- sulfonamidoethanol (N-Me-FOSE alcohol); N-Ethyl-Perfluorooctane- sulfonamidoethanol (N-Et-FOSE alcohol); 1H,1H,2H,2H-Perfluoro- octanesulphonic acid (1H, 1H, 2H, 2H- PFOS); 2H,2H,3H,3H-Perfluoro- undecanoic acid (4HPFUnA); Perfluoro-3-7-dimethyl octane carboxylate (PF-3,7-DMOA); 7H-Dodecafluoro heptane carboxylate (HPFHpA); 2H,2H-Perfluoro decan carboxylate H2PFDA); 1H,1H,2H,2H-Perfluorohexan-1-ol; 1H,1H,2H,2H-Perflourooctan-1-ol; 1H,1H,2H,2H-Perflourodecan-1-ol; 1H,1H,2H,2H-Perflourododecan-1-ol; Trifluoroacetic acid.*

[38] *Aleksandrov, K. et al. "Waste incineration of Polytetrafluoroethylene (PTFE) to evaluate potential formation of per- and Poly-Fluorinated Alkyl Substances (PFAS) in flue gas."* Chemosphere *(April 4, 2019).*

[39] *TEQ refers to the "Toxic Equivalency Basis." For reference, the US TEQ dioxin/furan emissions limit is 0.076 nanograms per dry standard cubic meter for energy recovery units that commenced construction after June 4, 2010, or that commenced reconstruction or modification after August 7, 2013. (See EPA 40 CFR Part 60 [EPA-HQ-OAR-2003-0119; FRL-XXXX-XX-OAR] RIN 2060-AT84,* Standards of Performance for New Stationary Sources and Emission Guidelines for Existing Sources: Commercial and Industrial Solid Waste Incineration Units; Technical Amendments).

[40] *Arkenbout, A. "Long-term sampling emission of PFOS and PFOA of a Waste-to-Energy incinerator,"* ResearchGate *(Preprint – September 2018).*

Figure 6-1: Long-Term Sampling of 3,976 Hours of PFOS and PFOA in Flue Gas at the REC Waste-to-Energy Facility in Harlingen, The Netherlands



SOURCE: Arkenbout, A. "Long-term sampling emission of PFOS and PFOA of a Waste-to-Energy incinerator," ResearchGate *(Preprint, September 2018).*

As indicated in Table 6-1, the annual PFOA emissions rate from the REC WTE facility equate to an emissions rate of 0.00000018 milligrams per kilogram (or 0.00000000035 pounds per ton) of waste processed. This emission rate is equal to 0.18 parts per trillion (ppt), which is 0.3 percent of the 70 ppt PFAS health advisory set for the combined weight of PFOS and PFOA in drinking water. Since the PFOA concentration in the MSW processed was not known, the PFOA destruction efficiency of the REC facility could not be estimated.

Table 6-1: REC Waste-to-Energy Facility, Harlingen, The Netherlands

Parameter	Units	Quantity
MSW Processed	Tonnes/year	228,000
	Tons/year	250,800
	Kilograms/year	228,000,000
Annual Emissions: PFOA	Milligrams per year (mg/yr)	40.1
	Milligrams per kilogram (mg/kg) waste processed	0.00000018
	Parts per million (ppm) waste processed	0.00000018
	Parts per trillion (ppt) waste processed	0.18
	Pounds per ton (lbs/ton) waste processed	0.00000000035

Waste Incineration as a Possible Source of Perfluoroalkyl Acids to the Environment: Method Development and Screening (2014)

Perfluoroalkyl acids (PFAAs) are a sub-group of PFAS that include both perfluorooctanoic acid (PFOA) and perfluorooctane sulfonic acid (PFOS), which are the two PFAS that have been most studied to date.

It has been suggested that air pollution could be a major source of the PFAAs found in the Baltic Sea. The main objective of this study was to determine if waste incineration plants in Sweden are a significant source of PFAAs to the atmosphere and ultimately to the Baltic Sea.[41]

During the study, samples of the byproducts from waste incineration were collected at four different Swedish incineration plants in 2013. The plants differed in size and technical advancement and were considered to be representative of the majority of waste incineration plants in Sweden. The samples were collected from four commercially operating WTE facilities having a combined processing capacity of 1.595 million tons per year. Samples were collected from:

- Bottom ash (four samples)
- Fly ash (five samples)
- Wet scrubber solids residue (two samples)
- Wet scrubber condensate (four samples)
- Stormwater drainage (one sample)

Two analytical methods were developed to quantify the PFAA content of the samples: one for solid samples and another for water samples. Method validation showed good performance for both methods in terms of precision and accuracy, despite low recoveries obtained for the method for solid samples.

The results of the sample analysis revealed PFAAs were present in all solid samples at concentrations in the low to sub ng/g range and in all but one condensate, and wastewater samples at concentrations in the low to sub ng/L range. The quantified concentrations were used to estimate the potential annual discharges of PFAAs from waste incineration plants in Sweden to the environment.

The findings of the study are presented in Table 6-2. As shown, an average of 4.794 nanograms per gram (ng/g) of PFAAs were found in the bottom ash samples, while 10.786 ng/g were found in the fly ash samples. The study analyzed data from 33 WTE facilities in Sweden and estimated that these facilities could process a maximum of 5.5 million tons of MSW, and generate an estimated 1.1 million tons of bottom ash and 277.3 thousand tons of fly ash. At this processing rate, it was estimated that a total of 7.552 kilograms (16.65 lbs.) of PFAAs would be contained in the bottom and fly ash produced annually by Swedish WTE facilities. Based on these numbers, it was estimated that, even if all of the bottom and fly ash were disposed directly into the Baltic Sea (rather than being landfilled or used in road construction), the PFAAs from the WTE facilities would contribute 0.23–0.31 percent of the PFAAs estimated to be discharged annually to the Baltic Sea.[42]

As there were no samples from the flue gases of the incineration plants available for this study, PFAAs emitted to the atmosphere could not be directly analyzed. However, three of the four investigated plants utilized wet scrubbers

[41] *Sandblom, O.* Waste Incineration as a Possible Source of Perfluoroalkyl Acids to the Environment – Method Development and Screening. *(Master's Thesis - Stockholm University, 2014).*

[42] *A mass balance study conducted in 2013 estimated that 2,450 – 3,300 metric tons of PFAAs are discharged to the Baltic Sea from rivers, wastewater treatment plants and the atmosphere. Filipovic, M., Berger, U., McLachlan, M.S. "Mass Balance of Perfluoroalkyl Acids in the Baltic Sea."* Environmental Science & Technology, *47, 4088-4095 (2013).*

in their air pollution control systems. Due to the low pKa values of PFAAs, the vast majority of PFAAs present would be trapped in the condensate in these plants. Nevertheless, only low- to sub-ng/L levels of PFAAs were detected in the wet scrubber condensate samples. It can thus be concluded that it is highly unlikely that any significant amounts of PFAAs are emitted from Swedish WTE facilities to the atmosphere.

The main conclusion of this study was that waste incineration in Sweden is not a significant source of PFAAs to the atmosphere or to the environment in general.

Table 6-2: PFAAs in WTE Bottom- and Fly-Ash from Swedish WTE Plants

	Nanograms per Gram (Average)[1]			Kilograms per Year[2]		
PFAA Type	**Bottom Ash**	**Fly Ash**	**Total**	**Bottom Ash**	**Fly Ash**	**Total**
PFBA	1.148	0.384	1.532	1.157	0.097	1.254
PFHxA	0.832	1.772	2.604	0.839	0.447	1.286
PFOA	0.196	0.395	0.591	0.197	0.1	0.297
PFNA	1.877	5.909	7.786	1.892	1.49	3.382
PFDA	0.141	0.318	0.459	0.142	0.08	0.222
PFUnDA	0.088	0.085	0.173	0.089	0.021	0.11
PFDoDA	0.118	0.118	0.236	0.119	0.03	0.149
PFHxS	0.014	0.027	0.041	0.014	0.007	0.021
PFOS	0.38	1.778	2.158	0.383	0.448	0.831
Totals	**4.794**	**10.786**	**15.58**	**4.832**	**2.72**	**7.552**

[1] *Values below the MDL were substituted with the corresponding MDL for the calculation pf averages.*
[2] *Based on an estimated combustion of 5.5 million tons of MSW in 33 Swedish WTE plants in 2013. The combustion of this waste generated an estimated 1.1 million tons of bottom ash and 277.3 thousand tons of fly ash.*

PFAS IN WTE ASH LEACHATE

Solo-Gabriele, H. et al. (2020)

PFAS are found in many consumer products which will be ultimately disposed in landfills. Limiting environmental contamination and future exposures will require managing leachates from different types of landfills, each with different PFAS levels depending upon the source of the waste.

The objective of this study was to evaluate the influence of waste type and on-site treatment on PFAS levels in landfill leachates.[43] 11 PFAS species (7 carboxylic acids, 3 sulfonic acids, and 5:3 fluorotelomer carboxylic acid) were evaluated in leachates from MSW, C&D, MSW ash (MSWA), and a mixture of MSWA and MSW with landfill gas condensate (MSWA/MSW-GC). Leachates were also analyzed before and after on-site treatment at two of these facilities.

Results indicate that MSWA leachate had significantly lower PFAS levels relative to other leachate types. Lower total PFAS concentrations in MSWA leachates were correlated with an increase in incineration temperature (R2=0.92, p=0.008). The levels of PFAS in untreated C&D and untreated MSW leachate were similar.

This is the first published paper to show that leachates from ash landfills have lower PFAS levels relative to leachates from other waste types. Furthermore, the total PFAS levels were correlated with the incineration temperature of the waste. More work is needed to confirm the correlation with incineration temperature and type of air pollution control system. As part of future work the fate of PFAS at full-scale incineration facilities should be evaluated to determine whether the decreased PFAS in ash leachate is due to destruction of PFAS, transformation to volatile species, or transformation to non-volatile species that were not measured.

[43] *Solo-Gabriele, H. et al. Waste type, incineration, and aeration are associated with per- and polyfluoroalkyl levels in landfill leachates.* Waste Management *107 (2020) 191–200.*

PFAS COMBUSTION EMISSIONS: SUMMARY OF RESEARCH FINDINGS

A summary of the research findings of the laboratory, pilot-scale, and full-scale tests on PFAS combustion emissions is presented in Table 8-1. Based on the information provided in this table and the summaries of the research studies provided above, the following statements can be made regarding the potential emissions of PFOA and PFAAs from WTE facilities in the US:

- PFOA was not emitted during the combustion of FTBPs, carpet treated with perfluoronated compounds, fabrics treated with FTBP, or polytetrafluoroethylene when these materials were processed in laboratory or pilot-scale facilities at temperatures (1000°C) typical of the high end of US WTE facility operations and residence times (2s) representative of US WTE facilities.
- PFOA emissions at a commercially operating facility in the Netherlands were found to be 40.1 milligrams from the combustion of 250,800 tons of MSW. This amount equates to 0.00000018 milligrams per kilogram (ppm) of waste processed.
- Based on the low- to sub-ng/L levels of PFAAs detected in the wet scrubber condensate samples at three WTE facilities, a Swedish study concluded that it is highly unlikely that any significant amounts of PFAAs are emitted from Swedish WTE facilities to the atmosphere.

Table 8-1: Summary of Research Findings Regarding PFAS Combustion Emissions

Year	Investigation	Location	Facility Type	Feedstock	Temperature	Residence Time	Findings
—	—		US WTE Facilities	MSW	800°C–1,100°C	2s	
2014	Lab Study	US	Thermal Reactor System	FTBPs[1]	1,000°C	2s	No detectable PFOAs[2]
2007	Pilot Scale Study	US	0.73 kW pilot-scale rotary kiln incinerator simulator	Carpet treated with perfluoronated compounds	< 1,000°C	—	No PFOA emissions from carpet combustion
2005	Lab Study	US		Fabric treated with FTBP	1,000°C	2s	No PFOA emissions detected
2018	Pilot Scale Study	Europe	Rotary kiln test facility	Polytetrafluoroethylene (PTFE)[3]	850°C	2s	Combustion of PTFE did not create any of the 31 type of PFAS tested including PFOA
2018	Full Scale Test at WTE Facility	Europe	Commercial WTE Facility in the Netherlands	MSW	850°C	2s	PFOA emissions of 0.00018 nanograms/g waste processed
2014	Full Scale Tests at WTE Facilities	Europe	Four Swedish WTE Facilities	MSW	850°C	2s	WTE facilities in Sweden are not a significant source of PFAAs[4] to the atmosphere or environment.

[1] *Fluorotelomer-based polymers (FTBPs) are a group of PFAS that are topically applied to textiles and paper to provide unique surface properties such as oil and water repellency for textiles and oil and grease penetration prevention for paper used in food packaging. A global inventory of the sources of PFOA emissions to the environment identified the waste incineration of FTBP products as a potential source of PFOA.*

[2] *Perfluoroctanoic Acid (PFOA) is an 8-carbon fluorocarbon with a carboxylic acid functional group. PFOA has been used in the process of making Teflon and several other industrial applications, including carpeting, upholstery, apparel, floor wax, textiles, fire-fighting foam, and sealants. Along with PFOS, it is one of the two most widely studied PFAS due to public health concerns.*

[3] *Polytetrafluoroethylene (PFTE) is a fluorocarbon solid with a high molecular weight that consists wholly of carbon and fluorine. PTFE is used as a non-stick coating for pans and other cookware. The brand name of PTFE-based formulas is Teflon.*

[4] *Perfluoroalkyl Acids (PFAAs) are a family of perfluorinated chemicals that consist of a carbon backbone (typically 4–14 carbons in length) bonded to fluorine atoms and a charged functional group (primarily carboxylate, sulfonate, or phosphonate). The two most widely known PFAAs contain an eight-carbon backbone and include perfluorooctanoic acid (PFOA) and perfluorooctane sulfate (PFOS).*

CONCLUSIONS

The following conclusions are offered with respect to the fate and transport of PFAS in WTE facilities based on the literature review and analyses conducted during this project.

PFAS in MSW

Based on a limited number of sources, it appears that a value of 10 ng/g (0.01 parts per million or ppm) can be considered a representative figure characterizing the overall MSW PFAS content. More testing of individual MSW waste streams will be required to determine if 10 ng/g is a true average representation of these substances across the board. It is not known, for example, if there are regional differences in the US or Canada based on either a concentration of historical production facilities or cultural practices that would result in higher levels of PFAS compounds in MSW from one region compared to another.

Destructibility of PFAS in WTE Facilities

The EPA has identified WTE combustion as a technology that can achieve up to 99 percent destruction of PFAS and has reported fluorinated organic compounds such as PFAS require temperatures above 1,000˚C to achieve 99.99 percent destruction with one second residence time for unimolecular decomposition of PFAS. It is worthwhile to compare these requirements to the actual operating temperatures (800°C–1,100°C) and residence times (2s) typically found at US WTE facilities. Nevertheless, the moisture content of incoming MSW loads can vary dramatically over time with rain or snow events resulting in lower boiler operating temperatures. More facility-specific evaluation and documentation of average plant boiler operating temperatures will be needed to reduce possible regulatory concerns that plants might not routinely achieve the 1,000˚C target for optimal PFAS destruction.

PFOA and PFOS Emissions from PFAS Combustion

The studies reviewed in this report indicate that PFOA is not emitted during the combustion of FTBPs or PTFE at temperatures (1000°C) and residence times (2s) typical of the many US WTE facility operations. This is encouraging as PFOA is one of the two primary PFAS chemicals (the other being PFOS) that are of most concern from a health standpoint. A literature review conducted by the Department of Chemistry at Umeå University in Sweden concluded that PFOS is destroyed in the combustion zone of WTE facilities and is not reformed in the post-combustion zone (albeit with a low level of confidence).

Products of Incomplete Combustion (PICs)

The EPA is concerned about the potential for PICs to form during the combustion of PFAS-containing wastes in WTE facilities. However, in a study conducted at a pilot plant in Germany operating under typical waste incineration conditions, none of the 31 types of PFAS that were identified as possible PICs from the incineration of PTFE were found in the flue gas.

Environmental Impacts

Conclusions regarding the environmental impact of combusting PFAS-containing waste in WTE facilities include the following:

- Waste incineration of fluorotelomer based polymers (FTBPs) should not be expected to be a source of PFOA in the environment.[44]
- Municipal incineration of PTFE using best available technology (BAT) is not a significant source of studied PFAS and should be considered an acceptable form of waste treatment.[45]
- Waste incineration in Sweden is not a significant source of PFAAs to the atmosphere or to the environment in general.[46]

In its interim guidance document, the EPA stated it is important to determine whether thermal treatment units and their associated post-combustion control devices are adequately controlling products of incomplete combustion (PICs), especially fluorinated PICs that might be created during the combustion of PFAS-containing waste. The EPA concluded there is a need to continue research activities investigating incineration of PFAS and that, after sufficient research has been completed to address the related knowledge and data gaps, EPA can make a more informed recommendation on disposal of PFAS compounds and PFAS-containing substances using incineration.

Based on the research conducted in this report, SWANA concurs with the need for the EPA and others to conduct additional research to confirm the capability of US WTE facilities to destroy PFAS chemicals contained in MSW through high-temperature combustion, while not generating harmful PICs in the process. This could be accomplished by stack testing air sampling data from a variety of US-based WTE plants after consistent test methods have been established by EPA and other regulatory bodies. SWANA is hopeful its Waste Conversion and Energy Recovery (WCER) Technical Division, which has 485 members, as well as the ARF WCER Research Group, can serve as a resource to the agency in this regard.

The findings of the studies reviewed in this report are encouraging with respect to the ability of today's US WTE facilities to effectively treat solid waste that contains PFAS and not emit detectable levels of PFOA in the process. With respect to the formation of PICs, the pilot-scale investigation conducted in Germany is encouraging in its findings that the combustion of PTFE did not create any of the 31 types of PFAS suspected of being potential PICs produced during the combustion process.

In conclusion, SWANA is cautiously optimistic regarding the role that WTE facilities can play in the destruction of PFAS in MSW. The thermal destruction of PFAS in high-temperature combustion systems such as WTE facilities may represent one of the few commercially proven options available to society for destroying these problematic, forever chemicals.

[44] *Taylor, P.H. et al. "Investigation of waste incineration of fluorotelomer-based polymers as a potential source of PFOA in the environment."* Chemosphere 110 *(2014) 17–22.*

[45] *Aleksandrov, K. et al. "Waste incineration of Polytetrafluoroethylene (PTFE) to evaluate potential formation of per- and Poly-Fluorinated Alkyl Substances (PFAS) in flue gas.".*Chemosphere *(April 4, 2019).*

[46] *Sandblom, O. Waste Incineration as a Possible Source of Perfluoroalkyl Acids to the Environment – Method Development and Screening. (*Master's Thesis, Stockholm University*, 2014).*

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