Team 6

Sebastian Fu, Amelia Ng, Dionisio S. Rolls, Aidan Wong, Amy Zheng

Organic Waste Separation Background Research Report

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Introduction

Waste management and organization, to many people, may seem like an inconsequential inconvenience. However, current waste management practices fail to separate organic from inorganic materials before disposal, causing up to 90% of organic waste to decompose anaerobically in landfills [1]. During this process, bacteria produce harmful greenhouse gases, accounting for 14% of all methane emissions in the United States [1]. Additionally, the slow decomposition rate reduces landfill capacity by keeping space occupied longer than necessary.

Entities like the New York City Department of Sanitation have been making attempts to address this problem by diverting organic waste from landfills and converting it to compost. However, of 1.2 million tons of organic waste collected in 2024, only 9.9% of the diverted waste could be used as compost, as shown in Table 1 [2]. Despite recent mandates on sorting compostable waste, current organic capture rates remain underwhelming at 7.2%, necessitating a new method of separating organic material from general waste [3].

Organics

Organics is diverted through both curbside and non-curbside programs, as well as third party-vendors. The capture rate for organics is therefore inclusive of material collected curbside as well. Divertible organics collections are inclusive of food scrap drop-off sites, food rescued by partners such as City Harvest, Rikers food waste, landscaper waste, horse manure, and leaves/brush.

Organics FY24	
Tonnage Diverted Non-Curbside (A)	**75,703.18**
Tonnage Diverted Curbside (A)	**49,701.60**
Tonnage Collected Curbside (B)	**1,136,114.81**
All DSNY-Managed Organics (B)	**1,261,519.59**
Organics Capture Rate (B)	**9.9%**

Table 1: NYC Department of Sanitation's definition of organics, as well as data depicting how much organic waste was disposed of and collected by DSNY, in tons. Only 9.9% of the total organic waste collected (1,261,519.590) was used for composting. [2]

Improving sorting methods would alleviate the logistical burden placed on sanitation departments, lessen the negative impacts of human activity on the environment, and promote more efficient resource use. The organic material isolated could then be reused by facilities to create biogas or fertilizer, benefiting farmers and local parks. Landfills would experience a decrease in organic waste, reducing methane emissions and freeing up land space for other revenue-generating activities. By exploring complete and ongoing studies that address this issue in parallel with biological systems that demonstrate efficient sorting behavior, this research will advance efforts in designing an efficient system to isolate organic waste. It will also consider the ethical implications of developing these technologies and suggest ways to lessen these burdens.

Human-Made Solution

There are two main categories of human innovations to address the issue of organic waste contaminating landfill waste: management and prevention. Each of these categories focuses on a different stage of the waste cycle and faces unique challenges.

Through a management approach, the need for sorting inorganic and organic waste is eliminated entirely. One of the most effective solutions is landfill gas capture. During this process, methane produced through anaerobic decomposition is collected and converted into energy instead of being released into the air [1]. A series of wells and a vacuum system are employed to collect gas. The gas is then purified and treated, depending on what it will be used for, a few examples of which can be seen in Figure 1 [1]. While the use of landfill gas in boilers, furnaces, or kilns require minimal treatment, the conversion for use as a natural gas source or other forms of energy requires more work [4].

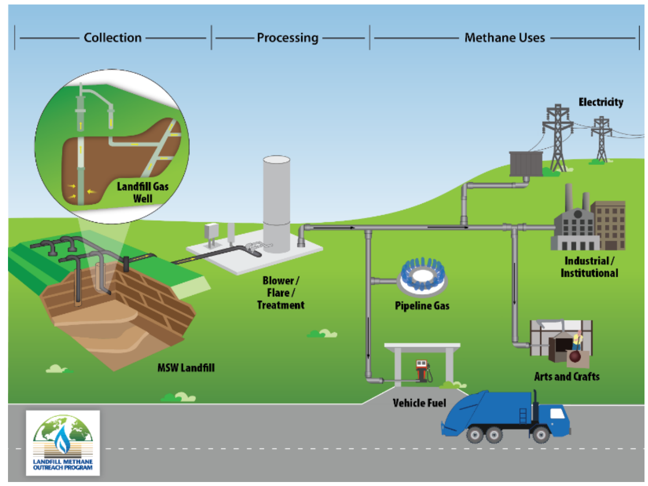

Figure 1: Diagram showing the collection, treatment, and possible uses of gases collected through landfill gas capture systems. [1]

Another solution devised to manage the emissions from landfills is using bio-filters as landfill covers. Landfill covers refer to materials that are used as a protective barrier over buried waste to prevent methane and odor from entering the atmosphere. Biofilters typically consist of porous material and organic material. These materials work to oxidize landfill gases and mitigate their effects.

Though managerial approaches have seen some success in mitigating the effects of excess methane from the mixing of organic and inorganic waste, it is still extremely difficult to keep methane levels in landfills manageable because of the large number of organics in landfill waste. Therefore, solutions that aim to manage current emissions are not effective in the long term.

Preventative solutions, on the other hand, reduce organic material entering landfills by aiming to achieve a higher percentage of collected compost. New York City has attempted to increase its composting output through various regulations. In 2013, restaurants were required to separate food waste from other waste. This policy was recently extended to households in April 2025, with a $300 fine for not placing food and yard waste into a separate bin for collection [5]. Although these regulations have increased the output of organic materials for composting, as mentioned earlier, the capture rate for compost is still very low: less than 5% of total organics in curbside waste was collected in 2024 and will likely not exceed 10% after the most recent policy [6]. Evidently, current policy and relying on individuals to manually sort organics and inorganics has proven to not be a viable solution.

Besides policy, recent studies have already been conducted concerning automated sorting of waste. For example, a study in 2022 by a group of contributors resulted in successful training of an algorithm that sorts recyclables into groups based on visual recognition from images of the trash [7]. The algorithm had an accuracy of 91.7% but faced difficulty in the expenses needed to implement their design on a larger scale and compare it to other methods. However, the use of algorithms to categorize waste may be expanded upon and implemented in future solutions.

This waste sorting problem has persisted among humans since 3000 B.C, and no definitive solution has yet been found [8]. However, humans aren't the only ones sorting waste; many animals sort and manage waste as part of their ecosystems.

Solutions in Nature - Biology

While the separation of waste is rarely as large an issue among animals compared to humanity, the animal kingdom still offers valuable insights into efficient resource management. Many animals engage in "sorting" through within their diets, both when selecting food and during the process of digestion. The first form of sorting occurs through physical means through distinguishing edible from nonedible materials in their environment.

Among all animals, birds demonstrate particularly refined methods of sorting when searching for food. All birds have olfactory bulbs, which is a neural structure that serves as the initial processing center for smell signals [9]. These bulbs play a significant role in finding food and are regarded as a measure of the acuity of birds. The larger the olfactory bulb, the more sensitive the sense of smell, which correlates to the accuracy of birds when it comes to "sorting" food.

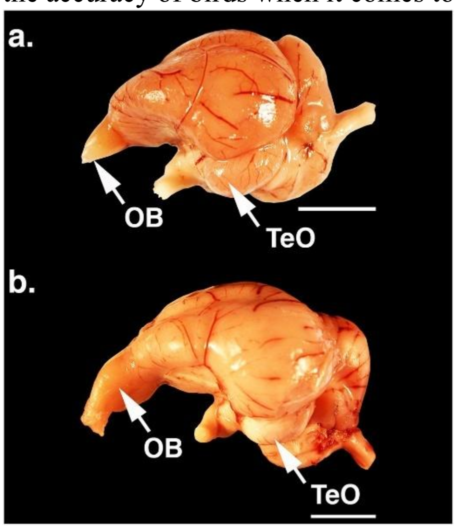

Figure 2: A comparison between a black vulture and turkey vulture's olfactory bulbs (OB) and optic lobes (TeO). (a) is a photo of the black vulture's brain, and (b) is a photo of the turkey vulture's brain. As shown, the olfactory bulb of turkey vulture is visibly larger than the black vulture's. [10]

For example, the scavenger turkey vulture, which has a large olfactory bulb and wide nostrils, has an especially keen sense of smell and sight. Compared to black vultures, their olfactory bulbs are four times larger, as shown in Figure 2, and have twice as many mitral cells, which connect the sensory information from olfactory receptors to the rest of the brain [10]. With significant olfactory bulbs, turkey vultures can search for food by detecting faint scents, such as ethyl mercaptan, of carrion from a far distance, even if the carrion is hidden [10]. This allows them to quickly find small carcasses that might be overlooked by other scavengers, especially in difficult terrains such as dense forests.

Similarly, burying beetles are also scavengers that use chemical smells to sort carrion out from inorganic materials. Their antennas contain the main part of their olfactory receptors, which allow them to detect chemicals from decaying animals, sulfur compounds, from distances as far as 3.2 miles [11], [12]. They also have auxiliary olfactory receptors, which are secondary sensory structures in addition to the main olfactory organs, on their palpi, which is a sensory organ located near the mouth [13]. These auxiliary olfactory receptors help burying beetles to enhance their short-range perception when finding carcasses.

Considering the approach of scavengers when hunting for food, scent-based detection can be utilized to identify organic materials from inorganic materials. Like how a vulture picks out the scent of ethyl mercaptan to locate its food in a dense forest, carbon dioxide sensors could be used to detect decomposing organic material from an environment of 20 pounds of densely packed trash. Additionally, there could be multiple sensors that detect different chemicals from decomposition at different ranges, like how burying beetles have two "separate" sensory structures. This would increase the sorting accuracy, providing more efficient results.

On the other hand, "sorting" in nature can also be observed through chemical means: digestion.

Many animals' diets normally include some form of easily digestible material (meats, plants, detritus) which is connected to or mixed in with indigestible material (bone, shells, husks, sediment). This problem is most prevalent among animals that directly consume indigestible material, such as predatory animals which eat prey whole or deposit feeding detritovores which consume sediment to filter food out of. These species have evolved in a variety of ways to separate what can be used for food and what cannot, both outside and inside their own digestive systems.

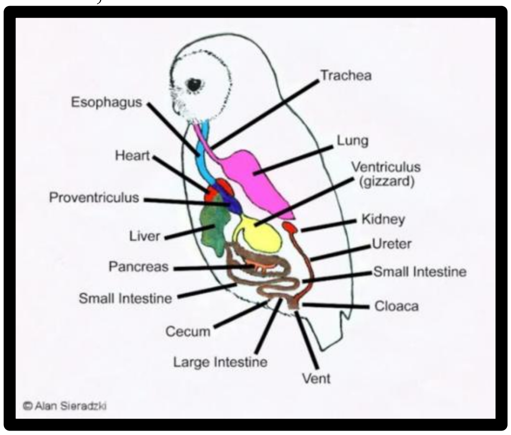

Figure 3: A diagram of the digestive system of an Owl. Highlighted in blue is the proventriculus, the stomach chamber responsible for releasing Gastric enzymes. Highlighted in yellow is the Ventriculus, the muscle-bound stomach chamber responsible for storing food Provided by Alan Sieradzki. [15]

Notably, birds have evolved to have a two-chamber stomach system consisting of the proventriculus (the true stomach) and ventriculus (the gizzard), as shown in Figure 3 [14], [15]. The ventriculus, unlike a "true stomach," is primarily used for mechanical digestion or the preparation of food in birds. Birds with grain-based diets use the ventriculus to grind grain into easily digestible forms via muscle contractions, while birds of prey use the ventriculus to store and compress the remaining indigestible material from their food (which is later regurgitated as a pellet) [14], [16].

Owls are an important order to focus on due to their relatively weak stomach acid and tendency to swallow their prey whole [15]. Owls digest food by first releasing acid in the proventriculus, then moving the food into the ventriculus so that the surrounding muscles can separate the partially dissolved edible material from harder indigestible material [15]. Many bird species pass food between the ventriculus to the proventriculus and back to introduce gastric acid and enzymes multiple times, until the digestible food is passed to the duodenum while holding onto the intact indigestible material using the muscles in the ventriculus [15], [16]. This process, despite the minimal absorption of the food in the stomach, allows for the accurate, gentle, and effective separation of digestible material into the intestines and the indigestible material into a regurgitated pellet.

The means by which owls and other birds separate digestible and indigestible material, which are primarily through mechanical separation techniques or mild chemical treatment, are relatively simple. These systems can be replicated artificially through motors and weak acids. While utilizing this process would not require knowledge regarding what is and is not organic, greatly reducing the data processing and expensive computational hardware needed to develop and implement it, one complication of reproducing a stomach system would be finding a way to use and dispose of chemicals such as mild acids.

Detritivores are provide an example of sorting during the digestive process. Sea cucumbers gather food by using tentacles around the mouth to collect and ingest small amounts of the surrounding sand [17]. Their diet primarily consists of small fragments of organic matter (such as small arthropods, plant matter, fungi, or bacteria) around or buried in the sediment [17], [18].To get the digestible matter from the sediment, sea cucumbers use a wide array of digestive enzymes to break down the complex proteins and fats so that they can be absorbed by villi lining the stomach [18], [19]. While the full digestive process cannot be easily translated into artificial methods, it is notable that it is made more efficient by reducing the size of the sand consumed [19]. Due to the chemical processes necessary to implement several proposed solutions, it is worth exploring whether processing waste into smaller and less complex particles carry over the same benefits to macroscopic filtration or chemical pretreatment as it does to sea cucumber digestion.

In summary, the pursuit of food and need for efficient digestion has led to nature developing useful processes which we can take inspiration from. Whether it is the ability for vultures and burying beetles to detect food with high accuracy and precision, the motions of bird stomachs to grind and separate their food during digestion, or simply the efficiency of sea cucumber intestines when digesting smaller grains of food and sand, artificial methods of separation can be developed from them such as sensors, rolling motors, chemical treatment, or maceration. Nonetheless, there are concerns to address regarding the safety of these systems, and the resources they may use.

Ethical Considerations

While nature provides efficient models for waste management, applying these principles at any scale raises important ethical questions. One key area for consideration is balancing tradeoffs in economic, social, and environmental impacts. In limited prototypes, these costs are minimal, consisting only of materials, labor, and modest energy use. However, citywide implementation would require substantial investment in infrastructure, processing facilities, and operational expenses. These initial expenses could be offset by the potential profit of sorting out organic material from landfills. In 2017, there were about 1 million tons of organic material wasted, which could have been worth approximately $12.5 million if processed into compost, or $22.5 million if converted to energy through biogas production [20].

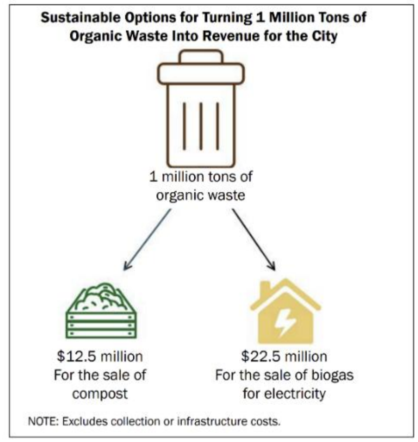

Figure 4: Simple flow diagram showing the potential profit from diverting organic waste from landfills. [20]

Yet, the economic gains from waste processing facilities are often unevenly distributed. One study found that waste processing facilities are disproportionately located in neighborhoods established as low-income and communities of color [21]. On the surface, this seems like an advantage due to the creation of new jobs. However, these facilities often cause businesses to avoid locating in these areas, which significantly decreases the availability of job opportunities and requires residents to travel outside of their community for necessities [22]. As community health declines and property values nose-dive, the area eventually goes through gentrification, and the existing populations are displaced. This promotes a cycle of long-term inequality and limits upward mobility.

In addition to socioeconomic factors, it is important to design solutions that do not create additional environmental problems. One key point is the system's resource management. Efficient use of energy, water, and raw materials is essential to ensuring that the environmental benefits of waste separation outweigh the costs of operation. This involves both the costs of separating the material, as well as the resources involved in transporting and processing the separate materials. The system also needs to be built in a way that components and by-products remain stable over time to prevent additional waste streams, such as electronic waste or hazardous residues when materials degrade [23].

Beyond socioeconomic and environmental considerations, it is critical to consider the unintended consequences from implementing waste management systems. One concern is that widespread reliance on automated waste separation could reduce public motivation to sort waste responsibly. This is supported by research on human interaction with an "imperfect" automation system, showing how users adjusted their reliance to it based on how many errors it made (over-relying when the system was missing things, under-relying on when the system had false alarms) [24]. This suggests that if automated waste separation systems are imperfect, people may either become too dependent on it or fail to trust it, reducing the effectiveness of sorting. Sorting incorrectly also has environmental implications, as non-organic materials mixed into compost introduce toxins and render compost unusable for agricultural use [25]. Furthermore, the deployment of automated waste systems may cause an unequal distribution of benefits. For instance, the systems may be exploited by corporations for profit, or by authorities as a tool to regulate industries rather than serving the public good [26].

Underlying many of these challenges are biases that need to be kept in mind when developing and implementing these large-scale sorting mechanisms. One critical bias is that automation of sorting is required, as it overlooks community efforts such as informal recycling networks. In South Korea, these “junk shops” became integrated with the national waste-processing infrastructure, reducing solid waste flows and boosting recycling rates across the country [27]. Finally, stakeholder bias plays a significant role in how these systems function, regardless of their theoretical effectiveness. The location, funding, and long-term management of these solutions are influenced by the differences in priorities between governments, corporations, and communities. Altogether, effective waste management is not only a technical challenge, but a social and moral one. Prioritizing equity and accountability at all stages of implementation, from design to building, is important to developing lasting, sustainable solutions.

Conclusion

Landfill gas emissions are a critical environmental issue that current solutions fail to solve effectively. One approach that is being taken to address this issue is diverting organic waste through household or community composting collection programs, as they are the main contributors to excessive methane production in landfills. However, results are limited due to residents’ lack of awareness or care of these programs. Other emerging approaches such as gas capture systems, biofilter covers, and automated sorting mechanisms show promise but are limited by high implementation costs and inefficiencies due to their early stages of development. Moreover, beyond technical challenges, any viable solution needs to balance ethical considerations like disproportionate burdens on low-income communities and promoting technologies in a way that doesn’t negatively affect public motivation for sorting responsibly.

Fortunately, nature provides many inspirations for waste organization and management systems in the way animals search for and digest food. Scavengers like turkey vultures and burying beetles, for example, can detect organic material within dense amounts of waste. This behavior could be replicated with a variety of sensors and used to direct a mechanical sorting mechanism, such as a piston or grabber system. Another source of inspiration can be found in birds of prey, which separate indigestible parts of their food with organized muscle contractions in their stomach. This can be replicated using motors and rollers, which allows for simple sorting mechanisms. These mechanisms can be made more efficient by shredding waste into smaller pieces, drawing from the way feeders increase their digestive efficiency when eating smaller grains of sand.

The next steps in this project involve translating these biological insights into functional artificial systems and/or integrating them into current solutions. The use of sensors, simple passive sorting systems, or new preprocessing methods, which may optimize current systems, all present interesting and feasible routes that can be explored when thinking about and prototyping solutions to this problem. However, certain methods, such as chemical treatment inspired by animal stomachs, require caution due to the potential environmental impacts. As the problem of sorting organic waste is meaningful due to its environmental impacts (landfill methane emissions), ignoring the environmental impact of the solution is not only ethically questionable but counterproductive. Overall, waste management is often an overlooked but significant problem. By using the food gathering behaviors of various animals, mechanical, chemical, and computational elements to a potential solution can be further explored, all in hopes of creating a safe, effective, and ethical solution.

References

[1] O. US EPA, "Basic Information about Landfill Gas." Accessed: Oct. 14, 2025. [Online]. Available: https://www.epa.gov/lmop/basic-information-about-landfill-gas

[2] "zero-waste-report-2024.pdf." Accessed: Oct. 14, 2025. [Online]. Available: https://www.nyc.gov/assets/dsny/downloads/resources/reports/zero-waste-plan/zero-waste-report-2024.pdf

[3] "zero-waste-report-2025.pdf." Accessed: Oct. 14, 2025. [Online]. Available: https://www.nyc.gov/assets/dsny/downloads/resources/reports/zero-waste-plan/zero-waste-report-2025.pdf

[4] "LFG Energy Project Development Handbook, Chapter 3: Project Technology Options." Accessed: Oct. 14, 2025. [Online]. Available: https://www.epa.gov/system/files/documents/2024-01/pdh_chapter3.pdf

[5] "NYC's Composting Rates Are Low. A Sustainability Expert Thinks AI Will Offer a Solution. Eventually. – State of the Planet." Accessed: Oct. 14, 2025. [Online]. Available: https://news.climate.columbia.edu/2025/09/23/nycs-composting-rates-are-low-a-sustainability-expert-thinks-ai-will-offer-a-solution-eventually/

[6] S. MacBride, "New York City Residential Curbside Organics Program: FY2024 Quarterly Capture Rate Report," *Academia.edu*, Jan. 2024, Accessed: Oct. 14, 2025. [Online]. Available: https://www.academia.edu/124136399/New_York_City_Residential_Curbside_Organics_Program_FY2024_Quarterly_Capture_Rate_Report

[7] M. A. Mohammed *et al.*, "Automated waste-sorting and recycling classification using artificial neural network and features fusion: a digital-enabled circular economy vision for smart cities," *Multimed. Tools Appl.*, vol. 82, no. 25, pp. 39617–39632, Oct. 2023, doi: 10.1007/s11042-021-11537-0.

[8] A. Bouazza, J. G. Zornberg, and D. Adam, "Geosynthetics in waste containment facilities: recent advances".

[9] "SMELL, TASTE, AND CHEMICAL SENSING | Morphology of the Olfactory (Smell) System in Fishes - ScienceDirect." Accessed: Oct. 14, 2025. [Online]. Available: https://www.sciencedirect.com/science/article/abs/pii/B9780123745538000241?via%3Dihub

[10] N. P. Grigg, J. M. Krilow, C. Gutierrez-Ibanez, D. R. Wylie, G. R. Graves, and A. N. Iwaniuk, "Anatomical evidence for scent guided foraging in the turkey vulture," *Sci. Rep.*, vol. 7, no. 1, p. 17408, Dec. 2017, doi: 10.1038/s41598-017-17794-0.

[11] A. L. Potticary *et al.*, "Revisiting the ecology and evolution of burying beetle behavior (Staphylinidae: Silphinae)," *Ecol. Evol.*, vol. 14, no. 8, p. e70175, Aug. 2024, doi: 10.1002/ece3.70175.

[12] "American Burying Beetle (Nicrophorus americanus) | U.S. Fish & Wildlife Service." Accessed: Oct. 16, 2025. [Online]. Available: https://www.fws.gov/species/american-burying-beetle-nicrophorus-americanus

[13] V. G. Dethier, "The Role of the Antennæ in the Orientation of Carrion Beetles to Odors," *J. N. Y. Entomol. Soc.*, vol. 55, no. 4, pp. 285–293, 1947.

[14] "Clinical Anatomy and Physiology of Exotic Species," ScienceDirect. Accessed: Oct. 14, 2025. [Online]. Available: https://www.sciencedirect.com/book/9780702027826/clinical-anatomy-and-physiology-of-exotic-species

[15] A. Sieradzki and H. Mikkola, "Discarded Knowledge: Unlocking the Secrets of Owl Pellets," *Res. Perspect. Biol. Sci. Vol 4*, pp. 155–190, May 2025, doi: 10.9734/bpi/rpbs/v4/5628.

[16] I. Langlois, “The anatomy, physiology, and diseases of the avian proventriculus and ventriculus,” *Veterinary Clin. North Am. Exot. Anim. Pract.*, vol. 6, no. 1, pp. 85–111, Jan. 2003, doi: 10.1016/S1094-9194(02)00027-0.
[17] C. Jia *et al.*, “Eukaryotic food sources analysis of two tropical sea cucumber species under different seasons providing insights into provender selection,” *Aquac. Rep.*, vol. 34, p. 101912, Feb. 2024, doi: 10.1016/j.aqrep.2023.101912.
[18] J.-P. Féral, “Activity of the principal digestive enzymes in the detritivorous apodous holothuroid Leptosynapta galliennei and two other shallow-water holothuroids,” *Mar. Biol.*, vol. 101, no. 3, pp. 367–379, May 1989, doi: 10.1007/BF00428133.
[19] S. B. M. Sembiring, R. Pratiwi, S. Hadisusanto, K. Mahardika, H. Haryanti, and J. H. Hutapea, “Grain sizes of sand substrates significantly influence the growth, survival, digestive enzyme profiles, and gut histology of sandfish (*Holothuria scabra* Jaeger 1833) juveniles during cultivation,” *Aquac. Rep.*, vol. 41, p. 102671, Apr. 2025, doi: 10.1016/j.aqrep.2025.102671.
[20] “organics-february-2019.pdf.” Accessed: Oct. 14, 2025. [Online]. Available: https://ibo.nyc.ny.us/iboreports/organics-february-2019.pdf
[21] C. Dunagan, “Why is so much pollution found in disadvantaged communities? | Encyclopedia of Puget Sound.” Accessed: Oct. 14, 2025. [Online]. Available: https://www.eopugetsound.org/magazine/IS/pollution-disadvantaged-communities
[22] “2023-1220-hazardous-waste-sites.pdf.” Accessed: Oct. 14, 2025. [Online]. Available: https://stockton.edu/hughes-center/documents/2023-1220-hazardous-waste-sites.pdf
[23] “Greenhouse Gas and Air Pollutant Emissions from Composting | Environmental Science & Technology.” Accessed: Oct. 14, 2025. [Online]. Available: https://pubs.acs.org/doi/10.1021/acs.est.2c05846
[24] J. Sanchez, W. A. Rogers, A. D. Fisk, and E. Rovira, “Understanding reliance on automation: effects of error type, error distribution, age and experience,” *Theor. Issues Ergon. Sci.*, vol. 15, no. 2, pp. 134–160, Mar. 2014, doi: 10.1080/1463922X.2011.611269.
[25] D. of P. S. plantsciweb@missouri.edu, “Contaminated Compost Equals Gardening Problems (David Trinklein).” Accessed: Oct. 14, 2025. [Online]. Available: https://ipm.missouri.edu/meg/2014/8/Contaminated-Compost-Equals-Gardening-Problems/
[26] “Why and how is the power of Big Tech increasing in the policy process? The case of generative AI | Policy and Society | Oxford Academic.” Accessed: Oct. 14, 2025. [Online]. Available: https://academic.oup.com/policyandsociety/article/44/1/52/7636223
[27] J. Lee, H. Han, J.-Y. Park, and D. Lee, “Urban Informatics in Sustainable Waste Management: A Spatial Analysis of Korea’s Informal Recycling Networks,” *Sustainability*, vol. 13, no. 6, p. 3076, Jan. 2021, doi: 10.3390/su13063076.

Contributions

Intro and Conclusion – Everyone

Human made solutions – Sebastian, Amelia

Bio – Dionisio S. Rolls, Amy

Ethical – Aidan

Bibliography – Dionisio S. Rolls, Aidan, & Amy