

Future vertical

Landfill Leachate

Enzymatic degradation of PET microplastics in landfill leachate prevents legacy plastic waste from re-entering water systems.

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SECTION 5 · VERTICALS

1. Customer Description

1.1 Landfill Leachates

Landfill leachate is a toxic byproduct generated when precipitation percolates through municipal solid waste (MSW) accumulated in landfills. As liquid passes through waste, it mobilizes organic matter, ammonia, and other contaminants (Abdel-Shafy et al. 2024). This causes heavy metals, microplastics (PE, PS, and PET microplastics), and organic compounds to collect into the ground, providing an entryway for contaminants into sensitive ecological environments and groundwater (Abdel-Shafy et al. 2024; Gupta, Verma, and Atri 2025). Essentially, landfill leachate is a complex mixture of contaminants originating from landfill waste. If left unaddressed, it can harm ecosystems and pose risks to human health.

The composition of waste masses in landfills varies depending on several factors, including landfill age and the surrounding climate (Wdowczyk and Szymańska-Pulikowska 2021). Leachate from younger landfills tends to be more acidic in terms of pH with an increased biochemical oxygen demand (BOD) while leachate from more mature landfills are rather neutral-to-alkaline with a significantly reduced BOD (Wdowczyk and Szymańska-Pulikowska 2021). This difference in pH is caused by the degradation of organic compounds and the release of humic acids. Across all landfill ages, however, the chemical oxygen demand (COD) of leachates is high (Podlasek et al. 2023).

1.1.1 Landfills and the Microplastics Problem

Microplastic pollution is a massive consequence of landfill maintenance. Approximately 21 to 42% of all plastic produced globally is deposited in landfills (Gupta, Verma, and Atri 2025). Given that modern landfills contain significant amounts of plastic waste, landfill leachate has become a hub for nanoplastics and microplastics. The concentrations of microplastics found in leachate vary drastically across the globe; Lahti, Finland, reported a concentration of 0.16 to 1.10 items/L, whereas Guangzhou, China, reported a high of 33,213 items/L (Sekar et al. 2026). Polyethylene (PE), polypropylene (PP), polystyrene (PS), and polyethylene terephthalate (PET) are reported as the most pervasive plastic polymer types obtained from worldwide leachate samples (Gupta, Verma, and Atri 2025). Once discharged, this microplastic-carrying leachate can follow two pathways. It may directly infiltrate into groundwater and enter surface water systems, or microplastics may be retained in leachate-treatment sludge that is subsequently reused as an

agricultural soil amendment, reintroducing microplastics into terrestrial agriculture and food systems (Premarathna et al. 2023).

1.2 Why Customers Would Want a PetaScale Product

Prior to discharge, landfill operators have a legal obligation to treat leachates. Traditional treatment and disposal protocols (including activated sludge treatment, sequencing batch reactors, and physical/chemical polishing) were designed to remove ammonia, BOD, and COD; they are incapable of depolymerizing plastics into smaller, environmentally harmless constituents. Physical microplastic removal methods (i.e., filtration, membrane processes) concentrate and capture microplastics, but do not degrade them. Furthermore, the efficiency of chemical and physical extraction methods drops drastically in landfill contexts (Premarathna et al. 2023). Cumulatively, landfill operators face a downstream disposal challenge following microplastic removal, as sludge concentrated with microplastics is either returned to the same landfill or repurposed as agricultural fertilizer.

In principle, the ability to mobilize PETases would offer landfill operators a novel approach to existing treatment solutions: in-situ chemical degradation of PET fractions in leachates, alongside biological treatment stages that currently dominate existing landfill treatment systems, with an approximate adoption rate of 46% (Global Growth Insights n.d.).

1.3 Existing Scientific Literature and Limitations

The realm of microplastic degradation in wastewater systems is rapidly evolving: Goddard et al. have engineered a PETase capable of functioning within dense sewage sludge, paving the way for the implementation of enzymes in wastewater treatment plants (Tullo 2024). This research is the closest analog to PetaScale's prospective use case, though it primarily targets municipal wastewater systems rather than landfill leachate specifically. Furthermore, PETase discovery has shown significant prevalence in naturally saline or extremophilic environments; for example, research published in 2026 identified putative halotolerant and thermostable PETases originating from microbial communities found in mangrove soil (Peña-Valencia et al. 2026), an environment known for high salinity. This finding is particularly relevant to landfill leachate treatment, as landfill leachates are often highly conductive and saline (Zhang et al. 2023).

1.3.1 Gaps in Existing Literature

Experimental testing to validate PETase activity directly in unmodified landfill leachate has yet to be conducted. Leachate environments are an amalgamation of several factors that can influence enzymatic performance, including high concentrations of ammonia, elevated ionic strength, and abundant organic matter, which may interfere with enzyme-substrate interactions (Mazzei, Oschkinat, and Piccolo 2013; Shi et al. 2025). Heavy metals, in particular, are notorious for inhibiting hydrolytic and oxidative enzyme classes through active site occupation or non-competitive inhibition (Cheng et al. 2025); however, no inhibition studies have been performed to examine whether PETases are inhibited at leachate-specific concentrations. Furthermore, PET plastics are a crucial but minor component of the general microplastic population typically identified in landfill leachate systems compared to more prevalent plastic types such as PE, PP, and PS (Gupta, Verma, and Atri 2025); using PET-only solutions would only address a fraction of the cumulative microplastic burden.

1.3.2 How PetaScale Fills Existing Gaps

The backlog of PETase discovery is the bottleneck the PETadex was built to solve. The PETadex's metadata-enriched pipeline can be queried to recover PETase homologs which originate from environments similar to landfill leachates' chemical environment. Enzyme candidates may originate from landfill soil, or other high-salinity, high metal and ammonia-rich environments (Kumar et al. 2024). In essence, the PETadex enables us to mine PETases that have already been selected for leachate-like conditions by nature itself (Peña-Valencia et al. 2026). A validated hit from the PETadex would then be fed into the Wet Lab to Hardware pipeline specific to leachate-adjacent conditions to verify functional degradation capacity.

1.3.3 Feasibility Assessment

Cumulatively, this vertical is scientifically plausible, though not yet validated. The premise of PetaScale's application to the landfill leachate market is supported by discovery literature (e.g., discovery of halotolerant PETases originating from high-salinity mangrove soil) (Peña-Valencia et al. 2026). A fundamental limitation, however, is that there is currently no evidence to demonstrate PETase functioning in unmodified landfill leachate, the inhibitory effects of landfill leachate's ammonia and heavy metal composition, and the fractional effectiveness that PETases provide to complex plastic mixes. Overall, this vertical represents a stretch application of the PetaScale commercialization matrix. It is worth pursuing given its broad potential for innovation, but

leachate-specific performance studies are necessary before the viability of PETase-based treatment can be established with confidence.

1.4 SWOT Analysis

PetaScale's strength is in its alignment with the existing landfill environment and existing treatment methodologies. Globally, microplastics are a prevalent contaminant within landfill leachates, driving a demand for decontamination services to treat leachate waste. Since landfill leachates are contained and regulated waste streams, they offer a highly controlled environment for treatments that is absent in diffuse, open-environment contexts (Gupta, Verma, and Atri 2025).

Additionally, the lack of thermal heating infrastructure typical of leachate reservoirs naturally results in room temperature conditions (Žgajnar Gotvajn and Pavko 2015). Together, these factors provide optimal operational conditions for PetaScale's enzymatic solutions. Furthermore, biological treatments already account for 46% of leachate waste alleviation, providing an established route of integration for novel enzyme solutions (Global Growth Insights n.d.).

In spite of these advantages, the technology faces limitations regarding its scope and applicability. Most notably, PET is only a minority constituent of the microplastics fraction found within landfill leachates. Plastic types such as polyolefins and polystyrenes are generally more dominant and are outside the current scope of PetaScale's technology (Gupta, Verma, and Atri 2025). Furthermore, landfill leachate composition varies greatly between sites, changing significantly based on the landfill's age, regional climate, and geography (Wdowczyk and Szymańska-Pulikowska 2021). Because of this environmental variability and the highly specialized operating environments of PET enzymes, successful implementation necessitates highly specific use cases, which complicates broad deployment and testing.

Regarding future opportunities, the current landscape offers considerable avenues for implementation and growth. Regulatory enforcement is actively driving the expansion of the leachate treatment market by mandating continuous upgrades to waste removal processes (Global Growth Insights n.d.). In Canada, aging infrastructure, with approximately 48% of landfill facilities built prior to 2000, creates a natural retrofit and modernization cycle that can serve as a primary entry point for implementation (Statistics Canada n.d.). Additionally, there are currently no identified competitors offering PET-targeted enzyme products tailored to the specific microplastics found in landfill leachates, providing a wide opportunity for independent innovation. There is also considerable dual-use potential within municipal wastewater treatment plants

(WWTPs), as landfill trucks regularly shuttle leachates to these municipal facilities (Maal-Bared, Li, and Suarez 2022).

Navigating these opportunities, however, requires overcoming significant regulatory and commercial challenges. Landfill leachate lagoons are generally open-air environments. Under CEPA's New Substances Notification Regulations (NSNR) for organisms, a "contained facility" is strictly defined as an enclosed building that satisfies biosafety regulations; therefore, open-air leachate treatment likely falls under the stricter "open environment release" classification (Environment and Climate Change Canada n.d.-a). Commercially, the product must compete in a sphere where existing bioremediation companies already hold ingrained customer relationships. Furthermore, municipal operators have been documented to be highly risk-averse toward novel biotechnology implementations (Cantor, Sherman, and Milman 2022). Ultimately, a significant market risk exists: if utility managers prioritize reducing their total pollutant burden over targeting PET-specific microplastics, customers will be less inclined to consume PetaScale's products.

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2. Landfill Leachate Market Size and Opportunity

2.1 Total Addressable Market (TAM): ~4.0 Billion CAD

PetaScale's TAM for the landfill leachate vertical is derived through a top-down volume-based approach, reflecting the lack of distinct market separation for microplastic-targeted technologies across landfill and leachate treatment systems. The TAM build starts from a theoretical ceiling of ~2.5 billion tonnes of Municipal Solid Waste (MSW) generated annually, assuming complete landfilling and full leachate capture and treatment (World Bank 2026). At a generation rate of 0.2 m^3 of leachate per tonne of waste, this produces ~500M m^3/yr of leachate globally. According to operator data, available methods for leachate treatment hover around 2 to 8 CAD/m^3 depending on off or on site treatment (Maal-Bared, Li, and Suarez 2022). Assuming that PetaScale's novel solutions are able to command the offsite market premium of 8 CAD/m^3 of treatment, the TAM is ~4.0 billion CAD. It is however, important to note that this number specifically is an illustration of the upper limits of the parent market that PetaScale has the opportunity to grow in, and not necessarily the immediate opportunity. The build deliberately treats all generated solid waste as addressable, whereas in reality only landfilled waste with collection infrastructure produces leachate that can be captured.

2.2 Serviceable Addressable Market (SAM): ~11 Million CAD

An important distinction is that not all Canadian landfills will be ideal candidates, as lining and collection of leachate is not standardized. Although full-scale expansion across all landfills represents the long-term opportunity, near-term deployment of PetaScale's solutions strategically leverages existing collection and treatment infrastructure to limit capital requirements and ensure scalable, cost-efficient growth. In 2022, 26.6M tonnes of Canadian MSW was disposed of (Statistics Canada 2026) and with an assumption that 85% of tonnage, or 22.6M tonnes goes to larger regional facilities with lining and leachate treatment infrastructure, means 4.5M m^3/yr of leachate is generated (at 0.2 m^3/tonne). Assuming that only 30% of landfill leachate requires advanced handling and can command the 8 CAD/m^3 premium, the Serviceable Addressable Market (SAM) is estimated at approximately 11 million CAD.

2.3 Serviceable Obtainable Market (SOM): 200,000 CAD

The SOM is calculated using the 3 year pilot to contract pipeline model, again with 3 pilots and an average contract value of 100,000 CAD. Assuming 2 converted contracts, by the end of Year 3 PetaScale looks at annualized revenue of 200,000 CAD in this sector. Although smaller than others, this is a conservative estimation and it is to be expected given how niche leachate treatment is, and how Annual Contract Value (ACV) will scale with facility size.

Table 2.1. Pilot-to-contract pipeline, Years 1 to 3

Year	Pilots	New conversions	Contracts	Revenue (CAD)
1	2	0	0	0
2	1	1	1	100,000
3	0	1	2	200,000
Total	**3**	**2**	**2**	**200,000**

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3. Barriers to Entry

3.1 Regulatory Barricades

Any commercialized product that involves a genetically modified organism (GMO) or a biochemical that has not been added to Canada's Domestic Substances List must be disclosed under the New Substances Notification Regulations (NSNR) prior to manufacture or import (Environment and Climate Change Canada n.d.-a). Furthermore, whole live organisms fall under NSNR's organisms stream, while a purified, cell-free enzyme product would fall under the biochemical/polymer NSN pathway (Environment and Climate Change Canada n.d.-a).

3.2 Procurement Cycle Length

A majority of landfills present in Canada are owned and operated by the municipal government (Statistics Canada 2018). As such, procurement is subject to multi-year financial planning cycles, municipal budget approval, and public-sector tendering; steps that private industrial consumer procurement would bypass. This is similar to the timeline challenge that the WWTP vertical faces. Canadian landfills are primarily under provincial and territorial jurisdiction, whereas WWTPs are municipally owned and operated (Canadian Infrastructure Council n.d.). Select landfills are municipally owned; however, both verticals' procurement cycles could overlap in the operational stage.

3.3 Technical Validation Prerequisites

As landfill leachate composition is subject to several factors such as climate, landfill age, and geographic region, relying on a single landfill leachate sample would not produce credible results for the purpose of technical validation (Abdel-Shafy et al. 2024). Instead, to account for how leachate composition is contingent on temporal factors like landfill age (Wdowczyk and Szymańska-Pulikowska 2021), validation studies would have to stretch to encompass a full precipitation cycle at a single site at minimum. Furthermore, any enzymatic treatment would have to be compatible with existing treatment methods present at landfills, such as sequencing batch reactors and membrane bioreactors.

3.4 Customer Risk Aversion

The Human Practices stakeholder interviews indicate that WWTP operators are cumulatively risk-averse and wary of adopting novel biotechnology into their waste management pipelines. In

comparison to WWTP management, landfill operators are smaller municipal departments that may have reduced financial and regulatory capacity. Combined with documented risk aversion towards novel biotechnology, it is reasonable to expect that landfill operators are likely to exhibit similar or greater levels of hesitancy towards adopting new treatment technology, given the relative financial and resource limitations. Commercialization would likely mandate a low-risk pilot structure (low-cost proof-of-concept) rather than a direct commercial sale.

3.5 Infrastructure Constraints

The dominant leachate management strategy at Canadian landfills located in rural geographic locales that lack any on-site treatment technology or infrastructure is siphoning leachate to neighbouring WWTPs that exist in proximal municipalities for co-treatment in treatment plant systems (Made in CA n.d.; Maal-Bared, Li, and Suarez 2022). Smaller landfill sites would be indirect customer targets, as their leachate and general waste load is shuttled to WWTPs that receive and treat their leachate. The addressable landfill customer base is concentrated in the ~270 larger landfills which may contain on-site biological treatment capabilities, something that cannot be verified from landfill size alone (Environment and Climate Change Canada n.d.-b).

3.6 PetaScale and Navigating the Barriers to Entry

Though the aforementioned challenges provide significant barriers to entry, PetaScale's commercial adaptability can mitigate these hurdles:

- **Favour cell-free enzyme products over a whole-cell product.** A purified enzyme would fall under the NSN biochemical pathway classification rather than the NSNR (Organisms) stream (Environment and Climate Change Canada n.d.-a).
- **Prioritize the addressable customer base.** The larger landfills, which are likely to contain on-site biological treatment capabilities, are PetaScale's prioritized addressable customer cohort rather than the full 3000+ landfill population. These facilities have potentially compatible treatment infrastructure that can be retrofitted, providing convenient structural and temporal integration points.
- **Design enzymatic treatment as a complementary waste management solution to existing streams.** If designed as a drop-in additive to existing treatment technology rather than a capital investment, both technical validation burden and the overall procurement cycle are expected to be reduced.

- **Deploy grant-subsidized pilots.** This simultaneously de-risks municipal customers' first commitment while providing site-level validation data.
- **Integrate with the WWTP vertical.** A single product could serve both verticals, especially because landfills regularly truck leachate to WWTP facilities for treatment.

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4. Existing Competitor Matrix

4.1 Company Summary

Table 4.1. Competitive landscape in landfill leachate and enzymatic plastic degradation

Key Actor	Current Strategy	Critical Gap
Microbial Discovery Group (MDG Bio) (Global)	MDG Bio utilizes strains of bacillus bacteria to remediate plastic pollution in terrestrial environments, which excludes them from being categorized as a free-enzyme deployment solution. The mechanism of remediation relies on the chemical dissolution of organic matter and larger solids, and does not have a specific focus on microplastics. They contain a landfill management and leachate solutions research division.	MDG Bio struggles with certain challenges that impede their commercial implementation. Bacilli are microbes, and introducing foreign microbes into environments with pre-established microbial communities causes competition with native flora (Wahalathanthrige et al. 2026). Furthermore, MDG Bio utilizes strains that are naturally selected, not synthetically engineered. As such, the baseline degradation rate of their bacillus microbes is inherently slow (Wahalathanthrige et al. 2026). Furthermore, the process of re-application is expensive (Wahalathanthrige et al. 2026).

Veolia Water Technologies (Global)	Veolia Water Technologies provides several leachate treatment solutions, such as sequencing batch reactors (SBRs), membrane batch reactors (MBR), and moving bed biofilm reactors (MBBR).	Their solutions generally target bulk amounts of BOD/COD/ammonia for removal. As such, they do not include any microplastic-specific enzymatic technology (Veolia Water Technologies n.d.).
Saltworks Technologies (Canada)	Saltworks technologies use membrane-systems that are crystallization and evaporation-based and are specific to high-salinity leachate and leachate concentrates.	Their solution does not involve any form of polymer degradation, but rather the reduction of waste volume by the dissolution of solids (Saltworks Technologies n.d.). Furthermore, their technology is not specific to microplastics.
bioprocessH2O (US)	BioprocessH2O manufactures biological treatment systems and designs that are compliant with regulatory frameworks.	This is a generalized biological treatment solution which does not have an enzymatic focus, nor a focus on microplastic degradation.
Carbios (France)	Carbios utilizes PETases for plastic recycling in exclusively closed-loop environments. Their enzymatic design is an engineered variant of LCC that is capable of functioning close to PET's transition temperature.	Carbios targets high purity PET exclusively for material recovery: PET is not depolymerized in open wastewater environments (MIT Technology Review 2021). Furthermore, Carbios' enzymes require temperature-controlled infrastructure due to their dependency on PET's glass transition temperature, which would be incompatible in a leachate lagoon environment (MIT Technology Review 2021; Abdel-Shafy et al. 2024). These enzymes exist

		primarily for recycling, making their target audience recycling plant owners.
Protein Evolution (US)	Protein Evolution utilizes AI to design PET-recycling enzymes, very similarly to Carbios (Protein Evolution n.d.).	In spite of the similarities with Carbios, there is no environmental remediation or leachate-specific focus or product in development. Furthermore, there is no focus on the open environment or mixed-containment matrices: it seems as though Protein Evolution primarily exists for enzymatic design purposes.
Breaking (Colossal Biosciences) (US)	Uses microbes to engage in bulk degradation of plastic waste.	Breaking uses a whole-organism approach rather than a purified microbial additive (Breaking n.d.). The regulatory prerequisites for whole-organism solutions are more data-intensive (Breaking n.d.; Environment and Climate Change Canada n.d.-a).
PolyGone Systems (US)	PolyGone Systems specializes in developing microplastic collection and removal devices exclusively for water systems. They collaborate with a research group originating from Washington University to study enzymatic upcycling of collected plastics (Sustainable Brands n.d.).	PolyGone's devices rely on the physical capture and removal of microplastic fragments: no degradation is performed whatsoever (PolyGone Systems n.d.). They primarily target open waterways (PolyGone Systems n.d.), and their enzyme focus is purely a research component rather than a step in product development for the company.

Goddard Lab (Cornell University) (US)	Julie Goddard's lab at Cornell University runs purely academic studies in which engineered PETases were shown to function in dense sewage sludge (Cornell CALS n.d.; Tullo 2024). Their work provides valid scientific precedent that applies to both WWTP and landfill leachates.	Their study did not yield nor produce a commercial product; they remained purely experimental. Their study did not include any hardware, bioreactor, or environmental deployment components, rather focusing on the enzymatic degradation capabilities itself.

4.2 Overall Competitive Landscape

No identified competitors offer a PETase product built specifically for landfill leachate environments. The most analogous commercial institutions (Carbios, Protein Evolution, etc.) operate in entirely different physical environments, and the nearest scientific precedent (Goddard Lab) demonstrates enzymatic effectiveness in sewage sludge, not in landfill leachate. The landfill leachate vertical is genuine white space that is capable of significant traction, but the underlying leachate-specific enzyme characterization has remained unattempted and unstudied by anyone.

References

Abdel-Shafy, Hussein I., Amr M. Ibrahim, Ahmed M. Al-Sulaiman, and Raouf A. Okasha. 2024. "Landfill Leachate: Sources, Nature, Organic Composition, and Treatment: An Environmental Overview." *Ain Shams Engineering Journal* 15 (1): 102293. https://www.sciencedirect.com/science/article/pii/S209044792300182X.

Breaking. n.d. "Breaking." Accessed October 16, 2026. https://www.breaking.com/.

Canadian Infrastructure Council. n.d. "State of Solid Waste Management Systems in Canada." Accessed October 16, 2026. https://canadianinfrastructurecouncil.ca/state-of-solid-waste-management-systems-in-canada-2.

Cantor, Alida, Luke Sherman, and Anita Milman. 2022. “Regulators and Utility Managers Agree about Barriers and Opportunities for Innovation in the Municipal Wastewater Sector.” https://www.researchgate.net/publication/363456921.

Cheng, Yu-feng, Yu-jia Zhao, Ce Chen, and Feng Zhang. 2025. “Heavy Metals Toxicity: Mechanism, Health Effects, and Therapeutic Interventions.” *MedComm* 6: e70241. https://doi.org/10.1002/mco2.70241.

Cornell CALS. n.d. “Engineering Enzymes to Degrade Microplastics in Wastewater.” Cornell University Agricultural Experiment Station. Accessed October 16, 2026. https://cals.cornell.edu/agricultural-experiment-station/engineering-enzymes-degrade-microplastics-wastewater.

Environment and Climate Change Canada. n.d.-a. “Biotechnology (Living Organisms): Overview of the Regulations — Discussion Paper.” Accessed October 16, 2026. https://www.canada.ca/en/environment-climate-change/services/managing-pollution/evaluating-new-substances/biotechnology-living-organisms/overview-regulations/discussion-paper.html.

Environment and Climate Change Canada. n.d.-b. “Reducing Methane Emissions from Canada’s Municipal Solid Waste Landfills: Discussion Paper.” Accessed October 16, 2026. https://www.canada.ca/en/environment-climate-change/services/canadian-environmental-protection-act-registry/reducing-methane-emissions-canada-municipal-solid-waste-landfills-discussion.html.

Global Growth Insights. n.d. “Landfill Leachate Treatment Market.” Accessed October 16, 2026. https://www.globalgrowthinsights.com/market-reports/landfill-leachate-treatment-market-123408
.

Gupta, Anshu, Akanksha Verma, and Rakesh Kumar Atri. 2025. “Landfills as a Potential Source and Origin of Microplastics: Formation, Composition, and Environmental Risks.” *Frontiers in Environmental Science* 13: 1689154. https://doi.org/10.3389/fenvs.2025.1689154.

Kumar, Akhilesh, Sudarshan Singh Lakhawat, Kashmir Singh, Vikram Kumar, Kumar Sambhav Verma, Umesh Kumar Dwivedi, S. L. Kothari, Naveen Malik, and Pushpender Kumar Sharma. 2024. “Metagenomic Analysis of Soil from Landfill Site Reveals a Diverse Microbial Community Involved in Plastic Degradation.” *Journal of Hazardous Materials* 480: 135804. https://www.sciencedirect.com/science/article/abs/pii/S0304389424023835.

Maal-Bared, Rasha, Rui Li, and Alfredo Suarez. 2022. “Evaluating the Impacts of Leachate Co-Treatment on a Full-Scale Municipal Wastewater Treatment Plant in Canada.” *Waste Management* 138: 19–29. https://pubmed.ncbi.nlm.nih.gov/34847466/.

Made in CA. n.d. “Waste Management Statistics in Canada.” Accessed October 16, 2026. https://madeinca.ca/waste-management-statistics-canada/.

Mazzei, Pierluigi, Hartmut Oschkinat, and Alessandro Piccolo. 2013. “Reduced Activity of Alkaline Phosphatase Due to Host-Guest Interactions with Humic Superstructures.” *Chemosphere.* https://www.sciencedirect.com/science/article/abs/pii/S0045653513009995.

MDG Bio. n.d.-a. “Microbial Discovery Group Files Provisional Patent for Plastic-Degrading Bacillus Blend.” Accessed October 16, 2026. https://www.mdgbio.com/microbial-discovery-group-files-provisional-patent-for-plastic-degrading-bacillus-blend/.

MDG Bio. n.d.-b. “Landfill.” Accessed October 16, 2026. https://www.mdgbio.com/landfill/.

MIT Technology Review. 2021. “Carbios Enzymes Recycle Plastics (PET).” October 6, 2021. https://www.technologyreview.com/2021/10/06/1036571/carbios-enzymes-recycle-plastics-pet/.

Peña-Valencia, María Fernanda, Semidán Robaina-Estévez, Gordon F. Custer, Onur Turak, Felipe Sierra, Lucas William Mendes, Carolina Rubiano-Labrador, et al. 2026. “Lignocellulose-Mediated Selection of Potential Halophilic PET-Degrading Enzymes from Mangrove Soil.” *Nature Communications* 17: 4930. https://doi.org/10.1038/s41467-026-71548-z.

Podlasek, Anna, Magdalena Daria Vaverková, Eugeniusz Koda, Aleksandra Jakimiuk, and Petra Martínez Barroso. 2023. “Characteristics and Pollution Potential of Leachate from Municipal Solid Waste Landfills: Practical Examples from Poland and the Czech Republic and a Comprehensive Evaluation in a Global Context.” *Journal of Environmental Management* 332: 117328. https://www.sciencedirect.com/science/article/abs/pii/S0301479723001160.

PolyGone Systems. n.d. “PolyGone Systems.” Accessed October 16, 2026. https://www.polygonesystems.com.

Premarathna, K. S. D., Sammani Ramanayaka, Thilakshani Atugoda, Madushika Sewwandi, and Meththika Vithanage. 2023. “Microplastics in Landfill Leachate and Its Treatment.” Chap. 12 in

Landfill Leachate Management. London: IWA Publishing. https://doi.org/10.2166/9781789063318_0267.

Protein Evolution. n.d. “Protein Evolution.” Accessed October 16, 2026. https://www.protein-evolution.com/.

Saltworks Technologies. n.d. “Saltworks Technologies.” Accessed October 16, 2026. https://www.saltworkstech.com/.

Sekar, Vijaykumar, Y. R. Satyaji Rao, Vinay Kumar Tyagi, Rajesh Singh, Baranidharan Sundaram, et al. 2026. “Microplastics in Landfill Leachate: Sources, Potential Impacts, and Remediation Technologies.” *Current Pollution Reports* 12: 3. https://doi.org/10.1007/s40726-026-00394-w.

Shi, Mingze, Hongbo Liu, Xuedong Zhang, Yajie Li, Cheng Zhao, Fang Huang, Yaya Sun, Xinmin Zhan, and He Liu. 2025. “Influence Mechanisms of Released Humic Substances during Sludge Thermal Hydrolysis on Anaerobic Digestion: Roles of Humic and Fulvic Acids.” *Journal of Cleaner Production* 489: 144670. https://www.sciencedirect.com/science/article/abs/pii/S0959652625000204.

Statistics Canada. 2018. “Waste Management Industry Survey.” *The Daily*, November 14, 2018. https://www150.statcan.gc.ca/n1/en/daily-quotidien/181114/dq181114b-eng.pdf.

Statistics Canada. n.d. “Canada’s Core Public Infrastructure Survey: Solid Waste and Asset Management, 2020.” Accessed October 16, 2026. https://www.statcan.gc.ca/o1/en/node/2087.

Statistics Canada. 2026. “Disposal of Waste, by Source.” Table 38-10-0032-01. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3810003201.

Sustainable Brands. n.d. “Startup’s Biomimetic Solution to Microplastic Pollution.” Accessed October 16, 2026. https://sustainablebrands.com/read/startup-biomimetic-solution-microplastic-pollution.

Tullo, Alexander H. 2024. “Enzymes to Make Plastics Disappear.” *Chemical and Engineering News* 102 (37), November 25, 2024. https://cen.acs.org/materials/polymers/Enzymes-make-plastics-disappear/102/i37.

Veolia Water Technologies. n.d. “Veolia Water Technologies.” Accessed October 16, 2026. https://www.veoliawatertech.com/en.

Wahalathanthrige, Hansani, Xunli Zhang, Jeremy S. Webb, and Ian D. Williams. 2026. “Enhancing Bioaugmentation in Wastewater Treatment: The Emerging Role of Aggregating Bacteria as Mediators in Cell Immobilization.” *Reviews in Environmental Science and Bio/Technology* 25: 12. https://doi.org/10.1007/s11157-026-09765-7.

Wdowczyk, Aleksandra, and Agata Szymańska-Pulikowska. 2021. “Comparison of Landfill Leachate Properties by LPI and Phytotoxicity: A Case Study.” *Frontiers in Environmental Science* 9: 693112. https://doi.org/10.3389/fenvs.2021.693112.

World Bank. 2026. *What a Waste: A Global Review of Solid Waste Management.* https://www.worldbank.org/en/publication/what-a-waste.

Zhang, Hao, Shuocheng Gao, Zehua Ji, Jun Cui, and Yuansheng Pei. 2023. “Solidification/Stabilization of Organic Matter and Ammonium in High-Salinity Landfill Leachate Concentrate Using One-Part Fly Ash-Based Geopolymers.” *Journal of Environmental Chemical Engineering* 11 (2): 109379. https://www.sciencedirect.com/science/article/abs/pii/S2213343723001185.

Žgajnar Gotvajn, Andreja, and Aleksander Pavko. 2015. “Perspectives on Biological Treatment of Sanitary Landfill Leachate.” IntechOpen. https://www.intechopen.com/chapters/48751.