RMI | WASTEMAP

A Playbook for Municipal Solid Waste Methane Mitigation

Recommendations Based on Global Waste Management Archetypes

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About RMI

RMI is an independent nonprofit, founded in 1982 as Rocky Mountain Institute, that transforms global energy systems through market-driven solutions to align with a 1.5°C future and secure a clean, prosperous, zero-carbon future for all. We work in the world°s most critical geographies and engage businesses, policymakers, communities, and nongovernmental organizations to identify and scale energy system interventions that will cut greenhouse gas emissions at least 50 percent by 2030. RMI has offices in Basalt and Boulder, Colorado; New York City; Oakland, California; Washington, D.C.; and Beijing.

About WasteMAP

The Waste Methane Assessment Platform (WasteMAP), a joint initiative by RMI and Clean Air Task Force, is an open online platform that brings together waste methane emissions data with decision support tools for stakeholders in the waste sector. The platform is supported by country engagement that involves collaboration with national and subnational governments, waste management officials, and other key decision makers to provide capacity building and technical assistance — providing a pathway to reduce solid waste methane emissions. Please visit our website www.wastemap.earth to learn more.

About GMH

The Global Methane Hub organizes the field of philanthropists, experts, nonprofits, and government organizations to ensure we unite around a strategy to maximize methane reductions. We have raised over $200 million in pooled funds from more than 20 of the largest climate philanthropies to accelerate methane mitigation across the globe. Visit www.globalmethanehub.org to learn more about organizations that support the commitment.

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Glossary

Advanced Thermal Treatment: The thermal degradation of feedstock such as municipal solid waste using gasification or pyrolysis to recover energy from waste. The process excludes waste incineration.

Anerobic Digestion (AD): The microbial decomposition of organic material in a controlled environment in the absence of oxygen to produce biogas that can be used for heating, cooking, electricity, or vehicle fuel. The digestate coproduct can be used as organic fertilizer or soil improver.

Biocover: A vegetative cover with unique microbial properties that oxidize fugitive methane to carbon dioxide.

Composting: The decomposition of organic waste by microorganisms in the presence of oxygen to produce compost. The compost can be used as a soil amendment.

Dumpsite: A land disposal site used for dumping solid waste material, which may be managed or unmanaged. Unmanaged or open dumpsites are uncompacted and uncovered. Managed or controlled dumpsites are slightly more advanced than open dumpsites because the solid waste is compacted and has daily covers but does not have other environmental control systems such as leachate collection and treatment, or gas collection and flare systems. In this report, dumpsites may be referred to as disposal sites or land disposal sites, or used to describe end-of-life disposal.

Embedded generation: Electricity generation connection to a distribution network rather than a transmission network. The plants are "embedded" into the distribution network for additional and/or backup electricity supply. The embedded generator can also sell its excess generation in the wholesale electricity market.

EU Candidate Countries: Countries that have applied to be a member of the European Union, been evaluated for membership by the European Commission, and, following this, have obtained the status of "candidate country" conferred by the European Council.

EU Landfill Directive: A legislative act for the European Union that seeks to minimize harm to the environment and human health by introducing technical and operational requirements for landfills.

EU Waste Framework Directive: A legislative act for the European Union that sets basic principles and requirements for waste management.

Flare: Thermal breakdown of the combustible elements of gases, like methane, using high-temperature oxidation. Under complete combustion, the flared gas is converted to carbon dioxide and water.

Food Loss: Edible food that is discarded, incinerated, or disposed of before reaching consumer or retail, such as during production, storage, processing, or transportation.

Food Waste: Food that is fit for consumption but consciously discarded by retailers or consumers.

Gas Collection and Control Systems (GCCS): Systems designed to help control odors, minimize non-methanogenic organic compound releases to the atmosphere, and increase safety by controlling migration at land disposal sites.

Greenhouse Gas (GHG): A gas that traps heat in the atmosphere by absorbing infrared radiation and contributes to the warming of the Earth's surface temperature.

Landfill Cover: A surface covering used to confine waste, minimize odors, deter scavenging and disease-carrying vectors, and protect public health. Landfill covers may be daily covers, intermediate covers, or final covers.

Landfill Gas (LFG): A gaseous by-product of the decomposition of organic matter in landfills comprising mainly methane and carbon dioxide, as well as trace amounts of nonmethane organic compounds.

Mechanical Biological Treatment (MBT): A system of processing mixed waste that combines a mechanical sorting component to retrieve recyclable materials and food waste with a biological treatment process to stabilize the biodegradable waste fraction prior to disposal at the landfill.

Methane Emissions: The release of methane (CH_4) into the atmosphere.

Methane Generation: The formation of methane during the anaerobic decomposition of organic matter in land disposal sites. Methane generation is different from methane emissions because it includes methane captured by a landfill gas collection system, methane emissions released into the atmosphere, and any residual emissions that are neither captured nor released.

Mixed Waste: A mixture of different municipal solid waste that has not been segregated.

Municipal Solid Waste (MSW): Solid waste from residential, commercial, industrial, and other establishments that is nonhazardous. This type of waste is often referred to as trash or garbage.

Open Burning: Burning municipal solid waste in open environments, such as barrels and fire pits. This process can release hazardous components from nonhazardous substances and, thus, poses health risks. Open burning may also include burning of non-municipal solid waste.

Organic Waste: Waste made up of plant or animal components that are naturally biodegradable. This type of waste is naturally compostable. Examples include food scraps, yard and garden waste, paper, and cardboard.

Project Preparation Facility (PPF): A facility that provides services to prepare projects for investment. This may include technical, financial, social, or regulatory support such as conducting feasibility assessments.

Recycling: The process of converting waste materials into new, potentially useful materials and objects. This concept often includes the recovery of energy from waste materials.

Sanitary Landfill: A managed land disposal site with regulatory oversight and environmental control systems to protect environmental health and safety. Sanitary landfills also have systems for gas collection for use or destruction through flaring. In this report, sanitary landfills may be referred to as disposal sites or land disposal sites, or used to describe end-of-life disposal.

Short-Lived Climate Pollutant (SLCP): Pollutants that have shorter life cycles compared with carbon dioxide but have a disproportionately stronger impact on global warming in the short term. Some examples include hydrofluorocarbons and methane.

Source-Separated Organics (SSO): The segregation of biodegradable waste from other waste components at the point of generation, for example, household.

Surface Emissions Monitoring (SEM): The process of monitoring the concentration of methane at the landfill surface with a gas analyzer to detect an exceedance in methane concentration and implement corrective action(s) accordingly.

Syngas: Also known as synthesis gas, syngas is a gaseous mixture that is mostly comprised of carbon monoxide and hydrogen and produced from the gasification or partial oxidation of hydrocarbon or biomass feedstock. Syngas is mainly used in the production of other fuels like methanol and diesel fuel.

Waste Diversion: The recovery of discarded materials that would otherwise be sent to land disposal sites. The recovered materials are converted to alternative products via processes such as recycling, composting, and anerobic digestion.

Waste Management Archetype: The different models that characterize the current landscape for municipal solid waste management practices deployed globally.

Waste Management Hierarchy: A system that ranks solid waste management practices from most preferred to least preferred environmental option.

Waste-to-Energy (WTE): A process in which solid waste is incinerated and the heat from the combustion process is recovered for energy and used to generate electricity or steam, or directly for heating. Incinerating solid waste reduces the volume of waste; however, it can also release toxins that have health implications.

Water Resource Recovery Facilities (WRRFs): Facilities that process wastewater effluent into clean water, energy, and other valuable resources including bio-based products from organic matter within the effluent. Biosolid fertilizer is a nutrient-rich example of such bio-based products.

Well Tuning System: A system that automatically adjusts gas well conditions, for example, gas composition, temperature, and pressure to minimize oxygen intrusion, fire hazards, and methane leaks.

Working Face: The area of a land disposal site where waste is actively dumped by a collection truck before being spread, crushed, or compacted.

Executive Summary

An estimated 2 billion tons of municipal solid waste (MSW) is produced globally each year, the majority of which ends up at landfills and dumpsites. With MSW generation projected to almost double by mid-century, there is an urgent need for more sustainable waste management solutions. Beyond the public health and safety implications, unsustainable waste management also has far-reaching climate impacts. The organic fraction of this waste, including food waste, yard waste, paper, and cardboard, generates methane as it decomposes in landfills and dumpsites, which is emitted if not properly captured.

Methane is a super potent climate pollutant with a global warming potential about 80 times higher than carbon dioxide on a 20-year time horizon, and the second largest contributor to greenhouse gas emissions. Accelerated reduction of methane emissions in this decade is the fastest way to reduce near-term warming and is critical to keep a 1.5°C temperature limit within reach. Fortunately, solutions to slash methane emissions from the waste sector, a top emitting source of methane after oil and gas and agriculture, already exist. Implementing all technically feasible abatement strategies could reduce methane from MSW by an estimated 80% below baseline in 2050.

However, countries and cities often lack actionable resources or a “playbook” that defines a pathway for deploying methane abatement strategies tailored to their unique waste management situation. This report develops solutions to mitigate methane emissions from MSW based on global MSW management archetypes. First, it provides an overview of MSW management practices globally, summarizing trends in waste generation, collection, diversion, and disposal in Africa, Asia, Australia and New Zealand, Europe, Latin America and the Caribbean and the United States and Canada, as well as some key waste management policies in select countries.

Next, it establishes the four MSW management archetypes, Build the Basics (BtB), Build the Basics Plus (BtB+), Move up the Hierarchy (MuH), and Close the Circle (CtC), which aim to characterize global waste management practices (see Exhibit ES1). These archetypes (summarized below) are informed by four building blocks: source reduction, waste diversion, waste disposal, and a crosscutting component that explores policy and regulatory framework, emissions transparency, finance, and stakeholder awareness and capacity-building opportunities.

MSW management archetypes

The BtB archetype is characterized by low to medium collection rates, poor waste management systems, low recycling rates, and limited or no waste recovery and treatment prior to final disposal. Waste is disposed of at dumpsites without methane monitoring, capture and control system, or other environmental control system. Illegal dumping and open burning of waste are common. Although waste management regulations exist, enforcement is weak and existing standards do not address organic waste or the emissions from this waste. There is limited technical capacity because waste management infrastructure is lacking. These countries can start reducing methane emissions by building basic infrastructure or implementing relatively low-cost operational improvements at the dumpsites. Example countries include the Dominican Republic, Guatemala, Nepal, Nigeria, Tajikistan, and Uganda.

The BtB+ archetype shares certain characteristics with BtB in their waste management approaches but demonstrates relatively more advanced waste management practices, evidenced by higher collection rates and a noticeable progression from dumpsites to sanitary landfills. Although waste may be disposed of at dumpsites and illegal dumping and open burning may occur, BtB+ countries have taken major steps toward improving their MSW management, advancing them beyond the BtB archetype. They can continue this trajectory by progressively transitioning to sanitary landfills with more stringent regulatory requirements on landfill gas (LFG) capture and control, improving technical capacity for waste service providers, and accessing affordable finance to support critical infrastructure development. Example countries include Argentina, Brazil, Colombia, Ecuador, India, Mexico, the Republic of Serbia, and South Africa.

The MuH archetype is characterized by universal or near-universal collection rates and wide adoption of sanitary landfills with regulatory oversight and environmental control. The recovery and treatment of organic waste is minimal, but efforts are underway to reduce the generation of biodegradable waste and expand organics recycling. Although standards may be in place to capture and control methane, these countries can move up the waste management hierarchy through more robust regulations and improved emissions transparency to phase out organic waste disposal and improve gas capture from landfills while advancing efforts to prevent food loss and waste. Example countries include Australia, Canada, New Zealand, and the United States.

The CtC archetype is similarly characterized by universal or near-universal collection and disposal in sanitary landfills. However, these countries are the least reliant on landfills for final disposal due to the heavy reliance on waste-to-energy (WTE) technologies, which incinerate the waste and reduce the volume of waste landfilled. Legislation is often in place to either ban landfilling of biodegradable materials or require that they be stabilized before disposal. Although deploying WTE technologies largely avoids methane generation, it raises concerns related to local air pollution and there is a missed opportunity to recover the carbon and plant nutrients. These countries can close the circle through food loss and waste prevention, organics diversion, and improved materials recovery. Example countries include Austria, Belgium, Finland, Germany, Japan, the Netherlands, Norway, Singapore, Sweden, and Switzerland.

Finally, the report develops a playbook that outlines strategies across the waste management value chain to deliver deep cuts in MSW methane emissions across all four archetypes after waste is generated. This playbook aims to assist key decision makers at the local, subnational, and national levels by providing tailored strategies that reflect the waste management approach currently deployed in different countries and regions, thereby acknowledging the unique differences in how waste is managed around the world and underscoring that the strategies to reduce methane must reflect these differences.

With a focus on post-waste generation, the playbook explores methane abatement opportunities including strategies to improve separation of organic waste at the source, enhance waste collection efficiency, expand organics processing capacity, optimize design and operation at land disposal sites to minimize fugitive emissions, develop an enabling policy environment, improve emissions transparency, and increase access to affordable finance, stakeholder awareness, and capacity building. The authors also assess the roles of key stakeholders in implementing these strategies.

To conclude, the authors recommend three key levers to improve waste management systems and better align current practices with the waste management hierarchy for each archetype:

- **BtB archetype:** Build basic infrastructure, build technical capacity among waste service providers, and provide affordable project finance.

- **BtB+ archetype:** Rehabilitate dumpsites to sanitary landfills with LFG collection, build technical capacity among waste service providers, and provide affordable project finance.

- **MuH archetype:** Promote food loss and waste prevention, improve source-separated organics programs and phase out organic waste disposal, and enhance efficiency of gas collection and control systems.

- **CtC archetype:** Promote food loss and waste prevention, ban the incineration of organic waste, and divert organic waste for more beneficial end uses.

These tailored approaches can unlock significant methane reductions in the waste sector on a global scale — helping avert global temperature rise in this decisive decade and beyond, while delivering powerful co-benefits including improved public health and safety and air quality.

Exhibit ES1 **Summary of MSW management archetypes**

REGIONS KEY

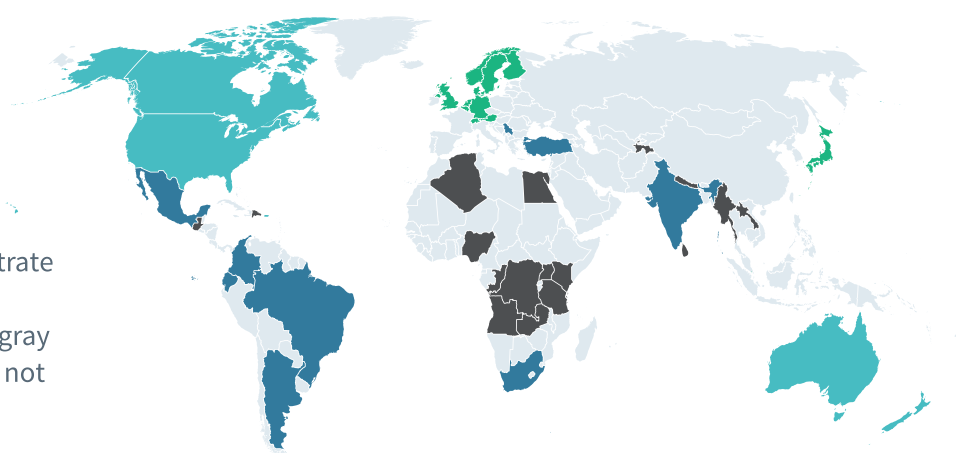
1	EU Countries
2	Japan and Singapore
3	North America (US & Canada)
4	Australia and New Zealand
5	LAC+*
6	Other European Countries**
7	LAC
8	South, Southeast & Central Asia***
9	Africa****

The landscape of waste management is diverse, often shaped by economic development, regulatory frameworks, available financing, and cultural factors. To navigate this complexity, this playbook categorizes global waste management practices into four distinct archetypes – **Build the Basics (BtB), Build the Basics Plus (BtB+), Move up the Hierarchy (MuH)**, and **Close the Circle (CtC).** These archetypes are anchored in four key building blocks — source reduction, waste diversion, waste disposal, and a crosscutting component — that guide tailored methane mitigation strategies.

BUILDING BLOCKS		SOURCE REDUCTION	WASTE DIVERSION			WASTE DISPOSAL	CROSS-CUTTING COMPONENTS			
BUILDING BLOCK ELEMENTS		Food Loss and Waste Prevention	Generation	Collection and Transport	Treatment	End-of-Life Disposal	Policy and Regulatory Framework	Emissions Transparency	Finance	Stakeholder awareness & capacity building
REGIONS CATEGORIZATION										
1	CtC	☑☑☑☐☐	☑☑☑☐☐	☑☑☑☑☑	☑☑☑☐☐	☑☑☑☑☐	☑☑☑☑☑	☑☑☑☐☐	☑☑☑☑☐	☑☑☑☑☑
2	CtC	☑☑☑☑☐	☑☑☐☐☐	☑☑☑☑☑	☑☑☐☐☐	☑☑☑☑☐	☑☑☑☐☐	☑☐☐☐☐	☑☑☑☑☐	☑☑☑☑☑
3	MuH	☑☑☑☐☐	☑☑☐☐☐	☑☑☑☑☑	☑☑☑☐☐	☑☑☑☑☐	☑☑☑☐☐	☑☑☑☑☐	☑☑☑☑☐	☑☑☑☑☐
4	MuH	☑☑☑☐☐	☑☑☐☐☐	☑☑☑☑☑	☑☑☑☐☐	☑☑☑☑☐	☑☑☑☐☐	☑☑☑☐☐	☑☑☑☑☐	☑☑☑☑☐
5	BtB+	☑☑☑☐☐	☑☐☐☐☐	☑☑☑☑☑	☑☐☐☐☐	☑☑☐☐☐	☑☑☑☑☐	☑☐☐☐☐	☑☑☐☐☐	☑☑☑☐☐
6	BtB+	☑☑☐☐☐	☑☐☐☐☐	☑☑☑☑☐	☑☐☐☐☐	☑☑☐☐☐	☑☑☐☐☐	☑☐☐☐☐	☑☐☐☐☐	☑☑☐☐☐
7	BtB	☑☑☐☐☐	☑☐☐☐☐	☑☑☑☐☐	☑☐☐☐☐	☑☐☐☐☐	☑☑☐☐☐	☑☐☐☐☐	☑☐☐☐☐	☑☐☐☐☐
8	BtB	☑☑☐☐☐	☑☐☐☐☐	☑☑☐☐☐	☑☐☐☐☐	☑☐☐☐☐	☑☐☐☐☐	☑☐☐☐☐	☑☐☐☐☐	☑☐☐☐☐
9	BtB	☑☑☐☐☐	☑☐☐☐☐	☑☑☐☐☐	☑☐☐☐☐	☑☐☐☐☐	☑☐☐☐☐	☑☐☐☐☐	☑☐☐☐☐	☑☐☐☐☐

☑☐☐☐☐ Least aligned with the waste management hierarchy ⟷ ☑☑☑☑☑ Most aligned with the waste management hierarchy

- Close the Circle (CtC)
- Move up the Hierarchy (MuH)
- Build the Basics Plus (BtB+)
- Build the Basics (BtB)



Countries highlighted in the map illustrate some examples of each global waste management archetype. Countries in gray (i.e., unshaded countries) may or may not fit into a single archetype.

* Certain countries in LAC that demonstrate more advanced waste management systems than other countries in the region.
** Non-EU European countries excluding Norway, Switzerland, and the UK.
*** The low- and lower-middle-income countries in South, Southeast, and Central Asia belong in BtB archetype although, there may be few exceptions, such as India, that fall under BtB+. Singapore is a high-income country in Southeast Asia and falls under the CtC archetype.
**** The entire continent of Africa falls under the BtB archetype, other than South Africa, which, based on our research, falls under the BtB+ archetype.

1. Reducing Waste Sector Methane Emissions: An Untapped Opportunity

Rapid population growth, economic development, and increasing consumption underscore the need for more sustainable waste management solutions. In 2020, global waste generated was estimated at 2.24 billion tons and is projected to reach 3.88 billion tons by 2050.[1] Unless more sustainable waste management practices — such as source reduction and waste diversion — that reduce reliance on land disposal sites are implemented, most of this waste will continue to be sent to landfills and dumpsites, many of which are approaching their maximum capacity.

Unsustainable waste management not only has public health and safety implications such as groundwater contamination, pests, and diseases, it also has adverse climate impacts. As more waste is generated and sent to disposal sites, methane emissions from the decomposed organic waste fraction will continue to increase unless the waste is prevented from being generated, is diverted, or the methane from decomposed waste is captured.

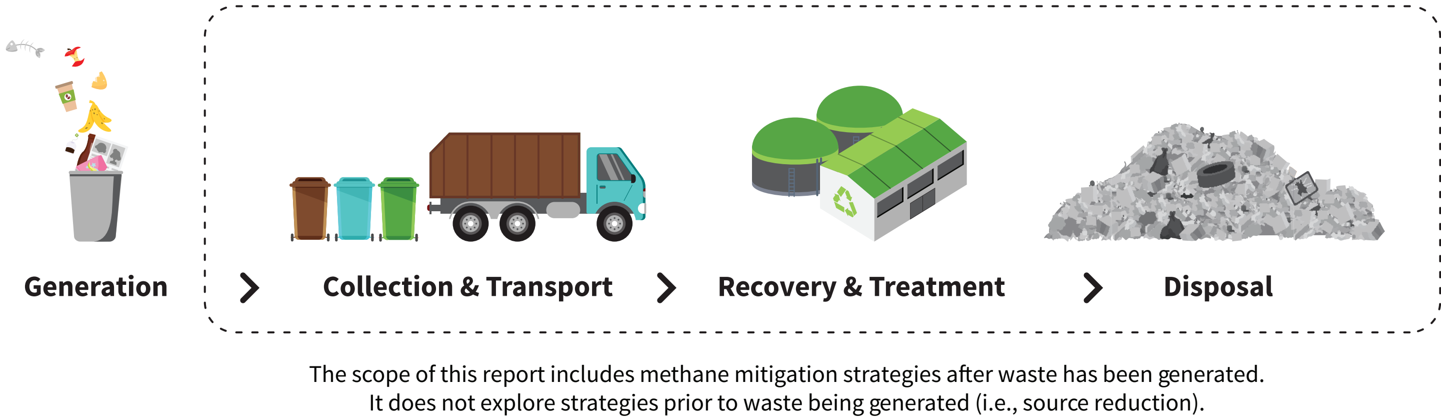
Methane is a potent greenhouse gas (GHG) that is responsible for about 30% of global warming since preindustrial times and has about 80 times the warming impact of carbon dioxide over a 20-year time frame.[2] As the third largest contributor to global anthropogenic methane emissions, the waste sector is responsible for about 20% of the global total.[3] Methane emissions from municipal solid waste (MSW) are estimated to increase by 13 million tons per year, which is equivalent to GHG emissions from 278 coal-fired power plants operating for a year, over the next decade alone.[4] Bold commitments like the Global Methane Pledge, which aims to reduce global methane emissions across high-emitting sectors (like the waste sector) by at least 30% of 2020 levels by 2030, are necessary to limit global warming to 1.5°C above preindustrial levels.[5]

Recent advancements in remote sensing technologies, mainly satellite and aircraft observations, have also brought more attention to the waste sector's contribution to this short-lived climate pollutant. For example, a study by the Netherlands Institute for Space Research found that in Lahore, Pakistan, methane emissions from landfills amount to more than 19 tons per hour.[6] This is equivalent to GHG emissions from 1 million gasoline-powered passenger cars driven for a year.[7] According to the study, methane emissions in Lahore, estimated using satellite observations, are twice as high as those recorded in city inventories.[8] These observations highlight near-term and long-term methane abatement opportunities for the waste sector.

This global strategy playbook identifies four waste management archetypes and explores strategies to slash methane emissions for each. By tailoring methane abatement solutions to different archetypes, the authors acknowledge the unique differences in waste management practices around the world and underscore that the strategies to reduce methane must reflect these differences. This playbook is intended to serve as a resource for key decision makers as they begin to prioritize abating waste sector methane; it provides a starting point to customizing solutions that consider the unique local context.

Although source reduction (i.e., preventing waste from being generated) is the best and preferred option to reduce methane emissions from solid waste, this playbook focuses on methane mitigation strategies after waste has been generated (see Exhibit 1).

Exhibit 1 The MSW value chain



RMI Graphic. Source: RMI analysis

2. Overview of Waste Management Landscape: A Global Perspective

Across the globe, generally accepted best practices for solid waste management follow a waste management hierarchy that prioritizes source reduction, material reuse, and recovery over disposal. Even as some regions make progress in these aspects, millions of tons of waste are still sent to disposal sites each year, and millions more are already sitting in landfills and dumpsites. Focusing on mitigation downstream is critical to cutting methane quickly from waste-in-place and protecting communities near disposal sites today, as we simultaneously advance upstream strategies.

When waste is sent to land disposal sites, the organic component, such as food waste, yard waste, paper, and cardboard, decomposes under anerobic conditions and generates landfill gas (LFG), which is primarily methane and carbon dioxide (CO_2). In the absence of a mechanism to efficiently capture this gas, methane and CO_2 are emitted into the atmosphere. Recovering the organic component before final disposal prevents methane emissions in future waste streams. Given that food and yard waste make up the single largest share of the MSW stream regardless of income level, ranging from 32% in high-income countries to 56% in low-income countries,[i] the biggest opportunity for accelerating methane reduction lies in diverting this organic waste fraction away from landfills and dumpsites.[9] Once organic waste is recovered, it can undergo treatment where it is transformed into useful end products and/or commodities. The following is a summary of technologies currently deployed to treat organic waste:

- **Composting** is the microbial decomposition of organic waste in the presence of oxygen to produce compost, which can be used as a soil amendment because it helps enrich the nutrient content and biodiversity of microbes in soil. The use of compost as an erosion control blanket can also help reduce stormwater runoff.

- **Anaerobic digestion (AD)** aims to reduce fugitive emissions from landfills and dumpsites by treating decomposable waste in a controlled environment outside the disposal site. The process involves the microbial decomposition of organic material in enclosed biodigester tanks in the absence of oxygen to produce biogas, which can be used for heating, cooking, electricity, or vehicle fuel (see Exhibit 2). The digestate coproduct can be used as organic fertilizer or soil improver.

- **Mechanical biological treatment (MBT)** combines mechanical sorting of mixed waste to recover recyclables and food and yard waste with biological treatment processes such as composting and AD. The main objective of MBTs is to stabilize any biodegradable waste before it is sent to the landfill; therefore, end products such as compost may have less value or end uses due to contamination from the residual waste stream.

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i This report refers to the following definitions by the World Bank to discuss the world's economies (in 2015 US$/capita/year): low income = $1,025 or less; lower middle income = $1,026–$4,035; upper middle income = $4,036–$12,475; and high income = $12,476 or more. World Bank, **https://blogs.worldbank.org/opendata/new-country-classifications-2016.**

- **Waste-to-energy (WTE),** also referred to as waste incineration with energy recovery, involves the combustion of solid waste to reduce its volume, and the heat recovered from the combustion process is used to generate electricity or steam or is used directly for heating. WTE technologies are widely deployed in Asia and Europe and the residual waste from the incineration is sent to landfills or utilized (e.g., ash for road construction). Although the combustion process largely eliminates any potential for methane generation, this technology should not be used to treat organic waste due to its high moisture content resulting in low calorific value and because the nutrients from the organic waste are not recovered. WTE technologies also produce toxic air pollutants like lead, mercury, acidic gases, nitrous oxides, and particulate matter that can lead to cancer, heart disease, birth defects, and premature death, especially in communities near where these facilities are located, which are often marginalized.[10]

- **Advanced thermal treatment** technologies employ gasification or pyrolysis to process MSW and recover energy from waste. It involves the thermal degradation of feedstock such as MSW. When this thermal degradation occurs in an oxygen-free environment, the process is known as pyrolysis.[11] Gasification, on the other hand, uses small amounts of oxygen (i.e., partial oxidation of the feedstock). Pyrolysis and gasification are used to treat the organic-based materials present in MSW and transform the feedstock to syngas and solid residue (biochar). Gasification and pyrolysis technologies are not widely deployed to treat MSW, although commercial-scale plants are in operation in Europe, Japan, and the United States.[12] Advanced thermal treatment does not include incineration. However, similar concerns of toxic air pollutants exist.

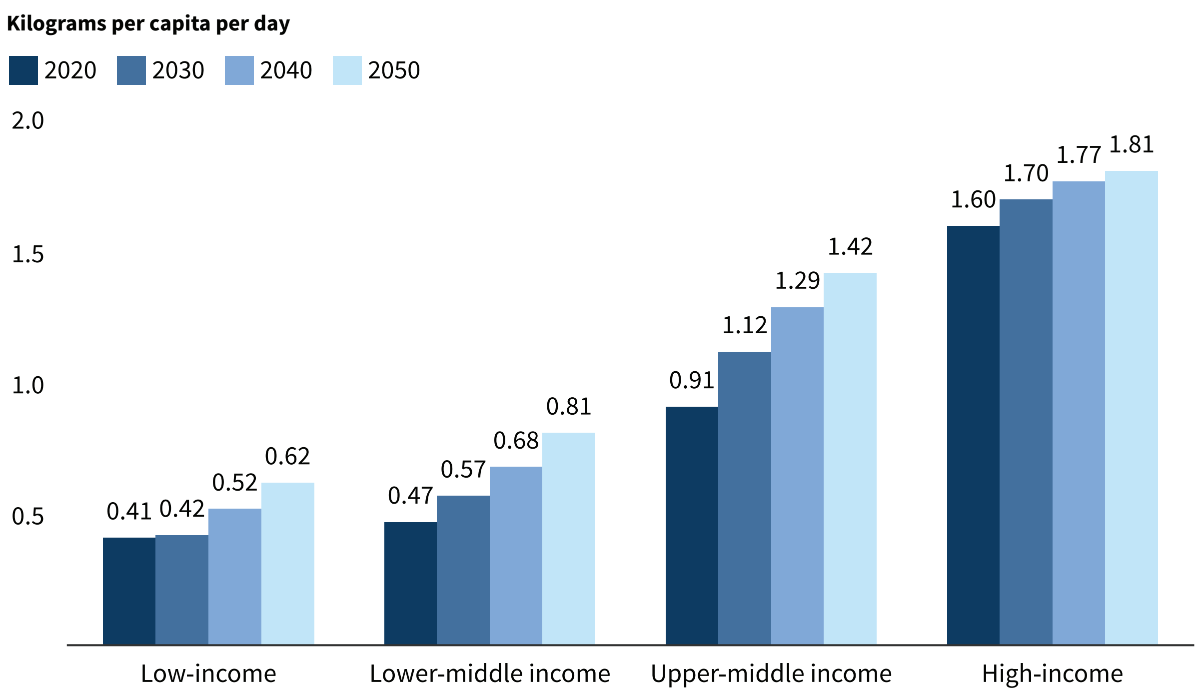
Exhibit 2 An AD pilot project in Canada that produces biogas from organic waste

Strategies to intercept organic waste prior to reaching final disposal should be prioritized. However, organic waste still makes its way to landfills and dumpsites, where it is decomposed and generates methane. Modern sanitary landfills may be fitted with gas collection and control systems (GCCS) — a series of wells and blower/flare systems — to extract LFG and minimize and control its migration. The GCCS may route treated and processed LFG for beneficial end use or to a flare system where methane is thermally destroyed. Examples of end uses include electricity generation, direct use in boilers, furnaces, and kilns, or upgrading to pipeline-quality natural gas, also referred to as biomethane. Although installing GCCS at disposal sites reduces methane emissions from decomposed waste, LFG collection efficiency and fugitive emissions vary widely across landfills, including regulated landfills, due in part to differences in landfill design, the use of landfill cover, GCCS efficiency, and flare efficiency.

The degree to which these waste recovery and treatment, landfill gas-to-energy, and other waste management technologies are adopted varies significantly across regions and is driven by the level of economic development, regulatory framework, available financing, and geographic factors such as land availability and cultural norms. For example, according to the World Bank's *More Growth, Less Garbage* report, in 2020, high-income countries were estimated to generate about four times as much waste as low-income countries on a per capita basis, and waste generation will continue to increase significantly across the globe over the next three decades (see Exhibit 3).[13]

The following section explores trends in MSW management practices around the globe; highlights waste generation patterns, collection, recovery and treatment, and disposal practices; and assesses the policy environment.

Exhibit 3 Projected global waste generation by income group



RMI Graphic. Source: The World Bank

Africa

According to the UN Environment Programme's (UNEP) *Africa Waste Management Outlook* and the World Bank's *What a Waste* report, per capita waste generation in Africa is much lower than the global average.[14] However, due to the lack of high-quality waste sector data in Africa, it is difficult to adequately assess the current waste situation. In 2012, total MSW generation was estimated to be 125 million tons per year, with 65% from sub-Saharan Africa, which increased to 174 million tons in 2016.[15] Per capita waste generation on the continent was estimated to be 0.78 kilogram (kg) per person per day, although huge variations exist among cities, ranging from 0.09 to 2.98 kg per person per day.[16] On average, biodegradable waste accounts for more than half of the total MSW generated in sub-Saharan Africa at 57%, followed by plastics (14%) and paper and cardboard (9%).[17]

In most African countries, the state government or municipalities are responsible for providing waste management-related services and infrastructure. However, it is difficult to sustain these services given that the collection system alone can account for the majority of their waste management budget, and that there is a lack of skilled labor for operation and maintenance. The waste collection rate in Africa ranges between 18% and 80%, with an average of 44%.[18] These estimates are mainly based on urban areas. Access to waste collection and transport services is weaker in rural areas, and as such, these activities are usually carried out by small-scale service providers and done communally. Waste collection services often do not cover the population living in impoverished communities, often resulting in open burning and illegal dumping that has a significant health impact on local communities due to elevated levels of heavy metal, black carbon, and other short-lived climate pollutants.[19] To address this long-standing issue, African environmental ministers committed to "eliminate open dumping and burning of waste in Africa by 2050" at the 18th session of the African Ministerial Conference on the Environment in 2022.[20]

Waste diversion practices are rare in Africa. The recycling rate is only 4%, and source-separated organics (SSO) programs are often not implemented.[21] Furthermore, in large part due to the heavy involvement of waste pickers, there is a lack of high-quality data on recycling activities. More than 90% of the waste collected goes to uncontrolled dumpsites and landfills with only a few WTE projects implemented in the region.[22]

Some African countries have established laws and regulations on waste management. For example, in Ethiopia, the 2007 Solid Waste Management Proclamation aimed to prevent the adverse impact of solid waste and improve waste management by detailing the obligation of various agencies in MSW management and requiring the design and implementation of action plans.[23] However, the lack of supporting guidelines has made implementation challenging. In Kenya, the Sustainable Waste Management Act (2022) introduced new requirements for waste management infrastructure planning at the county level and separating organic waste at the household level, but the effectiveness of its implementation remains to be seen, given financial and political challenges in the process.[24] South Africa enacted the National Environmental Management: Waste Act in 2008 and established the National Waste Management Strategy in 2011.[25] The 2020 update of the National Waste Management Strategy shifted its focus toward waste minimization and increasing awareness of compliance as the country aims to divert 40% of its waste from the landfills by 2025 and targets a 25% reduction in waste generation.[26]

Asia

Waste management varies significantly across Asia. In high-income countries like Japan and Singapore, the waste management infrastructure is well operated. These countries rely heavily on waste incineration with energy recovery, which greatly reduces the amount of residual waste sent to landfills and thus extends the life span of the landfills. For example, as of 2020, about 75% of the MSW generated in Japan was incinerated.[27] The waste sorting systems in these countries are built to prioritize heavy incineration by separating MSW into burnables, unburnables, and recyclables.[28] Both Japan and Singapore have long-standing policies and regulations pertaining to waste management, including Japan's Basic Act for Establishing a Sound Material-Cycle Society (2000) and the Act on Promotion of Food Loss and Waste Reduction (2019), and Singapore's Environmental Public Health Act (1969) and the Resource Sustainability Act (2019), with the latter targeting food waste.

Countries in South Asia have experienced tremendous economic growth and urbanization in the past decade. In this context, MSW generation has increased and efforts have been made to improve the waste management systems. On average, as of 2016, South Asian countries generated 0.56 kg of waste per person per day.[29] According to the World Bank, less than half of this waste is collected, and the waste collection system only covers about half of the geographical areas. Informal workers are integral in waste collection efforts in South Asia.[30] Most of the uncollected waste is openly burned. Source segregation is not common, and large-scale waste treatment facilities have faced significant operational challenges. However, there are successful community-level composting and AD facilities.

Similarly, open dumping is common in low-income and lower-middle-income countries in Southeast Asia, as they have seen a significant increase in waste generation over the past two decades, doubling in amount since 2005.[31] At the same time, diversion practices including recycling, composting, and AD are increasingly being adopted in these countries. On average, about half of the MSW generated in low- and middle-income Southeast Asian countries is organic, but some countries lack systematic planning of MSW management infrastructure and source separation that enables these wastes to be treated efficiently.[32] Although most Southeast Asian countries include waste management improvements in their national environmental planning, they rarely address organic waste management, methane management, or related infrastructure, and some fall short in the policies and regulations to enable implementation.

In Central Asia, the rate of source segregation and formal waste collection is relatively low across the region, ranging from 20% to 60%.[33] There is a heavy reliance on final disposal facilities. However, there are efforts underway to close and transition large dumpsites and construct and operate small-scale sanitary landfills and WTE facilities.

Due to rapid population and economic growth, MSW in China has increased significantly in recent decades, reaching 249 million tons of waste collected in urban areas in 2021, of which 54% was food and yard waste, followed by paper (17%) and plastic and rubber (14%).[34] China is transitioning from landfilling to incineration, as the percentage of landfilled waste decreased from 64% in 2015 to 20% in 2021, with most waste incinerated, and about 2% treated using alternative methods like composting and AD. The waste management situation in China varies significantly between different tiers of cities and between urban and rural areas, as open dumping and burning still exist in many rural areas.

Both waste management and methane management have been areas of increased policy focus in China. The Solid Waste Pollution Prevention and Control Law (2020) establishes the regulatory framework for the reduction, utilization, and harmless disposal of solid waste.[35] Provisions in the 14th Five-Year Plan have targeted improving waste treatment infrastructure and strengthening environmental monitoring, including the monitoring of waste sector methane emissions.[36] The Zero-Waste Cities initiative has prompted municipal governments to develop tailored local plans to improve waste management practices.[37] In 2023, China published a National Methane Action Plan with concrete measures to curb methane emissions from energy, agriculture, and waste.[38]

Australia and New Zealand

MSW generation in Australia has remained relatively steady in the past 15 years. According to the latest National Waste Report for Australia, MSW generation was estimated at 18 million tons, or 1.5 kg per person per day in 2022.[39] Food and yard waste accounted for 40% of the total MSW generated, followed by paper and cardboard (12%) and plastics (7%).[40]

Australia and New Zealand have both achieved high MSW collection coverage. In recent years, curbside waste collection separating yard waste, food waste, and recyclables has become increasingly available, which has led to an increase in SSO and waste recovery. In 2022, the overall recycling (including organics recycling) rate was 60%, while 58% of the organic waste generated was recovered.[41] Comparatively, New Zealand has a current overall recycling rate of 28%, while the remaining waste goes to landfills.[42]

In Australia and New Zealand, there is strong policy and regulatory support for MSW management, both at the national and jurisdictional levels. Australia's National Waste Policy: "Less Waste, More Resources" was agreed on in 2018 and implemented through the 2019 National Waste Policy Action Plan. The plan targets 10% reduction in per capita waste generation and aims to achieve 50% reduction of organic waste sent to landfills by 2030.[43] At the state level, Queensland released its Waste Management and Resource Recovery Strategy in 2019 and has finished consultation on a draft Organics Strategy that aims to improve management of organic waste across the entire supply chain. Meanwhile, New Zealand implemented the Waste Minimization Act (2008), which set out a landfill levy for disposal and allowed for regulations on GHG monitoring to be designed and implemented.[44] The New Zealand government is considering banning organics from landfills by 2030.

Europe

Since the introduction of the Landfill Directive and the Waste Framework Directive in the EU, many EU countries have prioritized progressing toward a circular economy, evidenced by their implementation of various measures such as organic waste disposal bans and landfill taxes to align waste management practices more closely with the waste hierarchy. In 2021, EU countries averaged 530 kg (1.45 kg per day) of waste generated per capita, of which about 27% was food waste, followed by paper and cardboard (20%) and plastics (13%).[45] Among the total waste generated, half was recycled and composted, and 18% was landfilled.[46] The remaining waste was treated through other practices including WTE. However, the EU has recently started to turn away from financially supporting this technology because it does not align with its carbon-neutrality and circular economy goals.[47] The EU also exports part of its waste to areas across Africa, Asia and non-EU countries in Europe. In 2021, 14.7 million tons of waste was exported to Turkey, which accounted for almost half of the total waste exported from the EU.[48]

According to the European Environment Agency, the EU aims to reuse and recycle (including traditional recyclables and organics) 60% of its municipal waste by 2030 and landfill less than 10% of its municipal waste by 2035.[49] Countries including Austria, Germany, and Slovenia have already achieved both targets, while newer members of the EU still rely heavily on landfills and dumpsites. The 2018 amendment to the Landfill Directive also requires that EU countries implement national strategies to progressively reduce the amount of biodegradable waste sent to landfills, which is another step toward improving resource recovery.

Compared with EU member states, EU candidate countries are typically less advanced in their waste management systems, as heavy reliance on landfills and dumpsites continues and a lack of coordinated initiatives, funding, and expertise slows progression toward sustainable management practices. For example, the Republic of Serbia's law on waste management, which mirrors EU waste legislation, has incorporated quantitative targets to move up the waste management hierarchy into its national waste management strategy, although these are still in the early stages of implementation. Further, efforts are underway to upgrade existing dumpsites to regional sanitary landfills (see Exhibit 4).[50]

Exhibit 4

Gas collection system at a sanitary landfill

The extracted gas is routed to the landfill gas-to-energy facility in the background where it is converted to electricity.

Latin America and the Caribbean

Countries in Latin America and the Caribbean (LAC) have also witnessed an increase in waste generation in recent decades, with significant variation in waste generation, collection rates, and waste composition. Waste collection rates vary widely in LAC, reaching as high as 90% in urban areas of countries like Chile and Argentina according to the UNEP report *Waste Management Outlook for Latin America and the Caribbean*.[51] However, the collection infrastructure is poor in rural areas and because transfer stations are not common, it is difficult for collected waste to reach the final disposal sites.

There have been successful waste diversion projects like composting and AD in high-income and upper-middle-income countries. However, in part due to the low tipping fee at landfills, the scale of these waste diversion projects is still limited compared with the need, as organic waste accounts for more than half of the total MSW in upper-middle- and lower-middle-income countries, and as much as 75% in low-income countries.[52]

Final disposal of waste in the LAC region has significantly improved, as more open dumps were covered and controlled, and upgraded to landfills, especially in high-income countries and urban areas. Chile, Colombia, and Costa Rica have the highest adoption rates of sanitary landfills at over 80%.[53] Despite these improvements, open dumping and open burning still exist, with more than 25% of waste disposed of using inadequate treatment practices.[54]

The United States and Canada

The MSW generation rate has continued to increase in both the United States and Canada. In the United States, total MSW generation increased by 7% from 2010 to 2018, reaching 265.3 million tons, of which 24% was recycled, 8.5% was composted, 12% was incinerated with energy recovery, and about half was sent to landfills.[55] Food waste is the biggest component of MSW in the United States, accounting for 24% of total waste landfilled, followed by plastics and then paper and cardboard, at 18% and 12%, respectively. However, the total organic component (food waste, yard trimmings, wood, paper, and cardboard) makes up about half of MSW landfilled.[56]

From 2002 to 2018, total MSW generation in Canada increased by 16% to 35.6 million tons, of which 28% was diverted and 72% was disposed of at landfills.[57] Waste diversion rates vary widely between provinces and territories in Canada, from 10% in Newfoundland and Labrador to 51% in Prince Edward Island.[58] Organic waste constitutes 69% of total MSW, and food waste is the largest component, accounting for about 40%.[59]

The United States and Canada have achieved near-universal waste collection, but SSO is still limited, although there have been positive improvements in recent years. In the United States, access to curbside organic waste collection programs has grown from just over 500,000 households in 2005 to nearly 14.9 million households in 2023.[60] Some states and cities have set ambitious targets: California aims to reduce disposal of organic waste by 75% by 2025 compared with 2014 levels.[61] The city of Austin in Texas aims to divert 90% of waste from landfills by 2040.[62] At the same time, several jurisdictions in Canada, including Nova Scotia, Ontario, and Prince Edward Island, have banned disposal of organic waste in landfills.[63]

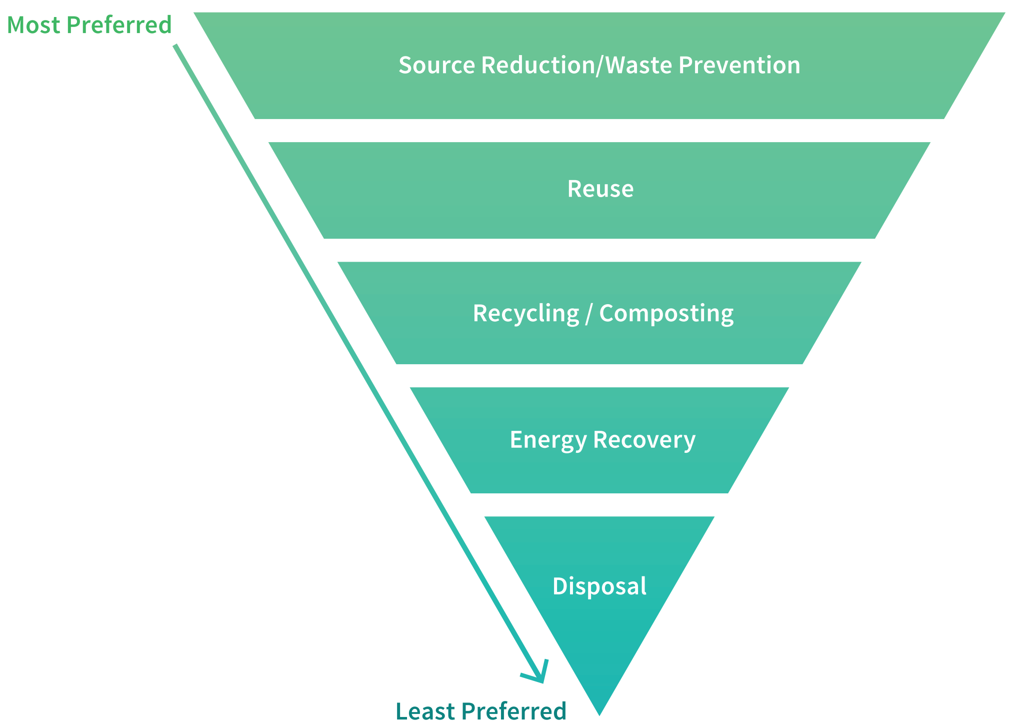
In the United States, provisions under the Clean Air Act require landfills above a certain threshold to install and operate an LFG collection system and route the recovered gas for end use or to a flare system, where methane is thermally destroyed. The standards also mandate certain design, operational, and monitoring practices, including quarterly surface emissions monitoring (SEM) to detect methane concentration above a certain limit and implement corrective actions as needed.[64] Some states, such as California, Maryland, and Oregon, have set more stringent standards than is currently required by the US Environmental Protection Agency (EPA). Landfills above a certain threshold are also required to estimate and report their methane emissions annually to the Greenhouse Gas Reporting Program.[65] In Canada, there are currently no national-level requirements on GCCS or SEM, but some provinces and territories, including Alberta, British Columbia, Ontario, and Quebec, have implemented regulations requiring larger landfills to capture and control methane.[66] Quebec also requires SEM at landfills with methane recovery systems.[67] In 2023, Canada proposed a national regulatory framework to reduce methane emissions from landfills.

This MSW management overview underscores that although waste management practices around the world vary, some countries and/or regions have adopted similar approaches. In the next section, the authors evaluate these commonalities and differences to characterize waste management systems.

3. Municipal Solid Waste Management Archetypes: A Methane Emissions Perspective

The waste management hierarchy ranks waste management practices from the most preferred to the least preferred environmental option, thereby prioritizing more sustainable strategies such as source reduction, reuse, and recycling over other alternatives like landfilling. Although this hierarchy is widely agreed upon, its implementation is less straightforward. From collection to source separation to treatment and final disposal, several factors including level of industrialization, per capita income, regulatory standards, and behavioral patterns influence the waste management approach in different countries, with many still relying heavily on practices at the bottom of the pyramid (see Exhibit 5).

Exhibit 5 Waste management hierarchy



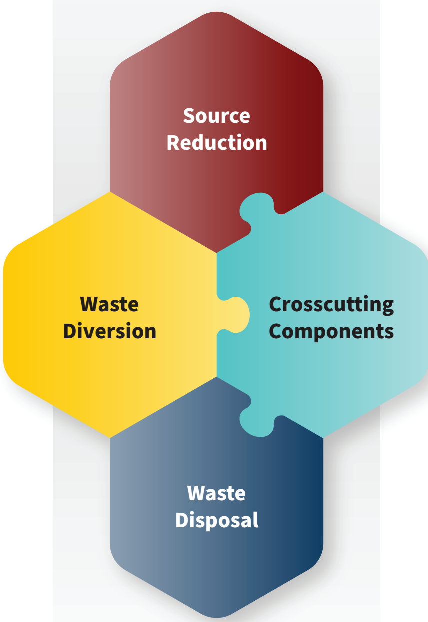
RMI Graphic. Source: RMI analysis

Although waste management practices vary vastly across the globe, many countries exhibit similar characteristics in their approaches and can be grouped into similar categories or “archetypes.” In this section, we examine several guiding questions to evaluate how MSW and methane emissions from MSW are managed (see Exhibit 6). The guiding questions, which inform the archetypes, are based on four main building blocks:

(1) source reduction, (2) waste diversion, (3) waste disposal, and (4) a crosscutting component. The first three building blocks follow the waste management hierarchy, while the final building block explores policy and regulatory framework, emissions transparency, finance, and stakeholder awareness and capacity building.

Exhibit 6 **Conceptual framework for global MSW management archetypes**

Building Blocks



Building Block Elements	Guiding Questions
Food Loss and Waste Prevention	Are there initiatives to reduce food waste?
Generation	Is waste separated at the source?*
Collection and Transport	What is the collection rate and coverage?
Recovery and Treatment	What is the recycling rate?** Are technologies deployed to manage and transform waste to beneficial end uses?
End-of-Life Disposal	What final waste disposal systems exist?
Policy and Regulatory Framework	Are there policies and regulations for waste management? Are there policies and regulations that address methane emissions from decomposed waste?
Emissions Transparency	Are technologies deployed to detect and mitigate emissions from biodegradable waste? Are waste data (e.g., waste characterization and waste flow) and emissions data publicly available?
Finance	Is financing available for waste management projects? Is there a cost recovery mechanism to ensure sustainable operations?
Stakeholder Awareness and Capacity Building	What is the local community's level of awareness and compliance towards waste management best practices? Is there technical capacity to operate and maintain waste management technologies locally?

*Source separation refers to segregating waste at the point of generation including recyclable materials such as plastics, glass, metals as well as biodegradable waste like food and yard waste.

**The recycling rate refers to the entire MSW stream, including the recycling of plastics, glass, metals as well as biodegradable waste like food and yard waste.

RMI Graphic. Source: RMI analysis

Using these guiding questions, the authors assess the current MSW management and methane management practices across the globe using a combination of qualitative and quantitative data. The current situation is rated in Exhibit 7, where one check mark is the least desirable/aligned with the waste management hierarchy and five check marks is highly desirable/aligned with the waste management hierarchy. For more details on these ratings, please refer to the *Appendix*.

Further, we use color codes to visualize similar characteristics to indicate countries and regions that are within the same archetype. We define "similar" as countries that either receive the same rating (i.e., number of check marks) or differ by one check mark in any given category. For example, the green color illustrates that waste management conditions and practices between EU countries and Japan and Singapore are similar; therefore, these countries are categorized as the Close the Circle archetype. Similarly, the blue color illustrates similar waste management practices deployed in some parts of LAC, the majority of Africa, and the majority of South, Southeast, and Central Asia, which are categorized as the Build the Basics archetype.

Exhibit 7 Comparison of MSW management practices across the globe

Building Blocks	Building Block Elements	EU Countries	Japan and Singapore	North America (United States and Canada)	Australia and New Zealand	LAC+*	Other European Countries**	LAC	South, Southeast, and Central Asia***	Africa****
Source Reduction	Food Loss and Waste Prevention	☑☑☑☐☐	☑☑☑☑☐	☑☑☑☐☐	☑☑☑☐☐	☑☑☑☐☐	☑☑☐☐☐	☑☑☐☐☐	☑☑☐☐☐	☑☑☐☐☐
Waste Diversion	Generation	☑☑☑☐☐	☑☑☐☐☐	☑☑☐☐☐	☑☑☐☐☐	☑☐☐☐☐	☑☐☐☐☐	☑☐☐☐☐	☑☐☐☐☐	☑☐☐☐☐
	Collection and Transport	☑☑☑☑☑	☑☑☑☑☑	☑☑☑☑☑	☑☑☑☑☑	☑☑☑☑☑	☑☑☑☑☐	☑☑☑☐☐	☑☑☐☐☐	☑☑☐☐☐
	Recovery and Treatment	☑☑☑☐☐	☑☑☐☐☐	☑☑☑☐☐	☑☑☑☐☐	☑☐☐☐☐	☑☐☐☐☐	☑☐☐☐☐	☑☐☐☐☐	☑☐☐☐☐
Waste Disposal	End-of-Life Disposal	☑☑☑☑☐	☑☑☑☑☐	☑☑☑☑☐	☑☑☑☑☐	☑☑☐☐☐	☑☑☐☐☐	☑☐☐☐☐	☑☐☐☐☐	☑☐☐☐☐
Crosscutting Component	Policy and Regulatory Framework	☑☑☑☑☑	☑☑☑☐☐	☑☑☑☐☐	☑☑☑☐☐	☑☑☑☑☐	☑☑☐☐☐	☑☑☐☐☐	☑☐☐☐☐	☑☐☐☐☐
	Emissions Transparency	☑☑☑☐☐	☑☐☐☐☐	☑☑☑☑☐	☑☑☑☐☐	☑☐☐☐☐	☑☐☐☐☐	☑☐☐☐☐	☑☐☐☐☐	☑☐☐☐☐
	Finance	☑☑☑☑☐	☑☑☑☑☐	☑☑☑☑☐	☑☑☑☑☐	☑☑☐☐☐	☑☐☐☐☐	☑☐☐☐☐	☑☐☐☐☐	☑☐☐☐☐
	Stakeholder Awareness and Capacity Building	☑☑☑☑☑	☑☑☑☑☑	☑☑☑☑☐	☑☑☑☑☐	☑☑☑☐☐	☑☑☐☐☐	☑☐☐☐☐	☑☐☐☐☐	☑☐☐☐☐

Emerging Archetypes	Close the Circle (CtC)	Move up the Hierarchy (MuH)	Build the Basics Plus (BtB+)	Build the Basics (BtB)
Example countries	Austria, Belgium, Finland, Germany, Japan, the Netherlands, Norway, Singapore, Sweden, and Switzerland	Australia, Canada, New Zealand, and the United States	Argentina, Brazil, Colombia, Ecuador, Mexico, India, the Republic of Serbia, and South Africa	The Dominican Republic, Guatemala, Nepal, Nigeria, Tajikistan, and Uganda

* Certain countries in LAC that demonstrate more advanced waste management systems than other countries in the region.

** Non-EU European countries excluding Norway, Switzerland, and the UK.

*** The low- and lower-middle-income countries in South, Southeast, and Central Asia belong in the BtB archetype, although there may be few exceptions, such as India, that fall under BtB+. Singapore is a high-income country in Southeast Asia and falls under the CtC archetype.

**** The entire continent of Africa falls under the BtB archetype, other than South Africa, which, based on our research, falls under the BtB+ archetype.

RMI Graphic. Source: RMI analysis

As depicted in Exhibit 7, four waste management archetypes emerge, Build the Basics (BtB), Build the Basics Plus (BtB+), Move up the Hierarchy (MuH), and Close the Circle (CtC). Their respective characteristics are illustrated in Exhibit 8 (next page).

The BtB archetype is characterized by low to medium collection rates, poor waste management systems, low recycling rates, and limited or no waste treatment prior to final disposal. Waste is disposed of at dumpsites without methane monitoring, capture and control system, or other environmental control system. Illegal dumping and open burning of waste are common. Although waste management regulations exist, enforcement is weak and existing standards do not address organic waste or the emissions from this waste. There is limited technical capacity because waste management infrastructure is lacking.

Because access to finance for capital projects is a major obstacle, these countries can start reducing methane emissions by building basic infrastructure or implementing relatively low-cost operational improvements at the dumpsites. This can include developing small-scale decentralized organics processing facilities, limiting waste pickers' access to dumpsites, installing landfill covers, and installing basic GCCS. Example countries include the Dominican Republic, Guatemala, Nepal, Nigeria, Tajikistan, and Uganda.

The BtB+ archetype shares certain characteristics with BtB in their waste management approaches; however, BtB+ countries demonstrate relatively more advanced waste management practices. The main differences include higher collection rates and a noticeable progression from dumpsites to sanitary landfills. Although waste may be disposed of at dumpsites and illegal dumping and open burning may occur, countries in the BtB+ archetype have taken major steps toward improving their MSW management, such as building sanitary landfills or expanding existing waste management laws and regulations to address organic waste, advancing them beyond the BtB archetype. Example countries include Argentina, Brazil, Colombia, Ecuador, India, Mexico, the Republic of Serbia, and South Africa.

The MuH archetype is characterized by universal or near-universal collection rates and wide adoption of sanitary landfills with regulatory oversight and environmental control systems. Recovery and treatment of organic waste is minimal, but efforts are underway to reduce the generation of biodegradable waste at the source and expand organics recycling. Although standards may be in place to capture and control methane emissions, these countries can move up the waste management hierarchy through more robust regulations and improved emissions transparency to phase out organic waste disposal and reduce fugitive methane emissions from landfills while advancing efforts to prevent food loss and waste. Example countries include Australia, Canada, New Zealand, and the United States.

The CtC archetype is similarly characterized by universal or near-universal collection and disposal in sanitary landfills. However, CtC countries are the least reliant on landfills for final disposal due to the heavy reliance on WTE technologies that incinerate the waste and reduce the volume of waste disposed of at landfills. These countries have legislation in place that either bans landfilling of biodegradable materials or requires that biodegradable waste be stabilized before disposal. Although deploying WTE technologies largely avoids methane generation from the organic waste fraction, WTE facilities emit toxic air pollutants that have severe health impacts on nearby communities, and there is a missed opportunity to recover the carbon and plant nutrients. These countries can close the circle through food loss and waste prevention, organics diversion, and improved materials recovery. Example countries include Austria, Belgium, Finland, Germany, Japan, the Netherlands, Norway, Singapore, Sweden, and Switzerland.

Exhibit 8 Global MSW management archetypes

Build the Basics (BtB)

- Low to medium waste collection rates
- Limited or no source-separated organics or recycling
- Limited or no waste treatment
- Waste is disposed of at dumpsites
- Illegal dumping and open burning of waste are common

Build the Basics Plus (BtB+)

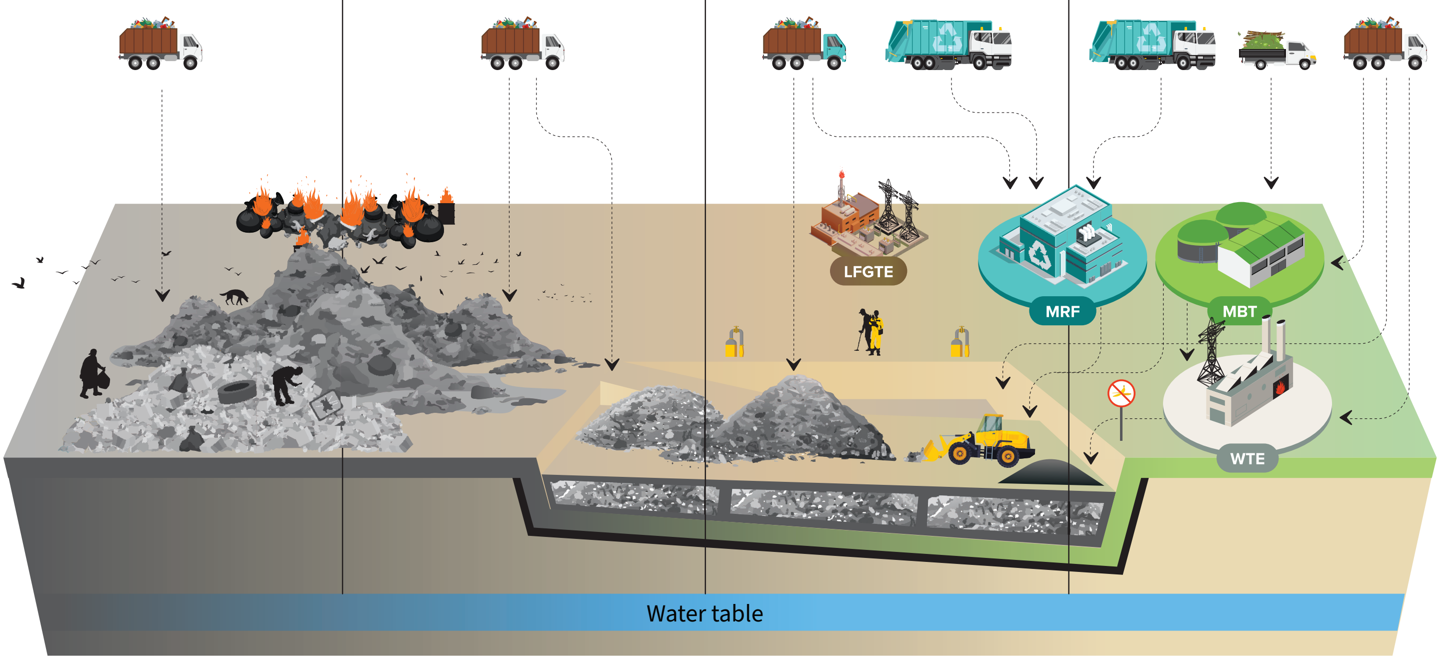
- Higher waste collection rate than BtB
- Limited or no source-separated organics or recycling
- Limited waste treatment
- Transitioning from dumpsites to sanitary landfills
- Illegal dumping and open burning of waste may occur

Move up the Hierarchy (MuH)

- Universal or near-universal waste collection
- Higher source-separated organics and recycling rates than BtB and BtB+; source-separated organics is still relatively limited compared to CtC
- Waste treatment and material recovery facilities are common
- Waste is disposed of in sanitary landfills
- Methane emissions monitoring and capture may occur

Close the Circle (CtC)

- Universal or near-universal waste collection
- In most CtC countries, source-separated organics and recycling rates are higher than in BtB and BtB+ countries and source-separated organics is mandated by law
- Most CtC countries have banned biodegradable waste from landfills
- Mechanical biological treatment and incineration of waste are common
- Least reliant on landfills



Waste collection, treatment, and disposal activities occur at different sites. Note that the primary outputs from the materials recovery facility and the mechanical biological treatment plant (e.g., plastics and biogas) are not depicted. The graphic has been simplified for illustrative purposes.

RMI Graphic. Source: RMI analysis

4. Methane Mitigation Strategies for Municipal Solid Waste Management Archetypes

The primary goal of waste management is to protect public health and the environment. However, the approach to waste management varies vastly around the world — from generation to collection and transport, to treatment, and final disposal. This is often evident in the waste management technologies deployed, the policy and regulatory framework, and the implementation of these systems. These differences in global waste management practices have been classified under four main archetypes. However, there is one commonality: except in some EU countries, waste management rarely focuses on sustainable management of biodegradable waste. Several near- and long-term opportunities exist across the value chain to improve how organic waste and the associated methane emissions are managed, regardless of the MSW management archetype. In this section, the authors outline an end-to-end strategy for driving deep methane cuts in the waste sector for each archetype — BtB, BtB+, MuH, and CtC — after the waste has been generated.

These abatement strategies are grouped into four building blocks, as discussed in Section 3. The building blocks are (1) source reduction, (2) waste diversion, (3) waste disposal, and (4) a crosscutting component. Source reduction and waste diversion strategies are implemented prior to waste reaching the disposal sites (pre-land disposal site); waste disposal strategies are implemented after the waste has reached the land disposal sites. Crosscutting solutions span the entire waste value chain and explore opportunities to improve policy and regulatory framework, emissions transparency, finance, and stakeholder awareness and capacity building.

This playbook is intended to provide a starting point for countries to design more robust solutions by tailoring these strategies to their local context.

Mitigating Methane Pre-Land Disposal Sites

4.1 Building Block — Source Reduction

Across the globe, managing waste relies primarily on disposal sites, with limited implementation of alternative management practices. Per the waste management hierarchy, waste prevention is the preferred option to manage waste, including organic waste. Waste prevention or source reduction describes any measures taken to minimize the generation of waste at the source. In the context of solid waste methane mitigation, these measures aim to reduce the generation of biodegradable waste and associated emissions.

Food and yard waste alone constitute 44% of global MSW. One-third of global food production by weight is lost or wasted between farm and table.[68] Studies show that if current trends continue, food loss and waste will double by 2050.[69] Reducing food loss and waste is not only beneficial to reducing methane emissions, it is also critical to addressing food insecurity and malnutrition. Further, it reduces economic losses for businesses and consumers and improves financial security for farmers.

As the largest component of the organic waste stream, **food waste prevention is the best and most preferred option to reduce methane emissions from MSW.** Understanding the drivers of food loss and waste, including poor distribution and storage infrastructure, suboptimal packaging, poor food management, and consumer behaviors, is necessary to develop robust methane abatement solutions. Tackling opportunities to reduce methane emissions before the waste is generated is beyond the scope of this report. However, several studies have explored robust solutions across the food loss and waste value chain, including near the farm, distribution, food processing, retail, and at the final consumer. Many organizations like ReFED and the World Resources Institute have identified priority interventions to reduce food loss and waste, including optimizing harvest, enhancing product distribution, optimizing product utilization, improving food rescue, and reshaping consumer behaviors.[70]

In the following sections, this report explores methane abatement strategies after the waste has been generated.

4.2 Building Block — Waste Diversion

Once waste has been generated, diverting biodegradable waste from disposal sites is the optimal strategy to reduce methane. Preventing biodegradable organic waste from reaching landfills and dumpsites avoids methane emissions from future waste streams. The diversion opportunities exist in the generation, collection and transport, and recovery and treatment phases.

Generation

Although significant improvements have been made over time in separating traditional recyclables like metals, glass, plastic, and paper at the source, many cities do not require households and commercial establishments to segregate food and yard waste at the point of generation. Where source segregation initiatives exist, waste generators are often unsuccessful at effectively separating organic materials due to a lack of awareness and difficulties in changing behavioral patterns.

Even within more advanced waste management archetypes like where SSO is more common, the use of WTE facilities incentivizes burning of organic waste, which can undermine source reduction and waste diversion programs. For example, in Japan, Singapore, and some EU countries, after recyclable materials like paper, plastic, glass, and metal are recovered, the residual waste (including organic waste) may be incinerated and the ash residue landfilled. In addition to discouraging source segregation, burning organic waste reduces the calorific value of the fuel due to the high moisture content of wet waste. Further, this represents a loss of carbon and plant nutrients (e.g., nitrogen) that could be applied to the soil. At the same time, incineration produces toxic air pollutants, which can increase the risk of cancers and birth defects and have other adverse impacts on public health and safety, especially for nearby communities.

Strategies to **separate organics from other waste components** at the point of generation are summarized in Exhibit 9. Note that the placement of an icon in this table and following tables denotes that the strategy is applicable to an archetype. For example, “implement SSO programs” is a methane mitigation strategy that is applicable to all four archetypes.

Exhibit 9 Methane mitigation strategies: Waste diversion, generation

Building block	Building block element	Methane mitigation strategy	BtB	BtB+	MuH	CtC
Waste diversion	Generation	Implement source-separated organics (SSO) programs				

RMI Graphic. Source: RMI analysis

Implement SSO programs

SSO programs aim to segregate organic waste at the point of generation (i.e., at the source). This can be introduced via pilots with large organic waste generators like restaurants, food markets, universities, and apartment complexes. Pilot initiatives allow implementers to test what works, document lessons learned, and prepare for deployment at scale. These programs should eventually be expanded to all waste generators.

SSO programs should provide waste generators with separate bins for food waste, yard trimmings, and other compostable organic waste with clear labels that distinguish biodegradable waste receptacles from other mixed waste and have separate collection. SSO programs should also consider whether to separate food waste from yard waste, or to collect food and yard waste in a single bin depending on if the processing facility is able to handle both types of biodegradable waste. It is also common to limit the size of the residual mixed waste bin and increase the size of the organics recycling bins to encourage greater segregation. Separating organics at the source reduces contamination of the waste feedstock during the treatment process and improves cost-effectiveness of organics recycling by avoiding the added cost of recovering biodegradable waste from the mixed waste stream. Further, these initiatives should include educational awareness campaigns to improve reception and encourage behavioral changes that enable effective segregation of organic waste. Additional details on educational awareness programs are provided below in the *Stakeholder awareness and capacity building* subsection.

Stakeholder roles and responsibilities:

- **Municipalities, local waste management authority, or service providers**: Implement SSO programs, provide color-coded bins, and conduct educational awareness initiatives on how to effectively segregate organic waste
- **Waste generators**: Segregate organic waste into designated color-coded bins for collection

Case Study: SSO Pilot Project in Kataragama Pradeshiya Sabha, Sri Lanka

As part of a technical assistance program, the Japan International Cooperation Agency (JICA) worked with the Central Environmental Authority of Sri Lanka to prepare solid waste management plans and implement pilot projects to promote SSO in selected local authorities including Kataragama Pradeshiya Sabha (KPS) between 2017 and 2019.

Before this project, KPS had already adopted a waste separation scheme that included segregating biodegradable waste from other mixed waste, but few residents and businesses followed the scheme due to lack of awareness of the rules and lack of clarity in disposal instructions. The pilot project reintroduced the SSO program in the first year. To improve understanding and compliance, KPS officials distributed new color-coded collection bins and bags to each household and business and provided instructions for effective separation of organic waste during the visit. The officials leveraged leaflets and noticeboards for continued awareness.

During this project, a new alternating-day waste collection schedule was also introduced, which reduced waste collection frequency. Residue mixed waste collection was reduced to three days per week compared with the previous daily collection, and biodegradable waste was collected four days of the week. This collection schedule indirectly encouraged timely separation of organic waste. The organic waste was treated in centralized composting facilities monitored by KPS staff to ensure correct separation and diversion from landfills. KPS also organized community leaders and businesses to visit the composting and final disposal facilities, furthering their sense of ownership and buy-in for the project.

Another important factor for project success was building capacity for solid waste management workers. To implement this project at KPS, new staff were hired, and regular training sessions were organized. JICA assisted in the development and improvement of training materials.

At the end of the first phase, a post-implementation survey showed improvement in the recovery and treatment of organics in pilot areas. From 2017 to 2018, while waste generation remained constant, the average amount of separated biodegradable waste received increased by 70%, exceeding the target of a 25% increase set in the Solid Waste Management Action Plan for 2018–22.[71] In the same period, the amount of waste disposed daily decreased by almost 80% from 1.4 to 0.3 tons.[72]

Enabling levers:

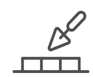
- Solid waste management plans with set targets of separate biodegradable waste collection
- Providing color-coded bins with clear instructions to waste generators
- Public awareness campaigns
- Reducing collection frequency of residual waste while increasing collection for biodegradable waste
- Monitoring of segregated organics for compliance
- Centralized composting facilities to treat organic waste
- Leveraging community leaders to secure buy-in
- Capacity building for waste management staff

Collection and transport

Waste collection systems connect communities to treatment and disposal facilities. Although SSO begins with the waste generator, keeping the waste segregated while transporting to the processing facility is necessary to minimize contamination. Existing collection trucks are unsuitable to haul the segregated organics due to contamination from the residual mixed waste — plastic, glass, and other undesired materials — and leakage from the wet fraction. Contaminated feedstock results in low-quality end products like compost and biogas that are undesirable and difficult to sell. Further, additional costs are incurred in removing impurities to improve product yield and economic viability of organics recycling. Strategies to **reduce contamination and optimize organics recycling** during collection and transport are summarized in Exhibit 10.

Exhibit 10

Methane mitigation strategies: Waste diversion, collection and transport

Building block	Building block element	Methane mitigation strategy	BtB	BtB+	MuH	CtC
Waste diversion	Collection and transport	Expand collection Infrastructure				
		Optimize collection frequency and routes				

RMI Graphic. Source: RMI analysis

Expand collection infrastructure

Collecting and transporting organic waste require specialized vehicles that are leakproof, have specialized containment for liquids, and address the corrosive nature of food waste, making traditional collection trucks less suitable.[73] Traditional collection trucks may be modified with new lifting systems and split-body truck beds, and equipped with tanks to contain liquids from spilling onto roads to allow dual-stream hauling of organic waste and mixed waste simultaneously.[74]

Municipalities and waste management companies should assess the capabilities of existing fleets to evaluate the need for these specialized vehicles. Where modification of an existing fleet is not suitable, purchasing specialized trucks is necessary to haul organic waste to processing facilities.

Optimize collection frequency and routes

To improve the overall efficiency and long-term sustainability of organics recycling, SSO programs must explore creative and cost-effective solutions to encourage high levels of participation as well as to transport the waste for processing. Reducing the collection frequency of residual mixed waste can encourage waste generators to properly separate biodegradable waste. A best practice is to collect food waste more frequently (e.g., daily or weekly) than the residual waste and other recyclables (e.g., every other day or week).[75] Waste haulers should assess the cost-effectiveness of collection routes and leverage existing routes where possible. For example, communities that already require separate collection of yard waste may leverage existing yard waste bins and collection routes to accommodate food waste and maximize collection efficiency.

Stakeholder roles and responsibilities:

- **Municipalities, local waste management authority, or service provider:** Evaluate existing collection infrastructure to assess infrastructure and investment needs and evaluate operations to optimize collection efficiency
- **Waste haulers:** Effectively handle segregated organics to minimize contamination
- **Investment community:** Provide funding to support capital and operating expenditures

Recovery and Treatment

The success of organic waste diversion will depend on the infrastructural capacity available to process and manage the diverted organic fraction. In many countries, the infrastructure to treat and convert organic waste into beneficial end products either does not exist or is insufficient. Strategies to **expand processing capacity for organic waste** and improve the recovery and treatment are summarized in Exhibit 11

Notably, the nonplacement of an icon in an archetype does not always mean the strategy is not applicable. For example, the notion that leveraging existing processing infrastructure is not applicable to BtB and BtB+ countries as indicated in Exhibit 11 does not imply that these facilities should not be leveraged, but rather that existing organics processing facilities are rare in these countries. A similar logic applies to subsequent exhibits in this section. A strategy that “does not apply” to an archetype indicates that the strategy is either incompatible with the current local waste management approaches or that countries within an archetype have made significant advancement already in this aspect, although further improvements can still be beneficial.

Exhibit 11

Methane mitigation strategies: Waste diversion, recovery and treatment

Building block	Building block element	Methane mitigation strategy	BtB	BtB+	MuH	CtC
Waste diversion	Recovery and treatment	Leverage existing processing infrastructure				
		Develop centralized and decentralized processing facilities				
		Support end markets for organic waste–derived product				

RMI Graphic. Source: RMI analysis

Leverage existing processing infrastructure

Municipalities and cities can improve the effectiveness of organics recycling by leveraging existing waste recovery and treatment infrastructures and optimizing their capacity. For example, digestion of food waste can occur in on-farm digesters, stand-alone digesters, or anaerobic digesters located at water resource recovery facilities (WRRFs). Of the 1,567 anaerobic digesters in the United States, about 80% are WRRF digesters.[76] The majority of these WRRF digesters already use biogas beneficially such as for heating; however, most are not co-digesting food waste. Adapting these digesters to co-digest food waste can help overcome significant infrastructural barriers, optimize capacity utilization, and improve efficiency gains and overall cost-effectiveness. Similarly, leveraging other existing infrastructure like yard waste composting facilities to co-process food waste can improve the cost-effectiveness of organics diversion technologies.

Develop centralized and decentralized processing facilities

Existing processing facilities alone are not sufficient to meet processing needs as segregation of organic waste expands. Developing AD, composting, and MBT facilities, as well as leveraging pretreatment technologies that reduce feedstock contamination and improve organics recovery prior to processing are essential. One such pretreatment solution leverages compressive force technology to extract food waste from SSO and residual mixed waste streams prior to treatment at an AD or composting plant.[77] Although not widely deployed, this technology already exists on the market and has use cases in Europe, India, and the United States. Technology providers claim up to 95% organics recovery rates.[78]

Both centralized and decentralized treatment facilities will play a role in improving organics recycling. Although centralized large-scale facilities require large capital investments that may pose a barrier to entry if funding is unavailable, these facilities can leverage economies of scale for cost savings if funding and feedstock are guaranteed.

A more cost-effective alternative for many low- and lower-middle-income countries and logistically hard-to-reach areas is to deploy small-scale decentralized solutions (e.g., on-site digester at a food and vegetable market or home composting). In addition to significant cost savings and a lower barrier to entry, they are easier to operate and maintain and do not pose the same space constraints often associated with securing land to build commercial-scale facilities. Municipalities and waste management companies should assess the economic viability of both options prior to project development to ensure solutions deployed are suitable to the local context.

Support end markets for organic waste–derived products

Methane abatement solutions will not scale if there are no robust end markets for these products. Support for end markets could include providing subsidies and tax credits for proven technologies to encourage more private-sector investment, leveling the playing field with competing products, creating an enabling policy environment, and other incentives to drive demand and in turn supply. End market analysis can provide unique insights to help assess limitations and risks for expanding markets for organic waste–derived products. For example, the private sector may be reluctant to invest in a project that converts biogas to electricity for connection to a central grid where there are no clear regulations on embedded generation. Understanding where these constraints exist is necessary to tailor unique solutions to enable organics-derived products to compete in the marketplace. Additional strategies to support robust end markets are discussed in the *Policy and regulatory framework* subsection.

Stakeholder roles and responsibilities:

- **Municipalities, waste management authority, and waste treatment facility operators:** Evaluate organics processing capacity requirements, develop new processing facilities or expand existing facilities, conduct project feasibility studies to assess technical and financial needs
- **Investment community:** Provide affordable financing to support capital and operational expenditures
- **Academic institutions, technology providers, engineering/consulting firms, and nongovernmental organizations (NGOs):** Provide capacity building to develop technical expertise for relevant stakeholders
- **Regulators and policymakers:** Create an enabling policy environment to support large-scale deployment of organics recovery and treatment technologies and the creation of robust end markets

Mitigating Methane at Land Disposal Sites

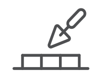
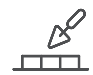
4.3 Building Block — Waste Disposal

For waste that has yet to reach disposal sites, source reduction and organics diversion strategies should always be prioritized. However, achieving high diversion rates often takes time due to slow implementation and behavioral patterns. Further, even if 100% diversion of organic waste is achieved, waste-in-place will continue to generate methane for years to come. Therefore, optimizing design and operation of landfills and dumpsites is the final opportunity to effectively capture and control the gas.

End-of-life disposal

Many landfills and dumpsites are not optimized to capture and control methane. Dumpsites, which are often found in BtB and BtB+ countries, do not have covers or gas collection systems, while those with sanitary landfills often do not have GCCS mainly due to poor project economics and lack of government incentives to build these systems. At the same time, many sanitary landfills in high-income countries also do not have GCCS. For example, in Canada and the United States, not all landfills are required to install GCCS. In addition to installing GCCS, other measures can be implemented to minimize fugitive methane emissions. Strategies to **optimize design and operations at disposal sites** to capture and control methane are summarized in Exhibit 12. A more comprehensive list of design and operational practices can be found in RMI's *Key Strategies for Mitigating Methane Emissions from Municipal Solid Waste.*[79]

Exhibit 12 Methane mitigation strategies: Waste disposal, end-of-life disposal

Building block	Building block element	Methane mitigation strategy	BtB	BtB+	MuH	CtC
Waste disposal	End-of-life disposal	Minimize surface area of the active working face				
		Install daily cover				
		Install intermediate and final covers				
		Utilize biocovers or biofilters to oxidize methane				
		Install GCCS and optimize gas collection and flare efficiency				

RMI Graphic. Source: RMI analysis

Minimize surface area of the active working face

Reducing the surface area of the exposed waste (i.e., without daily covers) where waste is actively received can slow down the release of emissions. However, this should be complemented by applying daily cover at the nonworking area (i.e., areas not actively receiving waste).

Install daily cover

Landfill covers minimize odors and deter scavenging, limiting disease-carrying vectors and protecting public health. Daily covers are often made of soil and used overnight in active areas of the land disposal site.[80] Installing landfill covers at the end of each day restricts the migration of methane emissions from the underlying waste to the surface and atmosphere. Non-soil materials may also be used as daily covers; these alternative daily covers include materials like compost, green waste, paper mulch, or shredded tires.[81]

Install intermediate and final covers

For more extended periods where the cell or area is not accepting waste for a few months, interim or intermediate covers should be placed over completed lifts. Final covers are more permanent and should be installed in areas that are no longer actively accepting waste.

Utilize biocovers or biofilters to oxidize methane

Biocovers are vegetative covers with unique microbial properties that oxidize fugitive methane to CO_2. Biocover materials include compost, mechanically biologically treated waste, dewatered sewage sludge, or yard waste.[82] Where GCCS have not been installed, biocovers can help reduce fugitive methane emissions; the biofiltration properties also reduce fugitive emissions at sites with gas collection systems, where capture efficiency is imperfect. These covers can be installed to complement an active gas collection system or at sites without GCCS but should not be considered an alternative to installing a gas collection system.[83]

Install GCCS and optimize gas collection and flare efficiency

Many dumpsites and landfills do not have GCCS. The system can recover gas through wells and pipelines for beneficial end use or destroy the gas in a controlled flare. Basic, low-cost GCCS can be deployed at dumpsites mainly found in BtB and BtB+ countries. Even in high-income countries where these GCCS are more common, not all landfills are fitted with gas capture systems, and where installed, the efficiency of the system can vary dramatically, with studies showing capture efficiencies ranging between 20% and 90%.[84] Although several factors may impact gas capture efficiency, measures can be implemented to optimize gas collection. Gas collection systems are often operated manually via a well tuning process that entails measuring gas composition and flow, temperature, and pressure and manually adjusting the system to minimize oxygen intrusion, fire incidents, and methane leaks.[85] This manual process can be optimized using a technology that automates the well tuning and adapts to well conditions.

Several other strategies may be implemented to improve gas collection depending on site conditions. Landfill engineers can work with operators and facility managers to design strategies suited to individual sites. Although preference should be to recover the gas for end use, where this is not feasible, utilizing high-efficiency flares ensures the gas is thermally destroyed and converted to CO_2, thereby avoiding directly venting methane.

Stakeholder roles and responsibilities:

- **Landfill and dumpsite operators:** Implement best management practices to improve design and operation of sites to minimize fugitive emissions; assess financial and technical needs for facility upgrades
- **Landfill engineers, technology providers, waste management consulting firms, and NGOs:** Identify design and operational improvement opportunities for disposal sites; develop technical expertise on how to operate and maintain GCCS and other technologies to optimize methane mitigation at disposal sites
- **Investment community:** Provide affordable financing to support infrastructure upgrades and operational improvements
- **Regulators and policymakers:** Create an enabling policy environment to facilitate the adoption of measures that minimize fugitive emissions at land disposal sites such as mandating the installation of GCCS

Mitigating Methane Pre-Land Disposal Sites and at Land Disposal Sites

4.4 Building Block — Crosscutting Component

The strategies discussed above do not include opportunities to reduce methane emissions that often span the entire waste management value chain. These crosscutting opportunities include developing robust policy and regulatory frameworks, enhancing emissions transparency, improving access to finance, and furthering stakeholder awareness and capacity building. This section explores these crosscutting solutions to improve organic waste management and optimize methane capture and control.

Policy and regulatory framework

Solid waste management standards are developed with a focus on public health and safety and generally regulate hazardous toxic air pollutants that do not include methane. In other instances where methane regulations exist, there is the need for more robust standards that promote organic waste diversion, enhance the capture and control of methane at the disposal site, and improve transparency of methane emissions from the waste sector. These frameworks should also incentivize the creation of sustainable end markets for waste-derived products like biogas, compost, electricity, and transportation fuel. An enabling policy environment will increase investor confidence and further mobilize private-sector investment. Strategies to **promote an enabling policy and regulatory environment** are summarized in Exhibit 13.

Exhibit 13 Methane mitigation strategies: Crosscutting component, policy and regulatory framework

Building block	Building block element	Methane mitigation strategy	BtB	BtB+	MuH	CtC
Crosscutting component	Policy and regulatory framework	Set minimum thresholds for mandatory source segregation for large waste generators	✓	✓	✓	✓
		Phase out organic waste disposal	✓	✓	✓	✓
		Ban incineration of recyclable materials including organic waste			✓	✓
		Implement landfill taxes and pay-as-you-throw (PAYT) models	✓	✓	✓	
		Integrate the informal recycling sector	✓	✓		
		Develop procurement standards and set purchase targets for organics-derived products	✓	✓	✓	✓
		Develop landfill design, operational, and monitoring standards to capture and control methane	✓	✓		
		Require GCCS at disposal sites	✓	✓	✓	✓
		Require more frequent emissions monitoring		✓	✓	✓
		Adopt policies that encourage the use of advanced monitoring technologies			✓	✓
		Mandate greenhouse gas reporting	✓	✓		
		Implement compliance mechanisms	✓	✓		
		Streamline permitting and zoning process for critical infrastructure projects	✓	✓	✓	✓

Policies on waste diversion | Policies on waste disposal | Policies on emissions transparency | Other policies

RMI Graphic. Source: RMI analysis

Set minimum thresholds for mandatory source segregation for large waste generators

This threshold (e.g., amount of waste generated or seating capacity at a restaurant) should target large generators such as restaurants, food and vegetable markets, and academic institutions. Mandatory participation thresholds should be informed by qualitative and quantitative analysis and consider local context to optimize organics diversion. Mandatory source segregation should eventually be expanded to all waste generators.

Phase out organic waste disposal

Most countries have no national or subnational policies to prevent landfilling of organic waste. Enacting policies that prohibit biodegradable waste from reaching disposal sites effectively ensures that the waste is collected and pretreated so that only the nonorganic residual waste is disposed of. This ban should be phased in with interim milestones and a timeline to allow jurisdictions to develop a comprehensive plan, allocate resources, secure sufficient treatment capacity, and allow time for proper acclimatization to support implementation. Some examples of jurisdictions that have successfully banned organic waste disposal include Austria, South Korea, and the state of Vermont in the United States.

Ban incineration of recyclable materials including organic waste

Although incineration eliminates the methane generation potential of any residual waste sent to landfills, this technology is unsuitable to treat organic waste. High moisture content from wet biodegradable waste reduces the calorific value of the fuel and the nutrients from the organic waste are lost. Further, WTE technologies produce toxic air pollutants like lead, mercury, acidic gases, and particulate matter, which can lead to severe health conditions like cancer and birth defects, especially in nearby and often marginalized communities, if not properly fitted with technology to remove these pollutants.[86]

In high-income countries in Europe as well as Japan and Singapore where incineration with energy recovery is widely adopted, instituting policies that prevent organic waste from being incinerated can drive the adoption of solutions at the top of the waste hierarchy like source reduction and organic waste recovery. Further, WTE technologies are an expensive way of managing waste because more cost-effective and sustainable solutions exist.[87] For these reasons, incineration of recyclables and organic waste should not be considered in countries where the technology is not currently deployed.

Implement landfill taxes and PAYT models

Landfill taxes and PAYT models are effective policy instruments to reduce reliance on landfills and incentivize waste reduction and diversion. A landfill tax, which is usually levied based on the volume or weight of waste disposed of at the landfill, is paid in addition to normal landfill charges. Although the landfill tax is charged to the operator, these costs are eventually passed on to the waste generator as higher user charges. Landfill taxes have been successful at reducing landfilling; however, adequate infrastructure for alternative waste management practices like recycling is necessary to avoid illegal dumping of waste. Apart from generating revenue, reduced reliance on landfills could reduce the expense of managing the environmental impacts of landfills.[88] PAYT models follow a similar principle, where the user charge is based on the volume of the waste disposed, creating a financial incentive for waste generators to send less waste to the landfill.

Case Study: Integrated Waste Management Planning in Austria: Creating an Enabling Policy Environment

Austria has been a leader in setting ambitious goals in improving waste management and implementing effective waste management policies and programs based on the waste management hierarchy. According to the European Environment Agency, Austria has already met both targets in the European Union directives with a 62% waste recycling rate and 9% waste landfill rate.[89]

Source reduction is the highest priority in the Austrian waste management system. The Federal Waste Management Plan, which was first implemented in 2011 and subsequently updated every six years, details the key principles of waste management in Austria and the prevention measures of different waste streams. Regarding food waste, Austria aims to halve it at the consumer and retail levels by 2030. Several initiatives have been implemented to encourage mindful food consumption and more efficient distribution of resources, such as the "Food Is Precious" initiative at the federal level. With improved distribution of resources, organizations, businesses, and individuals work together to prevent food waste at the source.[90]

Austria has a long history of incentivizing and requiring organic waste diversion from landfills. A landfill tax was first introduced in 1989 and went through several amendments in the decades that followed. Currently, 85% of the landfill tax collected is used for site remediation activities and 15% is used for data gathering purposes, mostly targeting problem sites.

In 2009, Austria introduced an "organic waste ban" on waste with total organic carbon content of over 5%, effectively banning all MSW from being landfilled without pretreatment. Combined with existing source separation of biodegradable waste in cities across Austria, these mechanisms effectively encouraged the recovery of organics and waste diversion from landfills.

Economic incentives, policies, and regulations, together with effective public awareness campaigns that align with the Federal Waste Management Plan, have led Austria to be recognized as one of the leading examples of effective organic waste management. This EU member state is also considering refinements to these policies that can drive the country toward a circular economy and improved resource efficiency.

Enabling levers:

- A Federal Waste Management Plan that details key principles based on the waste management hierarchy
- Ambitious goal setting at the EU and national levels including halving food waste by 2030
- Targeted initiatives to reduce food waste at the source
- Strong regulatory framework (i.e., landfill tax and organic waste ban) to promote organics diversion
- Effective public awareness campaigns

Integrate the informal recycling sector

For BtB and BtB+ countries, the informal recycling sector or waste pickers are a critical component of the value chain. Waste pickers recover valuable recyclables like glass, metal, and plastics either before collection by waste haulers or at the dumpsites to sell for a small profit. Because formal recycling facilities are often limited in these countries, informal workers are sometimes the only opportunity to recover these recyclable materials. Unfortunately, these waste pickers often face social discrimination, risk of injury from unsafe environments, risk of illness from exposure to toxins, and economic vulnerability.
Integrating these workers into the planning of local waste management systems will provide a more secure income stream, safer working conditions, and more accurate waste inventory, and will improve data tracking.[91] Further, these workers can be trained to better understand the environmental and economic importance of recovering this waste and subsequently play an important role in public awareness campaigns by helping educate their households and community about organics recycling initiatives.

Develop procurement standards and set purchase targets for organics-derived products

Procurement standards can help create product trust by establishing a minimum quality and safety threshold for any procured products. In addition to developing procurement standards, procurement policies can be a powerful instrument to help spur end market creation by aligning public spending with policy objectives and incentivizing private-sector investment. These policies can include purchase targets that require government agencies to procure organic-waste-derived products like compost or biogas, require jurisdictions to meet a minimum purchase threshold (e.g., annual tons of compost purchased), or prioritize purchase of locally produced end products to support the local economy. For example, Washington State law mandates that localities prioritize the purchase of compost produced locally.[92]

Develop landfill design, operational, and monitoring standards to capture and control methane

Many BtB and BtB+ countries have not developed standards for designing, operating, and monitoring landfills to capture and control emissions from methane. These standards can promote health and safety by establishing minimum design and operating requirements for active and closed landfills for waste management companies or municipalities that own and/or operate these facilities. Although not exhaustive, these standards should mandate early installation of GCCS, use of landfill covers, frequent methane monitoring, and leak repair, where applicable.

Require GCCS at disposal sites

After anaerobic conditions are established, organic waste decomposes and generates LFG. This gas can be collected through wells and pipeline systems; the recovered gas can be used to generate electricity, used as fuel for other heavy machinery like cement kilns, or destroyed in a controlled flare. Although GCCS are not commonly deployed in BtB and BtB+ countries, which mainly have dumpsites, basic, low-cost GCCS can be installed at these facilities. However, to ensure effectiveness of these systems, limiting waste pickers' access to dumpsites to avoid damage or fire incidents, installing daily covers, and hiring and training personnel to correctly operate and maintain these systems are important. Even in MuH and CtC countries where GCCS are more commonly deployed, GCCS are typically only required after landfills reach a minimum threshold (e.g., design capacity, emissions of nonmethane organic compounds, and concentration of surface methane).[93] In the meantime, landfills continue to release methane prior to reaching this threshold, which can take several years. Lowering the applicability threshold of mandatory GCCS to include these exempted landfills and requiring earlier and more timely installation underpin opportunities to improve methane capture.

Require more frequent emissions monitoring

The absence of timely detection and quantification of methane results in an inability to inform operational improvements at the landfill. Frequent monitoring as required by law compels landfill operators to detect emissions events in a timely manner and take corrective actions such as repairing methane leakage. Where SEM exists, it follows a cadence, often quarterly. As a result, emissions events can often go undetected for months. Increased monitoring frequency (e.g., monthly) paired with mandatory corrective actions within specified timelines will reduce the lag time in locating and fixing these leaks. Where mandating emissions monitoring is not feasible (e.g., at open dumpsites), it is essential to develop other design and operational standards to capture and control methane. In addition, these regulations should be expanded to include emissions monitoring at organics processing facilities, many of which are currently not monitored. This will help avoid simply shifting methane emissions from disposal sites to organics processing facilities.

Adopt policies that encourage the use of advanced monitoring technologies

Emissions monitoring technology deployment is primarily driven by regulations. For example, certain US landfill operators must conduct quarterly SEM by walking the landfill surface in a serpentine pathway using a gas analyzer to detect an exceedance in methane concentration. This prescriptive framework, although commendable relative to countries without such frameworks, is labor-intensive and time-consuming to execute and excludes monitoring any emissions from the active working face of the landfill — which are often sources of methane — due to health and safety concerns. Expanding existing frameworks to allow the use of advanced monitoring technologies like aircrafts, drones, satellites, ground vehicles, or continuous towers can optimize coverage and detection by scanning a larger surface area and accessing the hard-to-reach areas of the landfill like slopes and the active working face. Leveraging these technologies (either as an alternative or in tandem) to meet regulatory requirements can unlock further opportunities to optimize emissions detection and reduce fugitive emissions.

For BtB and BtB+ countries, deploying advanced monitoring technologies can be cost-prohibitive for many municipalities. Further, these technologies are not suited for frequent deployment at many dumpsites, which are typically unmanaged with no covers or gas collection systems. Although deploying certain advanced monitoring technologies may also be cost-prohibitive for municipalities in high-income countries, these technologies are increasingly being deployed voluntarily in Canada and the United States. However, they have not been widely adopted in the waste sector primarily due to high cost and/or lack of regulatory requirements. Incorporating these technologies into existing regulatory frameworks will further improve adoption. For instance, in the United States, the EPA recently introduced a super emitter response program in the oil and gas sector, in which the EPA will leverage data collected by third parties to identify large emissions events known as “super emitters” and require operators to investigate and repair any large leaks or releases.[94] Such programs may be extended to the waste sector to encourage the adoption of advanced monitoring technologies and optimize methane mitigation.

Case Study: Improving Methane Leak Detection and Repair by Leveraging Advanced Monitoring Technologies in California

Advanced methane monitoring technologies can complement the current SEM framework, enabling more comprehensive landfill coverage. As part of its research effort, the California Air Resources Board (CARB) has deployed remote sensing technologies for methane leak detection and repair for several years. The California Methane Survey conducted in 2016–18 was the first large-scale demonstration of hyperspectral remote sensing of methane, covering 80% of the known methane-emitting infrastructure in all sectors. In the waste sector, the survey found methane plumes at 30 landfills and two composting facilities with an average emission rate of 818 kg/hour, demonstrating massive mitigation potential.[95]

In 2020 and 2021, two additional airborne surveys were conducted by CARB and its collaborators. In 2020, landfill operators were voluntarily enrolled in the study and informed of methane observations at their facility for repair. More than half of the detected incidents were reported to operators, and more than 90% of the operators responded to the voluntary request for mitigation and about half of the leaks were successfully repaired.[96] Methane plume notification enabled by advanced monitoring technologies significantly reduced operator response time to implement corrective measures.

These experiences have not only supported continued investment in advanced methane monitoring technologies in California, they have also informed potential updates to the Landfill Methane Regulation. One of the key updates CARB is considering is making the voluntary Super Emitter Response Program mandatory by requiring ground monitoring and mitigation when a leak is detected by remote sensing and the operator is notified.[97] At the same time, a process to evaluate and approve the use of new technologies such as drones to supplement SEM is currently being considered.

Enabling levers

- Notifying operators of methane plume detection enabled prompt corrective actions
- Effective coordination between key stakeholders (technology provider, regulator, and operators) enables methane mitigation
- Airborne surveys are necessary to inform regulations that enable the adoption of advanced monitoring technologies
- Absent mandatory regulatory requirements, voluntary programs can promote deployment of advanced monitoring technologies

Mandate GHG reporting

Emissions mitigation would be more effective when there is a solid and comprehensive baseline for current conditions and when most emissions sources are known and measured; therefore, national and subnational authorities should mandate GHG reporting. The reported data can then be used to guide policymaking and implementation as well as to prioritize financial investment and allocate resources to locations that need them most. Mandatory GHG reporting can also lead to regular updates to the emissions inventory, which can serve as a mechanism to track progress of emissions reduction initiatives.

Implement compliance mechanisms

Regulations are only effective when enforced. Poor implementation and enforcement of rules may be due to a lack of awareness, limited capacity to enforce rules, corruption, or the absence of consequences for noncompliance. Compliance mechanisms may include curbside container audits, utilizing radio-frequency identification technology to scan curbside containers for compliance, ad hoc facility inspections, issuing notice of violations with plans for corrective action, and fines and penalties. Funds collected from noncompliance penalties can be devoted to other waste management initiatives.[98]

Streamline permitting and zoning process for critical infrastructure projects

One major challenge that can discourage project implementation is the long delays in securing new permits or upgrading existing permits. Although some of these delays are due to important community or other environmental and safety concerns that need to be comprehensively addressed, permitting and zoning should be more flexible and favorable to reduce delays. This may be achieved by exempting small-scale operations that accept food and yard waste from permitting while still requiring compliance with site and operational requirements. For example, in the US state of Iowa, composting facilities can accept up to 2 tons of food and yard waste each week without a solid waste permit.[99] Alternatively, implementing a tiered approach to permitting and operational requirements can help limit more stringent requirements to larger facilities. At the same time, state and local laws should facilitate favorable zoning for large-scale processing facilities to enable new development or upgrades to existing facilities.

Enhanced coordination among government agencies can also help streamline these processes. More broadly, close collaboration and improved coordination among agencies with jurisdictional overlap can enable continuity of methane abatement projects. This is often critical where there is a high rate of turnover of staff and government administrations, which can hinder project implementation. Creating an independent nonpolitical waste authority can mitigate these risks of changes in political leadership.

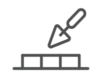
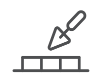
Stakeholder roles and responsibilities:

- **Regulators and policymakers:** Create an enabling policy environment; evaluate and update waste and emissions management policies and regulations to reflect advancements in methane mitigation technologies; consult the public sector, private sector, civil society, and impacted communities during rulemaking process; increase awareness on new policies and regulations
- **Public sector, private sector, civil society, and impacted communities:** Comply with existing and new policies and regulations; provide input into rulemaking process, where applicable
- **Academic institutions, waste experts, technology providers, infrastructure consulting firms, and NGOs:** Increase awareness of existing and new policies and regulations; comply with regulations

Emissions transparency

Limited data availability, including waste characterization, waste flow, and emissions data in many countries and cities, makes it more challenging to conduct efficient planning of waste management systems and to estimate emissions using LFG estimation models. Comprehensive and up-to-date data, that is available to the public, can facilitate the identification of methane abatement opportunities and the deployment of technical and financial resources needed to implement solutions. Strategies to **improve emissions transparency** are summarized in Exhibit 14.

Exhibit 14 Methane mitigation strategies: Crosscutting component, emissions transparency

Building block	Building block element	Methane mitigation strategy	BtB	BtB+	MuH	CtC
Crosscutting component	Emissions transparency	Conduct and/or update waste characterization studies				
		Collect robust waste sector data				
		Leverage advanced monitoring technologies to improve emissions quantification				
		Make waste and emissions data and methodology publicly available				

RMI Graphic. Source: RMI analysis

Conduct and/or update waste characterization studies

Waste characterization involves analyzing the components of a waste stream. These studies provide insights that inform waste management planning and enable jurisdictions to prioritize waste treatment interventions and infrastructure needs. Oftentimes, waste characterization data is limited, unavailable, or outdated, and hence may not provide an accurate representation of the waste situation. Waste characterization studies should be conducted regularly to enable more accurate assessments of the waste components, which in turn inform waste management planning and emissions estimates, especially where emissions monitoring technologies cannot be deployed.

Collect robust waste sector data

In addition to waste composition, collecting robust waste data such as waste generation, waste flow, waste-in-place, landfill size, site status, landfill or dumpsite capacity, and amount of LFG collected is critical to aid planning, operation, and maintenance of waste management systems. Several frameworks for collecting and reporting waste data, like the UN Habitat Waste Wise Cities Tool, the Climate and Clean Air Coalition Data Collection Tool for Urban Solid Waste Management, and the City MSW Rapid Assessment

Data Collection Tool, can help guide municipalities and waste management companies in developing a robust waste inventory.[100] Further, insights generated from the data should be shared with stakeholders that help compile the datasets to show how the data is being used and secure further buy-in.

Leverage advanced monitoring technologies to improve emissions quantification

Landfill emissions are usually estimated using an LFG estimation model, which is based on a first-order decay principle, to quantify methane generation potential and methane generation rate. Such models often rely on default parameters that may not accurately reflect conditions at the facility level and thus lead to inaccurate estimates. Studies have shown discrepancies between airborne surveys and model estimates.[101] Research efforts have also demonstrated that leveraging advanced monitoring technologies including aircraft, satellite, continuous, and near-ground technologies can improve the understanding of emissions, which can be used to validate and enhance existing models, and identify abatement opportunities — at individual sites and through policy.[102] Research is ongoing to better understand how these technologies can inform annual inventories because they typically quantify emissions at a snapshot in time. Although these technologies may be too expensive to deploy for some municipalities and landfill operators, advanced monitoring data may be available at little or no cost for some disposal sites. For example, some satellite and aerial observations are publicly available at no cost, such as data from Netherlands Institute for Space Research, Carbon Mapper, International Methane Emissions Observatory, and others. Nonetheless, this suite of technologies can be deployed today to reduce estimation uncertainty, enhance emissions transparency, and inform on-the-ground mitigation actions.

Make waste and emissions data and methodology publicly available

Updating waste characterization studies, collecting robust waste sector data, and improving emissions estimates are essential to enhancing emissions transparency in the sector. However, it is equally essential to make this data accessible to the public. Increased data transparency lowers the barrier for interested stakeholders to derive insights that can inform policies and infrastructure needs. The data can also hold relevant parties accountable against key performance indicators such as percent of waste diverted or percent emissions reduction. Improved transparency also promotes a sense of shared responsibility among the public. Further, by making the methodology for collecting, compiling, and estimating the data available, users can better understand differences in methodologies to enable more accurate comparison of different data sources.

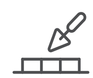
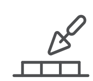
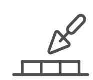
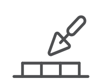
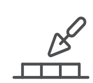
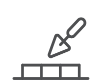
Stakeholder roles and responsibilities:

- **Regulators and policymakers:** Create an enabling policy environment to facilitate increased waste and emissions data transparency and promote the deployment of emissions monitoring technologies
- **Waste service providers, facility operators, and technology providers:** Develop robust inventories for waste and emissions data, update data regularly, and make data publicly available
- **Academic institutions, consultants, and NGOs**: Coordinate with relevant stakeholders to conduct waste characterization studies, provide input on improving data access and data accuracy, where applicable, and evaluate data for insights

Finance

Many countries do not have sufficient infrastructure to collect and treat organic waste or adequate gas capture solutions. Developing and scaling these technologies require significant investment. At the same time, continued citizen engagement and educational awareness programs also require funding. High up-front cost is often a major barrier to deploying methane mitigation technologies because many municipalities, facility owners and operators, and service providers cannot afford or justify these costs, especially if implementation is not a regulatory requirement. Access to affordable finance will enable infrastructural upgrades and accelerate the deployment of methane abatement solutions. Strategies to **improve access to affordable finance** are summarized in Exhibit 15.

Exhibit 15 Methane mitigation strategies: Crosscutting component, finance

Building block	Building block element	Methane mitigation strategy	BtB	BtB+	MuH	CtC
Crosscutting component	Finance	Provide subsidies for proven technologies				
		Provide affordable finance				
		Reduce the cost of finance through risk sharing mechanisms such as blended finance				
		Develop or access project preparation facilities				
		Guarantee revenue through procurement contracts and offtake agreements				
		Improve profitability by diversifying revenue streams				
		Improve cost recovery through PAYT models and other innovative pricing and tariff structures				

RMI Graphic. Source: RMI analysis

Provide subsidies for proven technologies

Subsidies are direct or indirect financial assistance provided by governments to lower the cost of products and commodities to make them more affordable to the consumer.[103] Subsidies, which can take several forms such as cash, grants, tax credits, or interest-free/low-interest loans, can support capital investments such as the purchase of equipment and machinery (i.e., investment subsidies) or can help bridge the gap to cover financial losses due to non-cost-reflective pricing (i.e., operating subsidies).[104] Subsidies can be an effective fiscal tool, particularly in nascent markets, to facilitate private-sector investment; enable large-scale deployment of organic waste treatment technologies, gas capture technologies, or other technological solutions that reduce landfill methane; and help waste-derived end products (e.g., biogas) become cost-competitive with alternative solutions (e.g., fossil-based fuel). Subsidies have helped technologies like solar photovoltaics and batteries to become commercially viable and attract private investment.[105]

Provide affordable finance

Accessing affordable finance to support waste management projects can be difficult, particularly for BtB and BtB+ countries. This could be due to several reasons such as perceived market risks in nascent markets, high-interest loans, nonbankable projects, foreign exchange volatility, or a lack of awareness of available funding programs. Grant foundations, donors, governments, and development finance institutions (DFIs) can play a critical role in bridging this gap by providing favorable financing terms such as philanthropic funding, grants, concessional loans, and loan guarantees to support technology adoption in emerging markets. This can help foster private-sector investment by lowering the entry barrier for new players, reduce the risks posed by nascent markets, accelerate technology adoption, and help achieve investment returns within a shorter time frame.[106]

Reduce the cost of finance through risk-sharing mechanisms such as blended finance

Blended finance is an approach to financing, rather than a specific financing mechanism, that combines different sources of funding, each with distinct objectives and risk tolerance. This type of financing often has an objective where public or philanthropic funding is used to attract and catalyze private-sector investment.[107] Because this approach lowers the overall risk associated with an investment, it can leverage diverse funding sources such as public, private, philanthropic, and other sources of capital like DFIs and multilateral banks.[108] Funding sources may also include carbon or climate finance. Blended finance has been crucial in climate investments and the waste sector because it allows recipients to also access expertise and resources on financial readiness to help in the preparation of a project, making it more technically and financially viable.

Develop or access project preparation facilities

A project preparation facility (PPF) can help unlock public, private, or alternative sources of finance by preparing investment-ready projects. PPFs may provide a range of support to project owners including conducting prefeasibility and feasibility analyses, developing engineering designs, developing procurement guidelines and best practices for navigating permitting and regulatory processes, improving technical capacity among project owners, and facilitating private-sector investments.[109] These PPF-provided services help de-risk waste infrastructure projects, making them attractive to public and private investors and financial institutions.

Case Study: The Waste Management Flagship Programme in South Africa: A Project Preparation Facility

In August 2018, the Green Climate Fund approved a project preparation funding proposal for the Waste Management Flagship Programme in South Africa. Based on the strategies for increasing solid waste diversion from landfills developed by the Department of Environmental Affairs of South Africa in partnership with the German development agency GIZ, the proposal aimed to pilot five alternative waste treatment (AWT) technologies in six selected municipalities, with planned deployment to 30 municipalities over its 20-year implementation period. The five AWT technologies are AD, open windrow composting, in-vessel composting, containerized composting, and nutrient upcycling.

In the two-year period of project preparation, funding from the Green Climate Fund would support activities in the six selected municipalities to carry out site identification and confirmation, a prefeasibility study, and an environment and social impact assessment. Then, an analysis on environmental authorization and permitting procedures would be conducted, as well as detailed techno-economic assessment of each facility. After project preparation, 70% of the capital expenditures for the construction of each facility would be through grant funding and the remainder through government funding.

During preparatory activities and implementation of pilots in the six municipalities, standardized procedures and documents would be developed. At the same time, piloting five AWT technologies in the same portfolio would demonstrate the possibility for different pathways toward diverting waste from landfills, thereby stimulating market appetite and private investment and providing a comparison between different use cases.

Documentation on the progress of this flagship program is limited, but with the variety of AWTs included in the pilot and the lessons learned through preparatory activities, successful implementation of this flagship program can promote prioritization of organic waste diversion and treatment in South Africa.

Guarantee revenue through procurement contracts and offtake agreements

Procurement contracts and offtake agreements can lower market risks and improve viability of organics-derived end products by guaranteeing a steady inflow of revenue for municipalities and waste management service providers. Such binding agreements can reduce the burden on the seller to recover costs while providing a guarantee of product and revenue for the buyer and seller, respectively.

Improve profitability by diversifying revenue streams

From the perspective of financial institutions, cost recovery is the most critical component in evaluating the suitability of a project for financing.[110] However, many municipalities struggle with recovering costs for waste management projects because user charges alone are often insufficient to cover the costs of operations. Municipalities and waste management service providers must balance tariffs affordability with the need to recoup investments. Affordability constraints are common in BtB and BtB+ countries, which often result in user charges that are set below cost recovery rates.[111] This may also be the case in rural towns and low-income communities in high-income countries. Although local context will determine the most suitable approach for cost recovery, service providers can often improve profitability by diversifying revenue streams. These could include tipping fees and income from the sale of recyclables and organics-derived products like compost and biogas.

Carbon finance and markets can also be an additional revenue source to finance methane mitigation projects. Most notable is the Clean Development Mechanism in which carbon credits were traded to fund emissions reduction projects in developing countries, including waste management improvements mainly related to LFG capture and use; revenue generated was used to finance operations the following year.[112] Although expired, the Clean Development Mechanism scheme underscores the need for similar carbon markets and emissions trading mechanisms.

Improve cost recovery through PAYT models and other innovative pricing and tariff structures

The ability and willingness to pay for waste management services often vary across customers, with high-income communities demonstrating a higher ability and willingness to pay than lower-income communities. Waste service providers can explore creative models to improve service fee collection. For example, PAYT pricing models can improve profitability by lowering the total volume of waste handled and more closely aligning user charges with cost-reflective tariffs. Other than direct user charges, service providers may also explore alternative cost recovery models like incorporating waste service fees into other utility bills that have a higher payment collection rate such as electricity, water, or sewage bills. Several countries in the LAC including Colombia, Ecuador, El Salvador, Panama, and Venezuela recover solid waste management cost using this means.[113] Other pricing structures could include charging higher tariffs in high-income communities to subsidize lower-income customers.

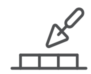
Stakeholder roles and responsibilities:

- **Investment community:** Provide affordable finance with favorable financing terms for investment-ready projects. Specifically, foundations, donors, and DFIs can provide grant funding, and DFIs and green banks can provide concessional loans and loan guarantees and support project pipelines
- **National and subnational governments:** Provide grant funding, subsidies, and tax credits to support mitigation projects
- **International bodies and national governments:** Establish a carbon marketplace to support financing of emissions reduction projects
- **Regulators and policymakers:** Create an enabling policy environment to mobilize private-sector investment, for example, eliminating import duties and fees and providing tax exemptions on methane mitigation technologies
- **Waste service providers, engineering firms, consultants, and NGOs**: Work collaboratively to conduct feasibility assessments and develop investment-ready projects

Stakeholder awareness and capacity building

Lack of awareness among various key stakeholder groups including dumpsite managers, landfill operators, regulators and policymakers, and the public can impede the implementation of best management practices. Be it promoting behavioral changes to improve SSO, deploying compactors and landfill covers at dumpsites, installing automated wellhead tuning devices to optimize gas collection at landfills, or implementing more robust regulatory frameworks, targeted educational awareness and capacity-building initiatives can promote deeper understanding of solid waste management and its link to climate change and public health, which in turn encourages reception and better decision-making at every level. Strategies to **enhance technical capacity and awareness** among key stakeholders are summarized in Exhibit 16.

Exhibit 16 Methane mitigation strategies: Crosscutting component, stakeholder awareness and capacity building

Building block	Building block element	Methane mitigation strategy	BtB	BtB+	MuH	CtC
Crosscutting component	Stakeholder awareness and capacity building	Build technical capacity among waste service providers				
		Build technical capacity among regulators and policymakers				
		Implement educational awareness and outreach programs				

RMI Graphic. Source: RMI analysis

Build technical capacity among waste service providers

There is generally limited technical capacity where methane monitoring and mitigation technologies are not widely deployed, as in many BtB and BtB+ countries. Developing technical capacity for facility operators and other waste service providers is critical to the long-term sustainability of projects. For example, the inability to effectively operate AD facilities or GCCS can lead to high fugitive emissions, long operational downtimes, and high maintenance costs to bring in nonlocal experts, which reduce the viability of these projects and can be a major roadblock in unlocking project finance. Building technical capacity among key personnel will improve waste management operations and enable deployment of critical technology. Capacity-building trainings may include workshops, facility tours, exchange programs, and educational curriculums at tertiary institutions.

Build technical capacity among regulators and policymakers

Beyond facility operators, lack of technical capacity within the regulatory authorities may result in deprioritizing policies and regulations that advance methane mitigation or enacting ineffective policies and regulations. Developing science-based training programs for elected officials and government representatives involved in developing regulations and policies for waste management will facilitate a deeper understanding of the technical and financial implications of new and existing regulations and ensure the efficacy and feasibility of new and updated regulations.

Implement educational awareness and outreach programs

The lack of awareness can often impede the implementation of best management practices. Outreach programs can help improve reception to new initiatives and encourage participation. These programs should be tailored to relevant stakeholder groups to educate them on practices that promote methane mitigation. These could include teaching waste generators simple strategies to reduce food loss and waste and how to effectively segregate organic waste to reduce contamination; provide information about curbside collection frequency; educate waste haulers on which bins to collect and the appropriate destination for waste collected; and conduct investment trainings to improve awareness on available financing options for waste service providers and project developers. Beyond the "how" and sharing best practices, these awareness programs should also address the "why" so that participants understand the underlying motivation and how the community benefits from these actions. Ideally, these awareness initiatives should use multiple languages and leverage different communication outlets such as leaflets, radio jingles, TV ads, social media, hotlines, conferences, workshops, and school curriculums, among others, to maximize reach.

Educational awareness programs are also essential during rulemaking. Regulatory officials should endeavor to engage with key stakeholders throughout the process such as through public feedback consultation, webinars, and workshops to socialize new regulations and compliance requirements and test the feasibility of implementing regulations.

Stakeholder roles and responsibilities:

- **Municipalities, local waste management authority or service technology providers, consulting firms, and NGOs:** Work collaboratively to identify knowledge gaps among key waste management personnel and other stakeholder groups, and conduct targeted technical capacity-building training programs and educational awareness initiatives tailored to specific audiences
- **Facility operators and key waste management personnel:** Attend training programs to build technical capacity and implement best management practices in daily operations
- **Regulators and policymakers:** Attend training programs to build technical capacity and knowledge about waste management and methane management, and leverage knowledge gained to promote the adoption of policies that support methane mitigation
- **Civil society and the public:** Actively participate in educational awareness and outreach programs to improve understanding and promote implementation of best management practices

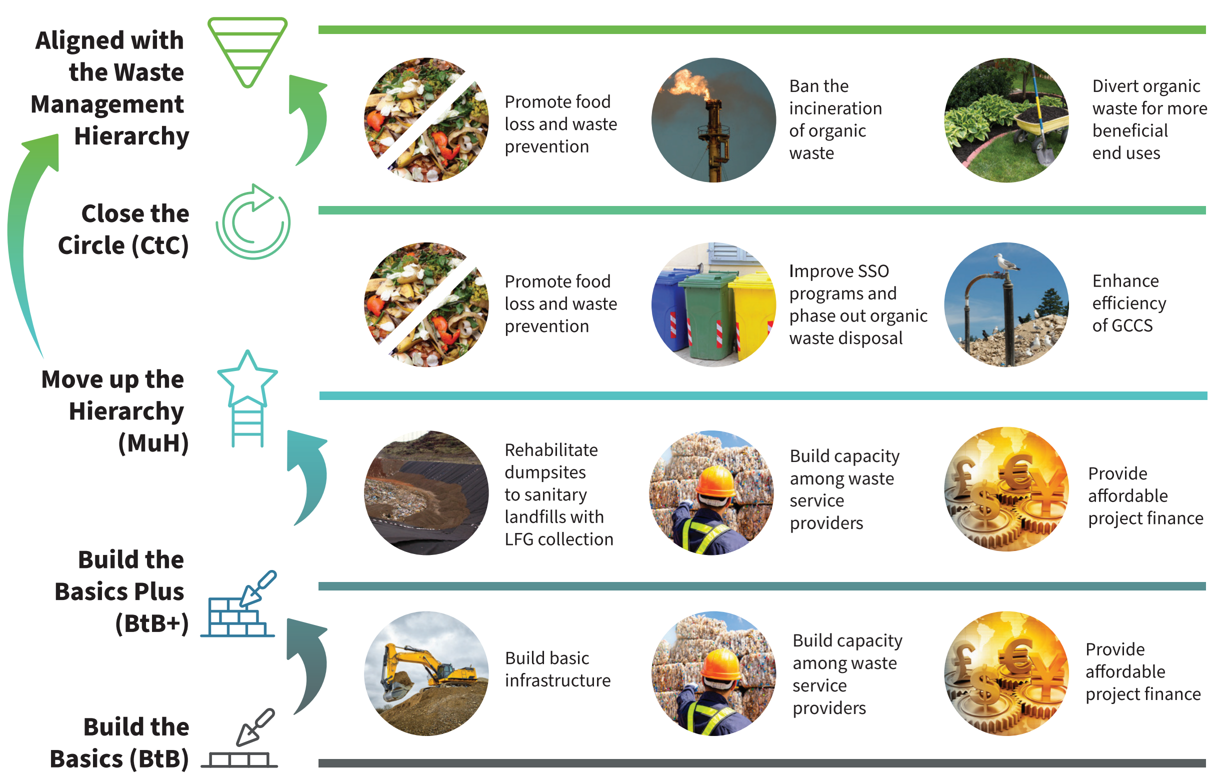
Curbing methane emissions from MSW requires planning and implementation efforts across the entire waste management value chain and effective collaboration among all key stakeholders. The timely implementation of tailored strategies presented in this section is critical to limiting global warming in the near term while delivering powerful co-benefits to local communities including improved public health and safety and air quality.

Conclusion and Recommendations

Methane emissions reduction is a critical step toward limiting near-term warming, and the waste sector remains a significant untapped opportunity. This strategy playbook develops four waste management archetypes based on the current practices of managing MSW in different parts of the globe: Build the Basics, Build the Basis Plus, Move up the Hierarchy, and Close the Circle. It also explores opportunities within each archetype to improve waste management and reduce methane emissions from MSW (see Exhibit 17).

For the BtB archetype — where many countries still lack some basic infrastructure — the authors recommend that countries consider robust waste management infrastructure build-out in the long term to improve operations. Recognizing existing financial constraints, the authors suggest starting with building relatively low-cost basic infrastructure in the near term, such as small-scale composting and AD, and installing landfill covers and LFG capture systems. Capacity building for waste service providers is crucial to improving long-term sustainability of projects. Access to low-cost financing is also critical to project implementation in these countries. By implementing some of these solutions, BtB countries can improve their current waste management practices, enabling them to move toward the BtB+ archetype.

Exhibit 17 Key levers for progressing across MSW management archetypes



RMI Graphic. Source: RMI analysis

For the BtB+ archetype with a higher waste collection rate and better infrastructure for waste collection and disposal, the authors recommend continuing the rehabilitation of dumpsites to sanitary landfills. These systems should be fitted with GCCS to reduce fugitive emissions. As these countries transition to the use of sanitary landfills for waste disposal, it is also important to routinely review and update existing MSW policies and regulations to reflect sustainable practices for managing organic waste and emissions from decomposed waste. Similar to BtB countries, capacity building for facility operators and other waste service providers is also critical to improving long-term viability of methane abatement projects. By progressively transitioning from dumpsites to sanitary landfills coupled with more robust regulations, improving technical capacity for waste service personnel, and accessing affordable finance, BtB+ countries will be able to move toward the MuH archetype.

For the MuH archetype where sanitary landfills are utilized and LFG capture and control systems are more widely adopted, the authors recommend enhancing food loss and waste prevention efforts, while also strengthening SSO programs and phasing out organic waste disposal in landfills. Although regulatory provisions to detect and repair leaks through periodic surface emissions monitoring often exist, there are opportunities to improve the robustness of these frameworks. Developing more robust policies to phase out landfilling of organic waste and to capture methane more efficiently from existing waste are necessary to optimize methane emissions reduction. As MuH countries reduce the landfilling of organic waste and improve gas capture efficiency at existing landfills, these countries can progress toward an aspirational system that is more closely aligned with the waste management hierarchy.

For the CtC archetype where countries have widely adopted WTE technologies and have laws and regulations that require the treatment and/or stabilization of waste before landfilling, the authors recommend instituting policies that ban incineration of organic waste and diverting this waste for beneficial end uses, while prioritizing food loss and waste prevention. This will allow these countries to similarly progress toward a system that more closely aligns with the waste management hierarchy and promotes a circular economy.

Appendix

Exhibit A1 **Archetype evaluation criteria**

Building Blocks	**Building Block Elements**	☑☐☐☐☐	☑☑☐☐☐	☑☑☑☐☐	☑☑☑☑☐	☑☑☑☑☑
Source Reduction	**Food Waste Prevention**	(1) Limited or no food waste prevention initiatives.	(1) Limited waste prevention initiatives are implemented at a small scale	(1) Food waste prevention initiatives are implemented in some major cities and have been implemented at the national level within the past five years.	(1) Food waste prevention initiatives are implemented in most major cities or states and have been implemented at the national level within the past 10 years.	(1) Food waste prevention is a priority in the national-level waste management strategy and initiatives have been implemented at the national level for at least 10 years.
Waste Diversion	**Generation**	(1) Less than 20% of the population or households have access to source separation. At minimum, MSW is separated into three bins for food and yard waste, recyclables, and residual mixed waste.	(1) 21%–40% of the population or households have access to source separation. At minimum, MSW is separated into three bins for food and yard waste, recyclables, and residual mixed waste.	(1) 41%–60% of the population or households have access to source separation. At minimum, MSW is separated into three bins for food and yard waste, recyclables, and residual mixed waste.	(1) 61%–80% of the population or households have access to source separation. At minimum, MSW is separated into three bins for food and yard waste, recyclables, and residual mixed waste.	(1) More than 80% of the population or households have access to source separation. At minimum, MSW is separated into three bins for food and yard waste, recyclables, and residual mixed waste.
	Collection and Transport	(1) Waste collection rate is below 20% on average.	(1) Waste collection rate is 21%–40% on average.	(1) Waste collection rate is 41%–60% on average.	(1) Waste collection rate is 61%–80% on average.	(1) Waste collection rate is above 80% on average.

Building Blocks	Building Block Elements	☑☐☐☐☐	☑☑☐☐☐	☑☑☑☐☐	☑☑☑☑☐	☑☑☑☑☑
Waste Diversion	**Recovery and Treatment**	(1) Recycling rate (including organic waste recycling) is lower than 20%. (2) Less than 20% of waste generated is diverted from landfills and dumpsites to composting or AD facilities.	(1) Recycling rate (including organic waste recycling) is 21%–40%. 2) 21%–40% of waste generated is diverted from landfills and dumpsites to composting or AD facilities.	(1) Recycling rate (including organic waste recycling) is 41%–60% (2) 41%–60% of waste generated is diverted from landfills and dumpsites to composting or AD facilities.	(1) Recycling rate (including organic waste recycling) is 61%–80%. (2) 61%–80% of waste generated is diverted from landfills and dumpsites to composting or AD facilities.	(1) Recycling rate (including organic waste recycling) is higher than 80% (2) More than 80% of waste generated is diverted from landfills and dumpsites to composting or AD facilities.
Waste Disposal	**End-of-Life Disposal**	(1) Heavy reliance on open or unmanaged dumpsites, although may utilize controlled dumpsites. There are no existing sanitary landfills. Open burning and illegal dumping are common.	(1) Relies mostly on controlled dumpsites, although the use of unmanaged dumpsites is not uncommon. There are few sanitary landfills. Open burning and illegal dumping may occur.	(1) A higher proportion of MSW is disposed of in sanitary landfills than in dumpsites. No open burning or illegal dumping.	(1) Waste is primarily disposed of in sanitary landfills but GCCS to recover LFG may or may not be installed. No open burning or illegal dumping.	(1) Waste is disposed of in sanitary landfills that have GCCS. LFG is recovered for beneficial end use or destroyed using high-efficiency flares. No open burning or illegal dumping.
Crosscutting Component	**Policy and Regulatory Framework**	(1) No clear policies and regulations on waste management. (2) No clear policies and regulations on methane management.	(1) There are plans, policies, and regulations to improve select aspects of waste management, but they are either outdated or poorly implemented and enforced. (2) Policies and regulations targeting organic waste are planned to be implemented within the next five years to reduce methane emissions from the waste sector.	(1) There are plans, policies, and regulations to improve select aspects of waste management, at least for the past five years, and they are well implemented. (2) Policies and regulations targeting organic waste have been implemented within the past five years to reduce methane emissions from the waste sector.	(1) Policies and regulations have been implemented and enforced in the past 10 years, and they are well implemented. (2) Policies and regulations targeting organic waste have been implemented and enforced to reduce methane emissions in the waste sector for at least five years.	(1) Strong policies and regulations have been implemented and enforced for more than 10 years, and they are well implemented. (2) Strong policies and regulations targeting organic waste have been enforced for more than 10 years to reduce methane emissions.

Building Blocks	Building Block Elements	☑☐☐☐☐	☑☑☐☐☐	☑☑☑☐☐	☑☑☑☑☐	☑☑☑☑☑
Crosscutting Component	**Emissions Transparency**	(1) No methane monitoring technologies deployed. (2) Limited or no waste data is publicly available, and the latest public GHG emissions inventory is more than 10 years old.	(1) SEM technologies are deployed at a pilot scale. (2) Some waste data is publicly available, but the latest is more than 10 years old, and the latest public GHG emissions inventory is more than five years old.	(1) SEM technologies are regularly deployed to monitor methane emissions and detect leaks for prompt corrective measures. (2) Waste data is publicly available, but the latest is more than five years old, and the latest public GHG emissions inventory is more than two years old.	(1) SEM technologies are regularly deployed to monitor methane emissions for prompt corrective measures, and some operators voluntarily deploy advanced monitoring technologies. (2) Waste data is publicly available, but the latest is more than two years old, and the latest public GHG emissions inventory is within the past two years, and emissions from waste disposal sites are publicly available.	(1) Advanced monitoring technologies are incorporated into the regulatory framework to complement SEM technologies to optimize methane detection and mitigation. (2) Waste data is publicly available and updated within the past two years, the latest public GHG emissions inventory is within the past two years, and emissions from waste disposal sites are publicly available.
	Finance	(1) There is no budget for waste management, and financing for waste projects is limited. (2) Revenue is insufficient to cover costs, and projects are generally abandoned.	(1) There is a budget for waste management, but financing for waste projects financing is limited. (2) Some waste projects (e.g., organic waste treatment and landfill gas-to-energy projects) are able to recover costs, but projects may still be abandoned for financial reasons.	(1) There is a budget for waste management, and financing for waste projects is available. (2) Cost recovery is generally certain and can sustain long-term operation of the project, although profit margins are very low. Projects are not abandoned due to the inability to recover costs.	(1) There is a budget for waste management, and financing for waste projects is available. (2) Mature cost recovery pathways for waste projects are available. Innovative revenue and pricing models are adopted to guarantee cost with modest return on investment.	(1) There is a budget for waste management, and financing for waste projects is available. (2) Mature cost recovery pathways for waste projects are available. Innovative revenue and pricing models are adopted to guarantee cost recovery with robust return on investment.

Building Blocks	Building Block Elements	☑☐☐☐☐	☑☑☐☐☐	☑☑☑☐☐	☑☑☑☑☐	☑☑☑☑☑
Crosscutting Component	**Stakeholder Awareness and Capacity Building**	(1) Lack of technical expertise among workers to operate and maintain advanced waste management technologies. (2) No educational awareness initiatives to promote understanding about waste management best practices.	(1) Limited technical expertise among workers in operating and maintaining advanced waste management technologies. (2) Educational awareness initiatives to promote understanding about waste management best practices are planned or underway.	(1) Available expertise in operating and maintaining advanced waste management technologies, but some further training may be needed. (2) Ongoing educational awareness initiatives to promote understanding about waste management best practices in the past five years that have resulted in improved stakeholder awareness, compliance, and buy-in.	(1) Highly skilled technical workers with expertise in operating and maintaining advanced waste management technologies. (2) Ongoing educational awareness initiatives to promote understanding about waste management best practices in the past 6–10 years that have resulted in improved stakeholder awareness, compliance, and buy-in.	(1) Highly skilled technical workers with expertise in operating and maintaining advanced waste management technologies. (2) Ongoing educational awareness initiatives to promote understanding about waste management best practices in the past 10+ years have resulted in strong stakeholder awareness, compliance, and buy-in.

RMI Graphic. Source: RMI analysis

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