MARKETING MATERIAL

A LAND(FILL) OF OPPORTUNITY – ANALYSING WASTE TREATMENT TECHNOLOGIES

NOVEMBER 2021

Despite best efforts over recycling, more than 50% of waste still ends up in landfills or is openly dumped. Humankind's waste creation is on an upward trajectory and there's a pressing need to handle this waste in an environmentally friendly and energy efficient way. We believe these newly-emerging technologies present significant investment opportunities. They could not only become market leaders in this rapidly growing market segment but also help tackle a key social and environmental challenge.

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Sustainable Investment Analyst

WHY MIGHT INVESTORS BE INTERESTED IN WASTE?

The challenge of waste management has long been one of society's primary challenges. Indeed, we can trace the origin of the waste management industry all the way back to the creation of the first municipal dump in Ancient Greece where, in c500BCE, regulations were introduced requiring waste to be dumped outside Athens' city limits.

Over the proceeding c2,400 years, technological progress within the industry has been glacial, with the fundamental concept of dumping in unpopulated areas remaining the principal solution. Only over the last century have we started to see developments in waste disposal techniques. Improvements in municipal recycling rates have only occurred over the last two decades. Underpinned by persistent social megatrends, global waste creation remains on a relentless upwards trajectory. As such, it presents a growing opportunity for new technologies to disrupt this industry and tackle this growing challenge.

SCHRODERS' PROPRIETARY TOOLKIT

From a risk management perspective, we draw investors' attention to several metrics in Schroders' proprietary sustainability toolkits, which can be used to assist in the analysis of company-level waste management practices.

Specifically, we highlight the "food waste" and "waste creation" metrics found in SustainEx — our impact measurement tool - and the ten waste and waste management datapoints in CONTEXT's "environment" and "regulator & governments" stakeholder groups. CONTEXT is our stakeholder analysis tool.

111 MILLION BIN LORRIES PER DAY AND INCREASING – THE TRENDS BEHIND A $2 TRILLION INDUSTRY

The world generates two billion tonnes of municipal solid waste (MSW) annually, according to the World Bank. Putting this into perspective, a bin lorry can hold up to 18 tonnes of rubbish. This means that globally we produce the equivalent of more than 111 million bin lorries' worth of waste a day.

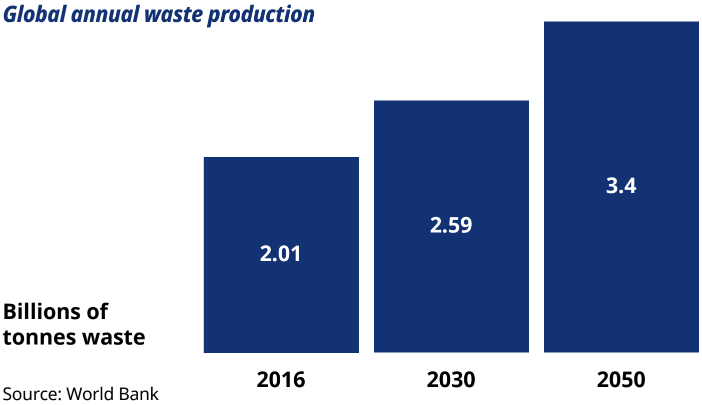
Municipal solid waste (MSW):

MSW is essentially "regular" rubbish that is produced from non-industrial sources (residential homes, restaurants, retail centres, and office buildings). Typical MSW includes paper, discarded food items, and other general discards. Green waste is considered MSW and includes grass clippings, leaves and tree cuts.

The mega trends of population growth, urbanisation, income growth and economic growth mean that global waste production remains on an unrelenting upward trajectory. In a business-as-usual scenario, annual waste production is expected to grow 29% to 2.59 billion tonnes by 2030 and by nearly 70% to 3.40 billion tonnes of annual waste production by 2050, the World Bank says. Consequently, the global waste management industry is today worth $2.08 trillion, and this is forecast to reach $2.34 trillion by 2027, a compound annual growth rate (CAGR) of 5.5%, according to analysis by Allied Market Research.

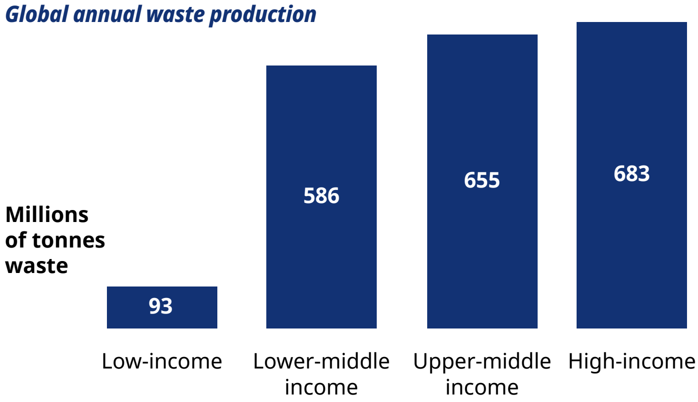
Schroders

Global annual waste production



Source: World Bank

Global annual waste production



Source: World Bank

IN DETAIL: THE FIVE WS OF WASTE (WHO, WHAT, WHY, WHERE, WHEN)

WHO IS CREATING THE WASTE?

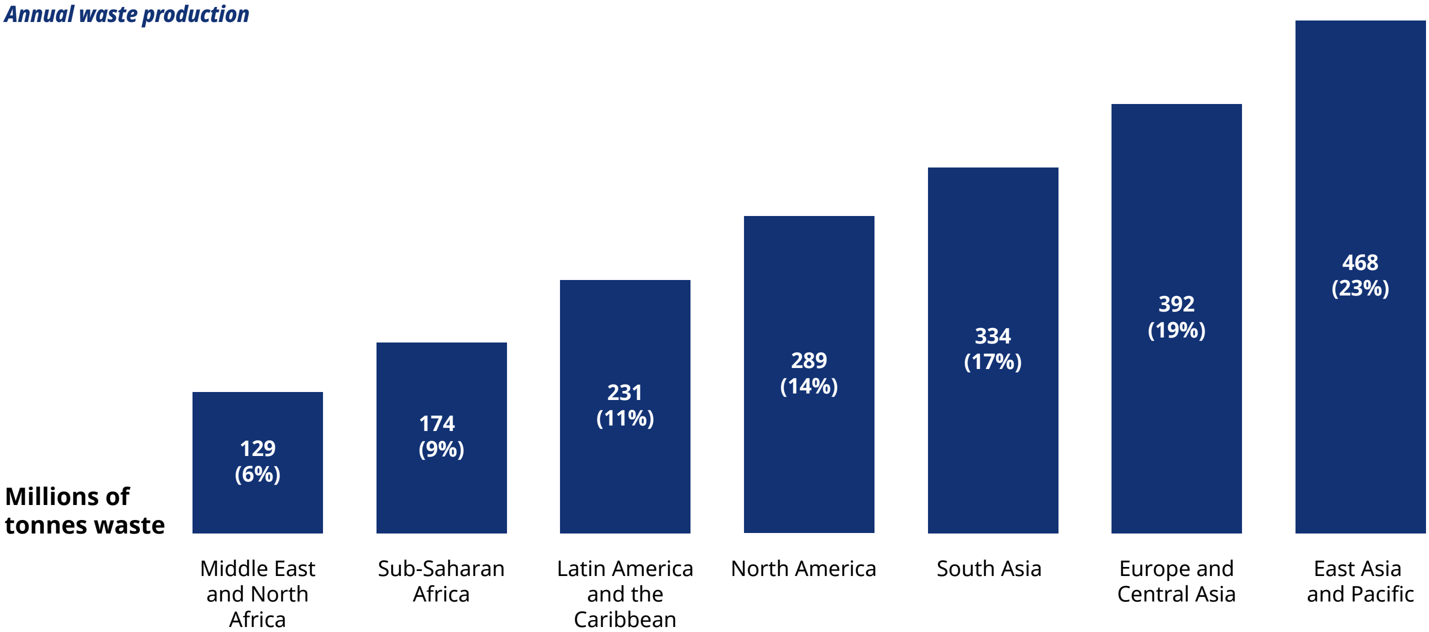
On a regional basis, countries in East Asia & Pacific and Europe & Central Asia create the greatest volume of waste, generating around 42% of global waste by magnitude. The Middle East & Northern Africa generate the least, with North America sitting in the middle of the pack.

Clearly, the absolute volume data only paints half the picture. When normalising for population, the average waste generated per capita is highest in North America and lowest in Sub-Saharan Africa. Similarly, when analysing by economic prosperity, high-income countries are responsible for 34% of the waste generated globally, despite only accounting for 16% for the world's population.

Waste production per capita	
Sub-Saharan Africa	0.46
East Asia and Pacific	0.56
South Asia	0.52
Middle East and North Africa	0.81
Latin America and the Caribbean	0.99
Europe and Central Asia	1.18
North America	2.21

Source: World Bank.

Annual waste production



Source: World Bank: (%) = share of annual waste production

WHAT IS WASTE COMPOSED OF AND WHAT ARE ITS GROWTH DRIVERS?

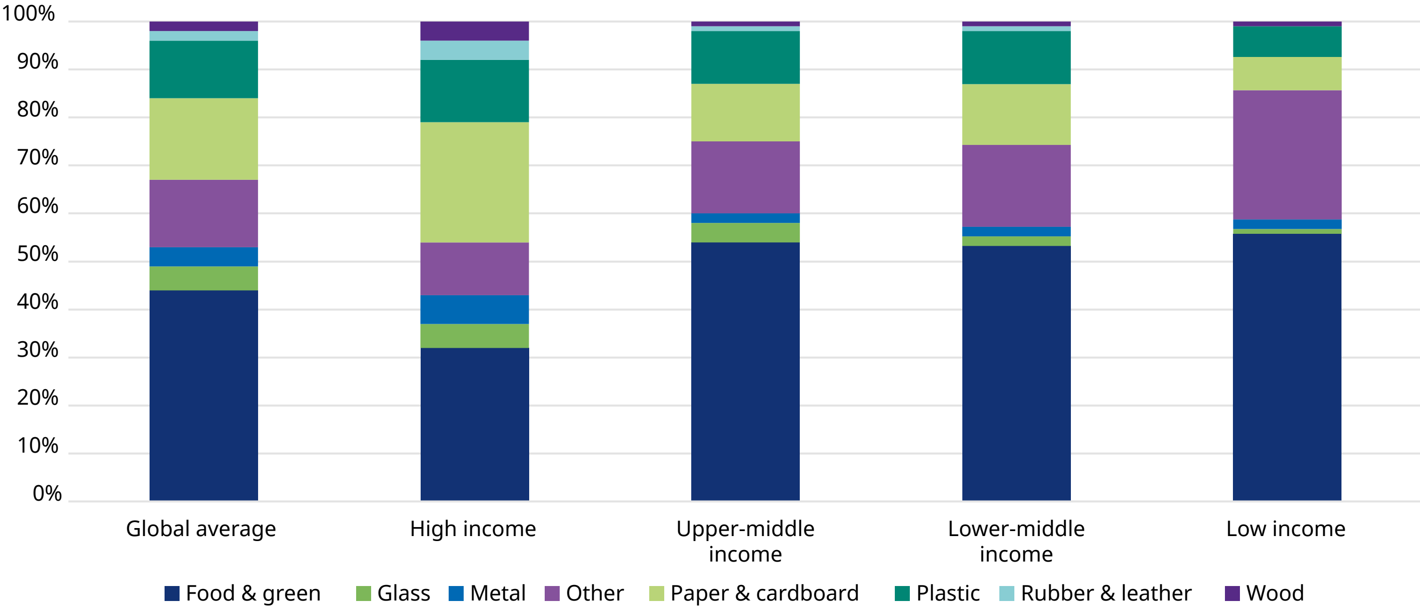
Whilst the composition of MSW varies somewhat between countries and income levels, one consistent trend is the fact that food & green waste make up the largest proportion of MSW globally and at all income levels. The other significant contributors to MSW internationally are paper and cardboard waste as well as plastic waste.

As shown in the next figure, as income levels rise, the level of organic matter in waste decreases and the level of material waste (paper/cardboard and glass) increases. Consequently, the waste management techniques and opportunities vary across geographies due to this differing MSW make-up.

The world's waste problem is worsening at an alarming rate, underpinned by several powerful megatrends:

- **Population growth:**
  - From an estimated 7.7billion people in 2019, under a medium-variant projection, the world population is expected to grow to 8.5billion by 2030, 9.7billion in 2050 and 10.9billion in 2100, according to the UN Department of Economic and Social Affairs.
- **Urbanisation:**
  - Today, 55% of the world population lives in urban areas.
  - Unsurprisingly, the highest waste producing region per capita, North America, also has the highest urbanisation rate at 82%. Similarly, the region with the lowest waste generation per capita, Sub-Saharan Africa, has a 38% urbanisation rate.
  - By 2050, it is estimated that 68% of the world population will be living in urban areas, the UN Department of Economic and Social Affairs says.
  - Virtually all the future population growth to 2050 (i.e. 2.2 billion people) is expected to be absorbed by urban areas.
- **Economic development:**
  - Economic growth and waste disposal are positively correlated. As income levels increase, material consumption increases and waste levels rise.
  - According to the Organisation for Economic Co-operation and Development forecasts, global gross domestic product could increase more than 2.5x by 2060. Clearly this would place continued upward pressure on waste creation rates, unless a drastic change in human consumption occurs.

Global MSW Composition

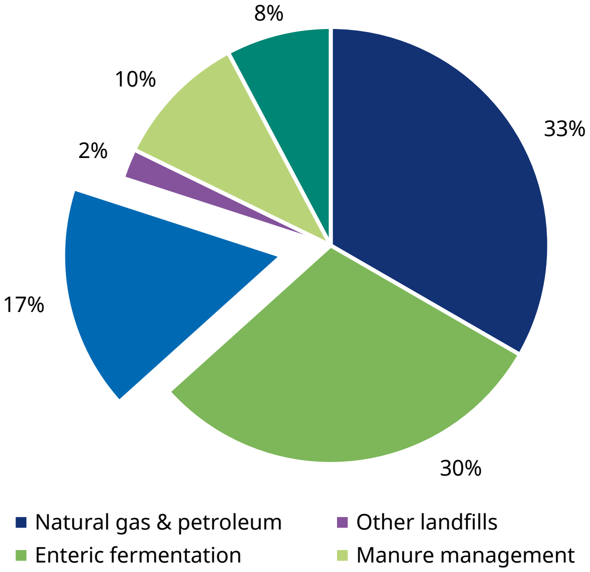


Source: World Bank

WHY IS WASTE SO PROBLEMATIC?

Simply put, poor waste management contributes to climate change, directly affects ecosystems, and generates air, water and land pollution. Globally, landfills alone account for 8-10% of human activity-based GHG, but in certain geographies the number can be higher. Indeed, in the US, 15% of all human-related methane emissions come from landfills, the Environmental Protection Agency has found.

2019 US methane emissions by source



Source: Environmental Protection Agency

Around one third of all food produced for human consumption goes to waste and, unsurprisingly, food & green waste account for 44% of global waste. In a working paper on food waste from the Food and Agriculture Organisation of the United Nations (FAO), it was determined that the economic costs of this food waste amounted to $1trillion each year. The study also outlined several other substantial costs borne from food waste as highlighted below.

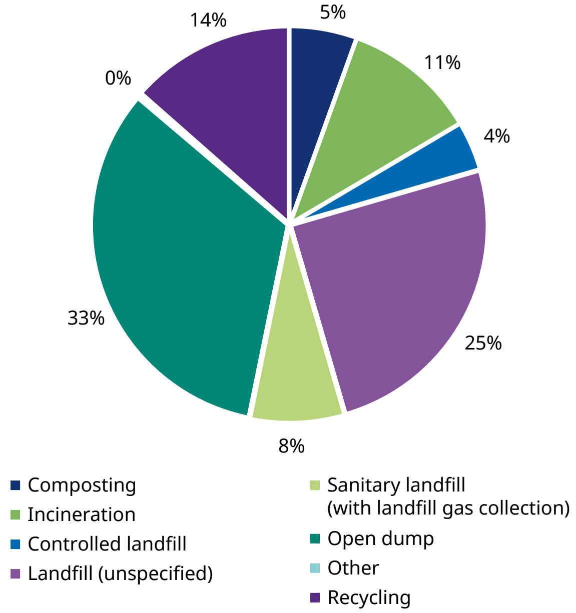
- **Increased water scarcity,** particularly for dry regions and seasons. Globally, this is estimated to cost $164 billion per year.
- **Soil erosion due to water.** This is estimated to cost $35 billion per year through nutrient loss, lower yields, biological losses and off-site damages. The cost of wind erosion may be of a similar magnitude.
- **Risks to biodiversity,** including the impacts of pesticide use, nitrate and phosphorus eutrophication, pollinator losses and fisheries over-exploitation are estimated to cost $32 billion per year.
- **Increased risk of conflict due to soil erosion** is estimated to cost $396 billion per year.
- **Loss of livelihoods due to soil erosion** is estimated to cost $333 billion per year.
- **Adverse health effects due to pesticide exposure** are estimated to cost $153 billion per year.

Beyond food waste, a study by McKinsey in 2016 focused on Southeast Asia and estimated the economic cost of uncollected household waste that is burned, dumped, or discharged to waterways to be USD 375/tonne.

WHERE DOES OUR WASTE END UP?

Globally, 37% of municipal solid waste is disposed of in some form of landfill, 33% is openly dumped, 19% is either recycled or composted, and 11% is treated via modern incineration, according to the World Bank. Unsurprisingly, waste disposal methods vary significantly by region and income level. As outlined in the figure below, more than two thirds of waste is openly dumped in South Asia and Sub-Saharan Africa, whilst North America has the highest percentage of waste that is recycled (33.3%).

Global waste treatment and disposal



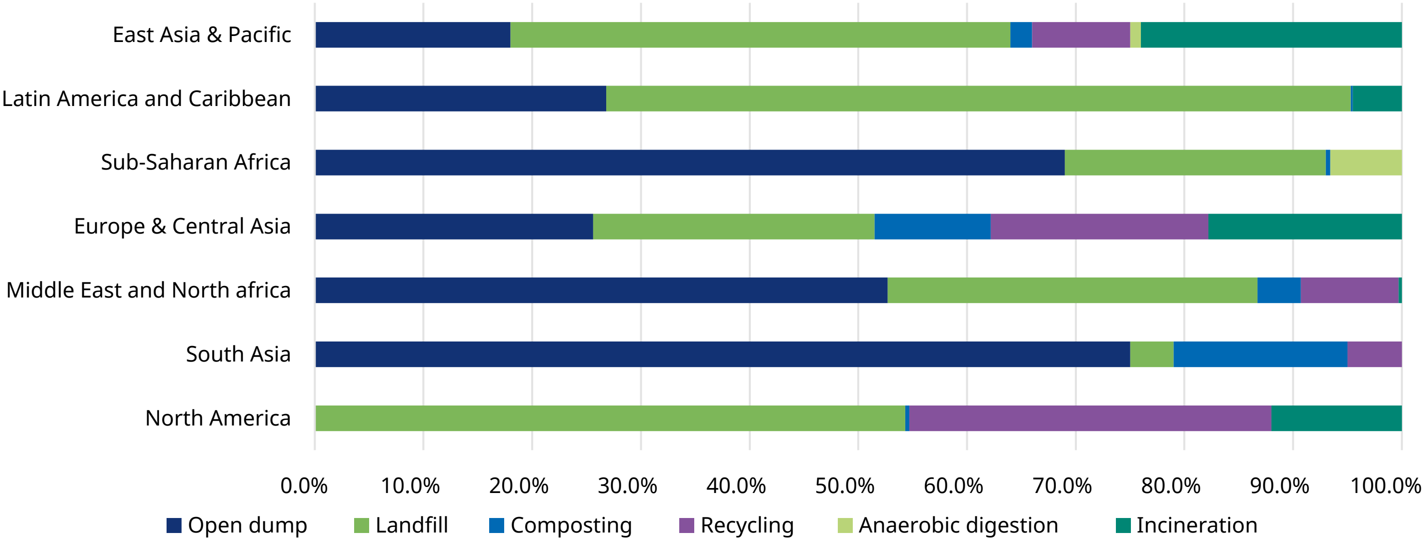
Source: World Bank

Beyond the domestic handling of waste streams, there is a strong international trading market for waste. By region, the European Union is the largest exporter of waste globally, with countries such as the Netherlands, Germany, Belgium, France and UK topping the list of largest exporters. The US is the largest single-country source of waste exports.

Before its recent ban on waste imports, China was the largest importer of waste globally. Indeed, in 2012 Chinese plastic imports peaked at 9 million tonnes, nearly half of the world's global plastic waste. However, since the introduction of the ban in 2018, waste imports in other regions of Southeast Asia have picked up significantly with Malaysia, Thailand, Vietnam, and Indonesia now taking the top spot as the region's largest importers.

The regulatory burden around waste management practices is increasing and social and political pressure for countries to handle the waste they generate domestically is intensifying. As this pressure translates into regulatory and policy changes, those countries who have previously relied on the export (or imports) of waste, will have to look for alternative solutions to their waste management needs.

Global waste treatment by region



Source: World Bank

WHEN WILL REGULATION INCENTIVISE THE SECTOR?

Globally, waste management practices are a function of municipal, regional and/or national waste management policies and thus there are significant variations in waste regulation. The heterogeneity of different waste streams adds further detail and complexity to the regulatory landscape within the industry.

There are, however, two emerging trends in regulations that can be identified across geographies and waste streams:

i. The rising costs facing those who create waste. There is unanimity amongst regulators to introduce measures that underpin the "polluter pays" principal. This can be borne out in a number of ways including increased taxes on waste imports/exports, rising landfill gate prices and increasingly punitive fines for mismanagement of waste/illegal dumping.

ii. The growing requirement and desire for countries to dispose of the waste they create domestically. This onshoring of waste management is forcing governments to explore new, environmentally-friendly ways in which to manage its waste, beyond simply exporting it.

These shifts in the regulatory landscape create a growing need for society to develop and evolve new ways of handling waste. Below we highlight some of the regulatory changes occurring in the industry:

Globally:

- In May 2019, 187 countries agreed to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (effective as of January 1 2021). As a result of these changes, transboundary shipments of most plastic scrap and waste are controlled, or regulated, for the first time.

Europe:

- As of January 1 2021, the EU has imposed a ban on the export of plastic waste from the EU to non-OECD countries (except for clean plastic waste sent for recycling, under very specific conditions). Waste exports and imports are only allowed between countries with reasonably advanced waste management regulations.
- Announced as part of the European Green Deal, the Commission intends to review the EU rules on waste shipments. In particular, it stated it wanted to "explore ways to reduce the export of waste".
- Swedish refuse-derived-fuel (RDF) tax. In April 2020, Sweden introduced tax of 75Kr per tonne on "waste that is burnt". Under the confirmed plans, the levy will then rise by a further 25Kr in both 2021 and 2022 before the annual rise will be indexed after 2022.
- Dutch waste import tax. In January 2020, the Netherlands introduced tax of €31 per tonne on the import of waste for incineration.
- Ireland landfill targets. From 2020, the biodegradable municipal waste going to landfill is to be reduced to below 35% of the total amount by weight of biodegradable municipal waste produced in 1995; and by 2035, the amount of municipal waste which is sent to landfill is to be reduced to 10% or less of the total amount generated by weight.
- The Waste Framework Directive, responsible for the "waste hierarchy", requires that, as of 2020, EU households must recycle or prepare for re-use 50% by weight of waste materials, such as paper, metal, plastic and glass. And by 2025, the recycling and preparing for re-use of municipal waste shall be increased to a minimum of 55%, 60% and 65% by weight by 2025, 2030, and 2035 respectively.

US:

- At a federal level, the Environmental Protection Agency (EPA), regulates waste under the Resource Conservation and Recovery Act. The agency has introduced schemes such as:
  - "Bottle bills" – a taxation on producing beverage containers (or refund for correct recycling of the containers).
  - "Pay-as-you-throw" – traditionally, households/businesses pay a fixed fee for waste collection. Pay-as-you-throw breaks this tradition and charges residents/businesses based on the amount they throw away.
- At state level, there are numerous initiatives underway to improve recycling rates and minimise landfill disposals.

Asia:

- In 2017, China introduced “Prohibition of Foreign Garbage Imports”. This banned the import of 24 types of solid waste, including plastic waste.
- Following this, Malaysia, Vietnam, Thailand, India, and Indonesia imposed a slate of restrictions on imported non-recyclable plastic, including bans, inspections, freezes on new licenses, new taxes and fees, and raids on illegal operations. However, these countries still remain some of the largest importers of waste globally.
- China now offers the equivalent of a $30 credit per megawatt-hour of electricity generated by waste-to-energy plants.

The regulatory burden around waste management practices is increasing and social and political pressure for countries to handle the waste they generate domestically is intensifying. As this pressure translates into regulatory and policy changes, those countries who have previously relied on the export (or imports) of waste, will have to look for alternative solutions to their waste management needs.

WASTE MANAGEMENT TECH (I) – AI AND AUTOMATED SORTING

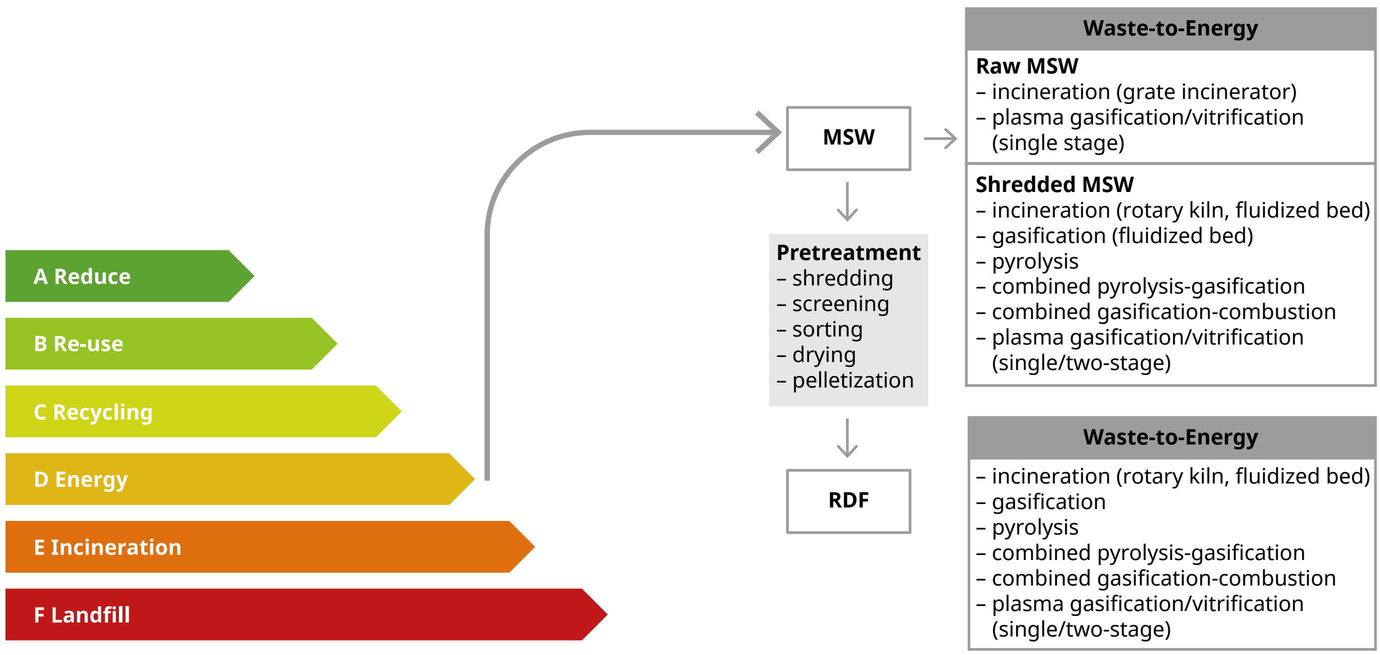
Modern waste management prioritises initial waste prevention (reduce) and material recovery (re-use and recycle), or the first three phases of the waste hierarchy first outlined by Dutch politician Ad Lansink in 1979 (see figure below). However, despite the enhanced focus on more sustainable waste management practices, global MSW generation continues to rise and, as outlined previously, is forecast to increase nearly 70% by 2050.

Consequently, we are directing our focus on the emerging technologies and waste management methodologies that are being developed to reduce waste once it has already been created. Specifically, we are looking at the bottom three actions in Lansink’s waste hierarchy “ladder”. The figures below show Lansink’s waste hierarchy and the different pre-treatment and waste-to-energy methodologies.

The opportunity for automation within the waste management industry is large. More than half of all waste management tasks in material recovery facilities can be automated and, in the US alone, there are more than 300 material recovery facilities with an estimated market size of $6.6 billion, Ibis World Research has estimated.

Whilst municipal waste sorting plants can be highly automated, within most plants, some sorting tasks still need to be carried out manually. These are low ergonomic working conditions which involve repetitive manual picking, high noise levels and direct contact with waste. As a result, worker productivity decreases throughout the shift. Robotic technologies in waste management present a solution to these labour-intensive tasks and offer a significant opportunity to improve the sorting performance of plants, particularly if the waste in question is hazardous.

Through the use of computer vision, 3D laser scans and metal sensors, combined with machine learning and advanced robotics, the accuracy and sensitivity of automated sorting can be dramatically improved. Indeed, some technologies can sort material as granular as a type of plastic, at a pick rate of nearly 80 items a minute, which is twice as fast as human sorting. Additionally, intelligent robotic systems can have greater bale purity (99% sorting accuracy), do not suffer productivity deteriorations during the shift and can be run 24 hours a day, seven days a week.



Source: Recycling.com

Source: Journal of Cleaner Production

The vast majority of companies emerging in this space offer advanced scanning and sorting technologies that can be retrofitted onto existing conveyer belt sorting lines. This means that significant capital outlays of designing entirely new material recovery facilities can be avoided. Additionally, many of the companies offer their technologies on leased contracts, again, reducing the initial capital outlay for the MRF owner. Given the emerging nature of these technologies, many of the companies offering these solutions are smaller start-up companies.

WASTE MANAGEMENT TECH (II) – WASTE TO ENERGY

Waste-to-energy, or energy from waste (EfW), is the method by which electricity or heat is generated from the processing and treatment of waste. WtE has a plethora of benefits for society including reducing demand for landfill and dumping sites, lowering the dependence on fossil fuels and, with some methods, reducing environmental pollution.

Underpinned by increasingly strict landfill legislation and the growing trend of MSW import/export bans, waste-to-energy is expected to be one of the fastest-growing waste management sectors over the next five years. Indeed, from a 2019 valuation of $35.1 billion, the global WtE market is projected to reach $50.1 billion by 2027, growing at a 5% CAGR from 2020 to 2027, according to Allied Market Research.

Currently, Europe is the largest and most sophisticated market for WtE technologies. However, the Asia-Pacific region is forecast to exhibit the strongest growth over the coming years (CAGR 7.5%), driven by increasing waste generation and government initiatives in China and India and higher tech penetration in Japan, according to the World Energy Council.

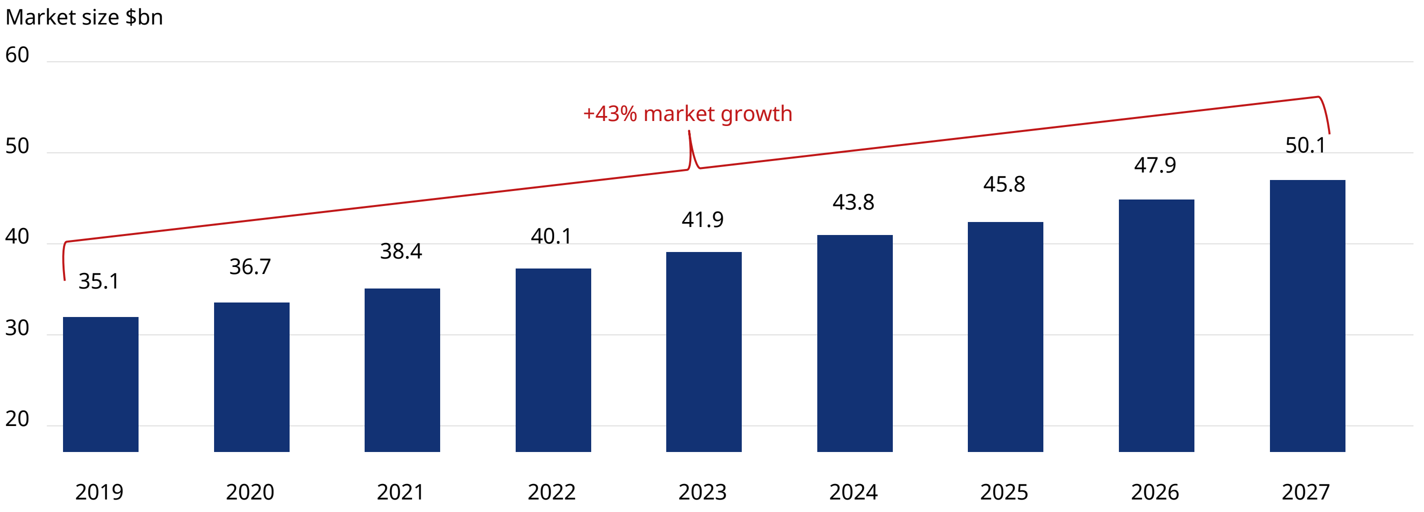
There are several different WtE technologies that are currently being implemented globally. Below we outline the four major types of WtE methodologies and identify some of the key players within each area:

1) INCINERATION

- The most widely-applied WtE methodology.
- Involves full oxidative combustion of MSW, resulting in the energetic value of waste material being recovered as heat.
- This heat is then used to generate electricity, typically via a steam generator.
- The average energy efficiency of an incineration plant is around 14-28% but modern plants can reach up to 60%.
- The ash produced as a bi-product of incineration can be processed using magnets to recover any metals that can then be recycled. The remaining ash can then be used in construction aggregates or sent to landfill.

Incineration	
Advantages	**Disadvantages**
– Decreases waste mass by 80% and volume by 90% – Efficient – incineration is effective for 90% of waste generated – Produces heat/electricity – Reduces pollution (rel. to landfills) – Prevents the production of methane gas – Eliminates germs and harmful chemicals in waste – Effective metal recycling – Resulting ash has commercial value (construction)	– Installation is expensive - $169m for a medium-sized 250,000 tons per annum plant – Pollutes the environment – combustion results in the production of CO_2, N_2O, NO_x, carcinogen dioxin, and particulates – Potentially discourages sustainability – incineration does not encourage recycling and waste reduction

Global waste-to-energy market



Source: Allied Market Research

2) GASIFICATION:

- Gasification is the thermal decomposition of waste into a combustible gaseous product (syngas).
- Unlike incineration, gasification typically requires homogenous feedstock, meaning the MSW needs to be pre-treated to create either shredded MSW or refuse-derived-fuel (RDF), before it is heated.
- The gasification process involves the reaction of waste with a mixture of oxygen, steam and air at 500-1,800ºC or higher.
- Gasification differs from incineration in that during gasification a highly controlled supply of oxygen or steam is applied in a way that prevents full combustion. This process creates syngas, which can be used in a variety of different applications:
  - Burned in a boiler to generate steam for power generation or industrial heating
  - Used as a fuel in a dedicated gas engine
  - Used in a gas turbine
  - Used as a chemical feedstock

3) PYROLYSIS:

- Pyrolysis is the thermal decomposition of organic waste in the complete absence of oxygen (anaerobic). Like gasification, pyrolysis requires homogenous feedstock.
- Pyrolysis involves the heating of waste to temperatures between 300ºC and 800ºC, in the absence of air, which results in the creation of bio-oil.
- The other two pyrolytic products, which are produced to a lesser extent, are syngas and biochar.
- Bio-oil has many applications:
  - Food manufacturing
  - Ethylene production
  - Fuel oil

4) PLASMA-BASED TECHNOLOGIES:

- Plasma is the fourth state of matter and it occurs when gas is superheated. Like when a liquid is heated and boils, superheating a gas causes the electrons to rip apart from the atoms (ie the gas ionises).
- During plasma gasification, MSW is fed into a plasma reactor which has been heated to extremely high temperatures using plasma torches (usually two to six torches burning at 8,000ºC). This causes the thermal degradation of the MSW into its constituent elements and creates syngas.
- The syngas created can be used to fuel the electricity for the plasma torch and all excess electricity is sold to the grid.
- Any metals, metal oxides or glass in the MSW will melt down and be collected at the bottom of the reactor as a solid vitrified aggregate (which can be resold as construction aggregates).

Gasification	
Advantages	**Disadvantages**
– Produces syngas – which can be stored and used later in many different applications – Creates less pollution vs incineration (due to non-combustion) – Produces biochar (rather than fly ash) – which has greater commercial applications – Gasification is c25-30% more efficient than incineration	– The gas produces from gasification needs to be "cleaned' before the syngas is created is usable – The process is more complex vs incineration and is therefore more expensive – Technology is less well understood compared to incineration

Pyrolysis	
Advantages	**Disadvantages**
– Produces bio-oil AND syngas – Requires a lower level of heat within the process (c550oC vs. 1150oC for gasification) – Produced syngas can be used to fuel the heating process – Can be used for waste with higher moisture content (thus minimising the cost of drying)	– When combusted, the bio-oil can produce more exhaust emissions vs diesel obtained from direct hydrocarbon processing – Difficult to store bio-oil for long durations due to its corrosiveness

Plasma-based technologies	
Advantages	**Disadvantages**
– Plasma plants create minimal air pollution, dust or ash – The only real waste is the vitrified aggregate which can be used in construction – Plasma recycling can be used with virtually any kind of waste (both hazardous and non-hazardous) – Does not require the waste to be pre-treated	– Plasma gasification is a relatively new technology (hence why it hasn't been widely adopted) – Much more expensive than the other waste-to-energy technologies

BUT WHICH WTE TECH IS BEST?

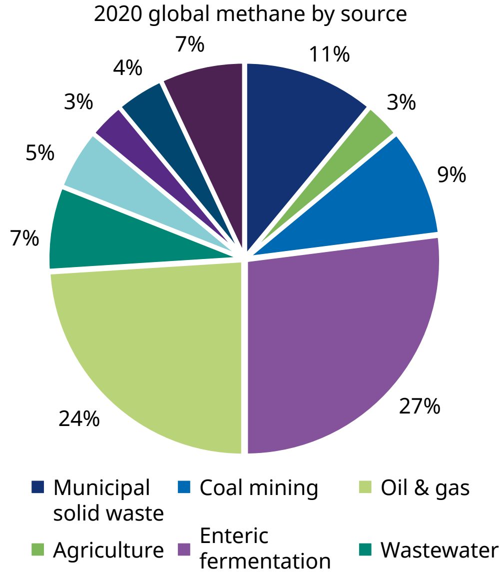
Within each area of WtE, there is a multitude of different technologies and techniques that can be used for each of the four processes outlined previously. Additionally, the heterogeneity of MSW that enters each process also has huge implications on the efficiency of the WtE process. Consequently, trying to determine which WtE process yields the best results (maximum energy with the lowest environmental impact) is massively dependent on a number of varying input and process factors.

As such, it is necessary to undertake a case-by-case analysis of each technology and its individually constructed process when trying to determine the environmental credentials of the companies operating within the WtE sector. We have, however, attempted to construct a broad comparison table to give an indication of the key differences between the three main technologies (incineration, gasification and pyrolysis) and landfill gas capture, which we outline below (note: the plasma technologies are ways to achieve gasification or pyrolysis and thus is not separated as a distinct process).

WASTE MANAGEMENT TECH (III) – LANDFILL METHANE CAPTURE

As the organic waste within landfills undergoes anaerobic decomposition, it generates methane gas. Methane emissions have a significantly higher global warming potential compared to carbon dioxide. Landfills account for around 11% of global methane emissions. This landfill methane can be captured and used as a relatively clean fuel source, thus providing two climate benefits i) preventing landfill gas emissions and ii) displacing the use of fossil fuel alternatives.

Estimated global anthropogenic methane emissions by source



Source: Global Methane Initiative

The landfill gas capture is a relatively straightforward process. To collect the gas, the MSW is first covered with a layer of soil to create an airtight seal over the waste and then a network of horizontal and vertical perforated tubes are drilled into the landfill body. The tubes criss-cross the layers of waste, collecting and transporting the biogas to a local industrial site for processing.

	Incineration	Gasification	Pyrolysis	RNG landfill
Capital cost (USD/tonne)	14.5 – 22	17 – 25	17 – 25	7.5 – 11.5
Operational cost (USD/tonne MSW	1.5 – 2.5	2 - 3	2 - 3	< 0.5
Energy conversion efficiency (%)	50 - 60	70 - 80	70	50 - 70
Complexity	Low	High	High	Low
Skill level	Low	High	High	Low
Geographical location	Urban	Industrial urban	Industrial urban	Rural
Process pollution	High	Low	Low	High

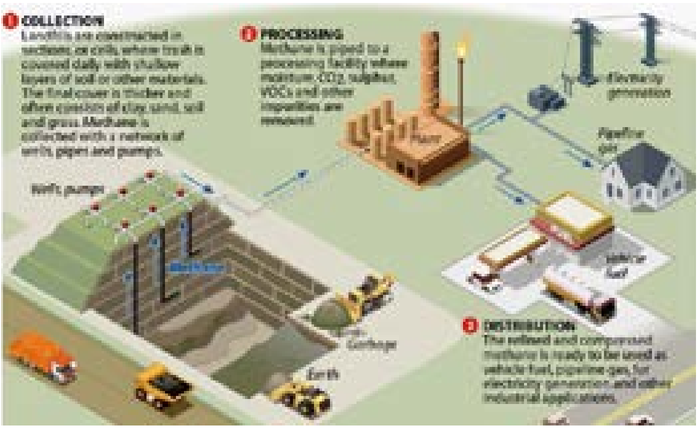
Source: IEA, Farooq Ahsan, Haputta Piyanon, Silalertruksa Thapat, Gheewala Shabbir H., *A Framework for the Selection of Suitable Waste to Energy Technologies for a Sustainable Municipal Solid Waste Management System*, Journal: Frontiers in Sustainability, 2021

The formation of gas will vary site-by-site and be affected by a number of different variables, such as waste composition, storage height and density, local air temperature and local atmospheric pressure. The landfill gas production starts soon after the waste is deposited and can continue to produce gas for up to 15–25 years. Typically, landfill gas is composed of five main gases:

- Methane (35-55%)
- Carbon dioxide (30-44%)
- Nitrogen (5-25%)
- Oxygen (0-6%)
- Water vapour (saturated)

Roughly one million tonnes of MSW can generate between 1.7-2.5 million m3 of collectable methane which can be used to generate around 6,500 to 10,000 MWh of electricity per annum. To put that into perspective, the average house in the EU consumes c4.5MWh of electricity each year. In other words, one million tonnes of MSW could theoretically power c1,850 homes for a year.

A typical landfill gas energy project



Source: EPA

HOW EFFICIENT ARE LANDFILL GAS COLLECTION METHODS?

The EPA estimates that modern landfill gas energy projects are between 60%-90% efficient at collecting the methane gas from landfills. However, this varies significantly from site to site. Additional literature suggests the efficiency could be significantly lower, with efficiencies ranging from 10%-90% depending on various factors, including waste composition and timing of landfill methane capture. It is worth noting the IPCC guidelines allow a default collection efficiency of 20%.

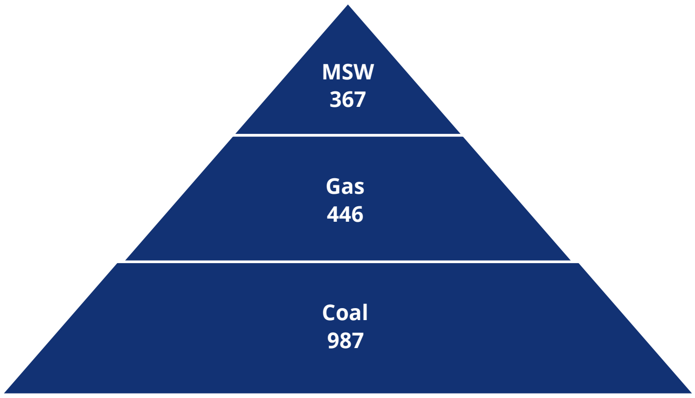
Landfilling sits at the bottom of Lansink's waste hierarchy ladder. Even with methane capture technologies in place, the other WtE technologies are more favourable due to their higher energy conversion efficiency. However, where landfills already exist, the environmental impact of capturing methane that would otherwise be entering the atmosphere is clearly positive.

CLIMATE IMPLICATIONS – TO BURN OR NOT TO BURN?

MSW IS LESS CARBON INTENSIVE THAN COAL AND GAS...

The total life-cycle emissions for conventional MSW energy recovery systems (e.g. incineration) is c1,833 grams of CO2 per kWh (or 1100kg CO2 per tonne of MSW). However, because c80% of MSW is classed as biomass[1], the non-renewable element of the emissions is c367 grams of CO2 per kWh. This compares very favourably to both coal and natural gas energy generation, which are both non-renewable. As shown below.

Life cycle CO2 emissions – grams per kWh of electricity



Source: IEA.

...ESPECIALLY WHEN CONSIDERING AVOIDED EMISSIONS

The above emissions data does not account for the emissions that are avoided as a result of using MSW for energy generation. Indeed, MSW WtE avoids carbon in two ways; i) by displacing conventional fossil fuel energy generation and ii) by avoiding the emissions generated if the waste was sent to landfill.

If consigned to landfill, one tonne of MSW (with an average moisture content of 60%) will generate around 75kg of methane (range 50-100kg), equivalent to c1,610kg of CO2. The average methane capture rate in modern landfill gas recovery sites is 50% thus, even if methane capture is in place, the average avoided emissions from MSW energy generation (vs landfill) is around 805kg CO2.

Consequently, one tonne of MSW incineration generates c600kWh of energy and creates 1,100kg CO2, of which c220kg is non-renewable. The equivalent CO2 emissions when generating 600kWh of energy via coal combustion is 592kg CO2, all of which is non-renewable. Furthermore, if the tonne of MSW was landfilled (with gas utilisation), rather than put into the WtE process, it would have generated c805kg CO2 equivalent emissions. **Therefore, the substitution of energy from MSW vs coal leads to savings of 1,177kg CO2 emissions per 600kWh.**

1 Biomass is considered renewable and carbon natural because; i) the biomass can be regrown and ii) the carbon emitted during it's combustions is reabsorbed during the growth phase of the next crop.

1 tonne MSW	MSW incineration → 600kWh	1100kg CO_2 (o/w 220kg non-renewable)
Coal	Coal combustion → 600kWh equivalent	592kg CO_2
1 tonne MSW	Landfill → with gas capture	805kg CO_2 (1610kg CO_2 without gas capture)

Net reduction in total CO_2 = 1100 - 592 - 805 = -297kg
or
Net reduction in CO_2 (non renewable): 220 - 592 * 805 = -1177kg

Source: IEA

WTE ALSO HAS A FAR SMALLER LAND REQUIREMENT (VS LANDFILLS)

A WtE plant processing 1 Mt/y for 30 years requires less than 100,000 m2 of land. If this MSW was sent to landfill, it would require c3,000,000m2 of landfilling space for c30 Mt of MSW. Additional independent studies also estimate that about one ton of equivalent CO2 is saved per ton of waste combusted rather than landfilled.[2]

2 C.S. Psomopoulos, A. Bourka, N.J. Themelis, *Waste-to-energy: A review of the status and benefits in USA*, Journal: International Journal of Integrated Waste Management, Science and Technology, 2009

CONCLUSION

SOCIETY'S WASTE PROBLEM IS NOT GOING AWAY

Underpinned by strong social megatrends and increasingly stringent regulations, the need to handle society's waste in an environmentally-friendly and energy efficient way is increasing. In an industry that has remained broadly unchanged for centuries, we believe this presents a significant opportunity for new emerging technologies to not only become market leaders in this rapidly growing market segment, but also help tackle one of mankind's key social and environmental challenges.

While each technology must be assessed on a case-by-case basis, we can surmise that the two most cost-effective ways of treating waste (incineration and landfill) are also the most pollutive. This financial and environmental dilemma is clearly most challenging to overcome within developing nations.

DEVELOPING NATIONS SHOULD FOCUS ON CLEAN INCINERATION...

Given the infancy of the gasification and pyrolysis technologies, particularly at commercial scale, we believe the best solution for developing nations lies in WtE incineration plants. These incineration plants, when fitted with strict flue gas cleaning systems, can offer the most cost-effective and least environmentally-damaging solution to waste management. In addition, WtE incineration can provide low-carbon energy to even the most remote areas, while also helping to alleviate the significant health implications linked with the informal waste sector in many parts of the developing world.

DEVELOPED NATIONS SHOULD SEEK TO ADVANCE THE MORE ENERGY EFFICIENT WTE TECHNOLOGIES

For developed nations, with more advanced waste management infrastructure and MRFs, we believe the greatest opportunity lies within the gasification and pyrolysis technologies. Due to the maturity of the waste management industry in these regions, the homogenous feedstock of MSW is more readily available and thus the efficiency of these technologies can be properly captured. As gasification and pyrolysis technologies mature, and Wright's Law of Technological Progress unfolds, the superior environmental credentials of both technologies will outweigh their higher capital costs. As such, we believe there will be significant public and private sector demand for those companies that are able to offer these more advanced waste management solutions.

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