REPORT

Plastic waste (r)evolution – Dynamic sector with growth opportunities

Global plastic waste management outlook in the wider context of municipal solid waste management

Roland Berger

Contents

Fast Facts

2.2 bn
tons of MSW

Key challenge: Extracting value from municipal solid waste can generate over EUR 800 bn per year by 2050

EUR 370 bn / year

Fast fact: For instance, the global market **value of plastic waste** can increase 12-fold to **EUR 370 bn per year by 2050**

45%
recycling

If we increase global plastic waste **recycling rates from 10% today to ~45% in 2050**

The global context of municipal solid waste

A continuous century of growth (from the 1960s to the 2050s)

1

"Waste is the only growing resource of our planet"

Summary: Municipal solid waste volumes are expected to continue growing, doubling by 2050 to ~4 bn tons, driven by demographics and consumption convergence, mainly in emerging countries in Asia and Africa.

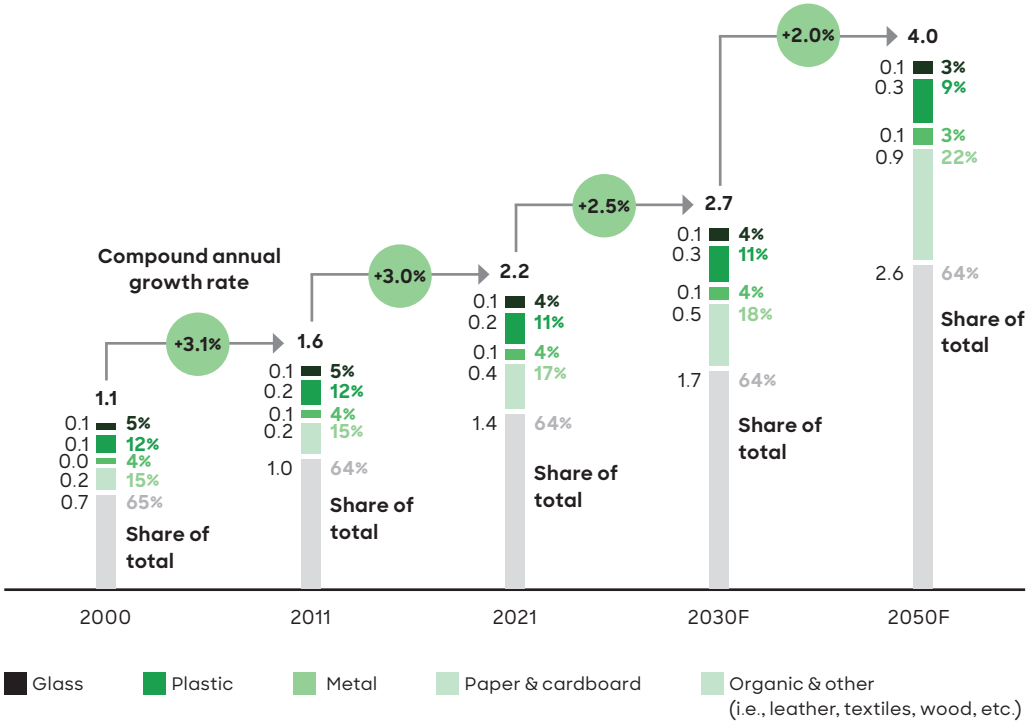
"Waste is the only growing resource of our planet" is a statement made by a UN official in the 1960s, which remains valid today and even more so in the future.

Between the 1970s and 1990s, global municipal solid waste (MSW) volumes expanded at approximately 8% per year due to growth in global population, economic development, and increased (convenience) consumption. Since the 1990s, the pace of MSW growth per capita has been slowing down within some developed economies at levels comparable to or below the rates of GDP expansion. This slowdown resulted from the "peaking" quantity of products a household can consume regularly and the growing awareness of environmental topics. The latter has triggered both the population's attention and the authorities' efforts to limit waste generation and ramp up waste recycling & recovery.

The current average volume of MSW generated globally is approximately 250 kg / capita per year. There are significant differences between developing economies (with values below 200 kg / capita) and developed economies (with values >500 kg / capita in Europe or >800 kg / capita in the US). At the same time, in developing economies, waste volumes (overall and per capita) have been continuously increasing at a pace similar to those previously observed in developed economies between the 1970s and 1990s (8-9%).

Driven by the same (historical) drivers of population growth and mass consumption, we expect global MSW volumes to continue increasing over the coming decades at annual growth rates of ~2-3% until 2050, thus doubling the overall annual global MSW volumes from today's ~2 bn tons to ~4 bn tons by 2050.

A Municipal solid waste and key recyclables volumes (fibers, metals, plastic, glass) global 2050 outlook [m tons]

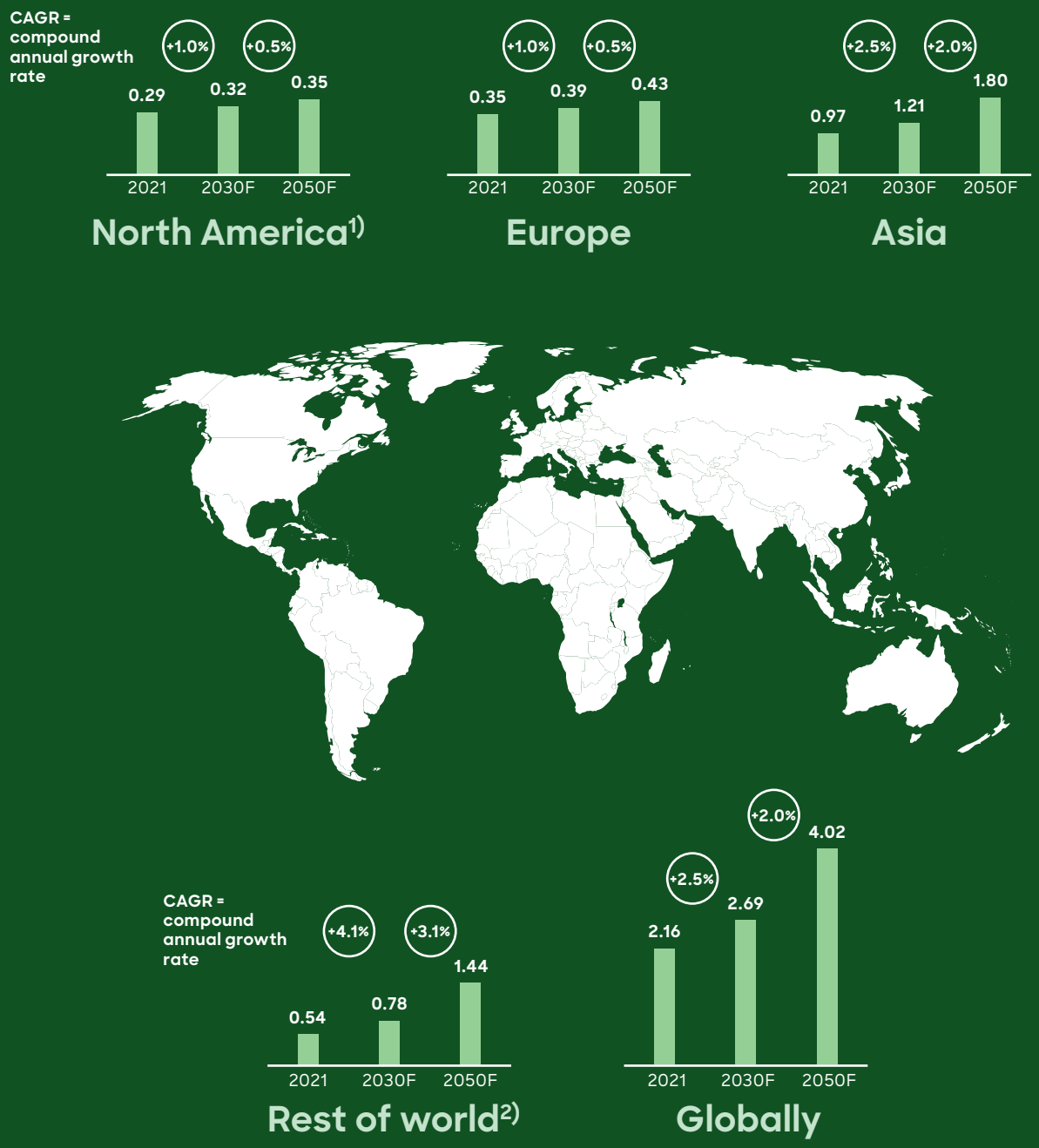


Source: OECD, World Bank, Plastics Europe, PRE, Roland Berger

The composition of MSW in developing economies will continue to evolve as their economies grow and consumption behaviors mature, from a high proportion of organics and non-recyclable waste (in developing economies) to a higher proportion of dry recyclable materials (in developed economies). For instance, today, the four most recycled non-organic components of MSW (fibers, metal, plastic, glass) represent a cumulative share of ~35% of global MSW, a portion which we expect to remain (relatively) constant until 2050. Driven by e-commerce, sustainability trends, and the increase of the fibers' share in MSW (as economies develop), we estimate a global compound annual growth rate (CAGR) of 6-7% for fibers waste. In turn, we estimate a slowdown in the growth rates of other recyclable materials (e.g., plastics, metal, or glass).

Geographically, it is reasonable to assume that MSW volumes will increase at a more accelerated pace in regions with higher population & economic growth. Within this scenario, by 2050, almost half of the world's ~4 bn MSW volumes are estimated to be generated in Asia and ~35% in Africa and Latin America.

B Municipal solid waste volumes, 2050 outlook by region [bn tons]

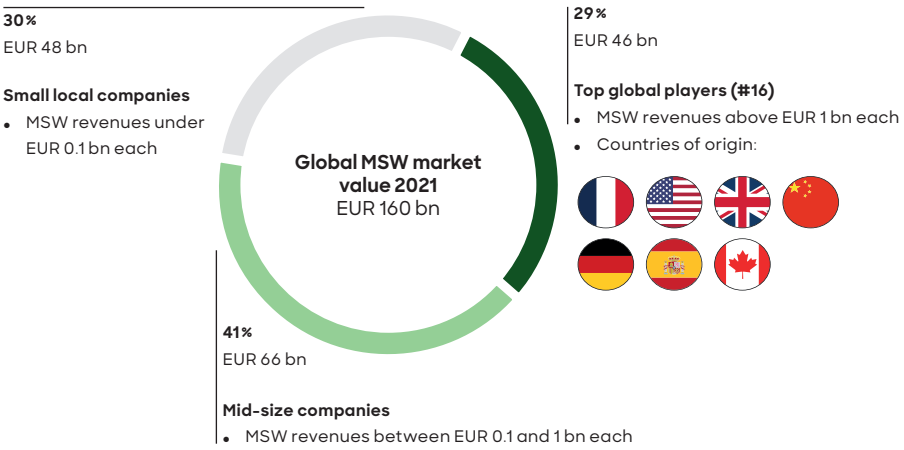


1) United States and Canada; 2) Africa, South and Central America, Middle East, Oceania

Source: OECD, World Bank, Plastics Europe, PRE, Roland Berger

The management of municipal solid waste has traditionally been a local business, historically dominated by local / municipal "champions," often majority-owned by state entities. Over time, with the increasing importance of capital and productivity / efficiency gains, certain private companies have gained the upper hand vs. the "slower" state-owned companies. This has allowed them to expand regionally or sometimes internationally. Today, across the globe, there is only a limited number (i.e., hundreds) of municipal waste management companies that exceed annual revenues of EUR 100 m and less than 20 companies with annual revenues from municipal solid waste activities exceeding EUR 1 bn. These top international players have benefitted well from economies of scale, cumulating 29% of the global municipal solid waste market.

C Current global municipal solid waste market structure, by type of companies (MSW business only)



1) Estimated number derived as % of MSW-derived revenue, from the total number of direct employees at group level – Does not include contractors or other affiliates; 2) Revenues from MSW considered, based on detailed analysis of reports; water, sewage, sludge and industrial waste revenues excluded; 3) Annual revenue above EUR 0.1 bn; 4) Annual revenue below EUR 0.1 bn

Source: ORBIS Global Database, S&P Global, Company Websites, Annual Reports, Market Research, Roland Berger

Recyclables with a “golden” future

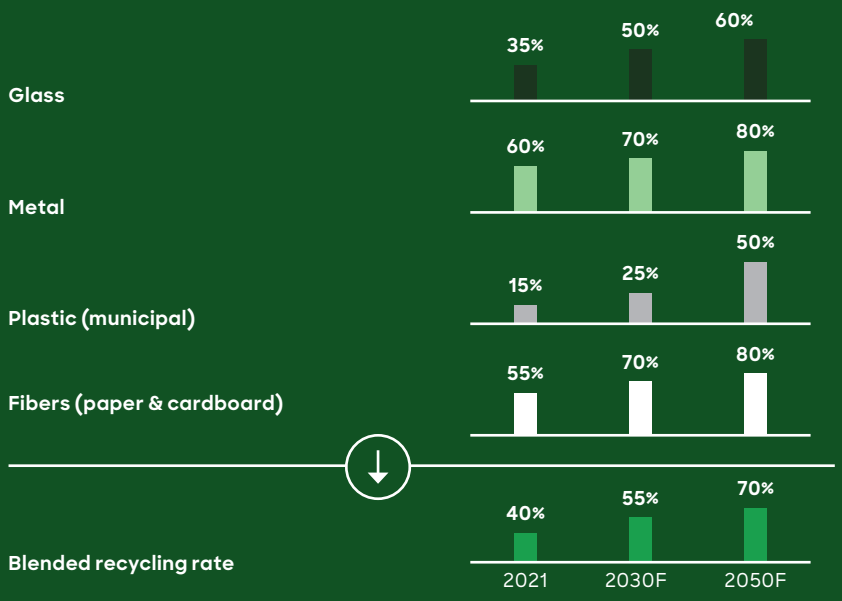
2

Summary: The share of recyclables (plastic, glass, fibers, and metals) in total MSW is expected to remain relatively constant globally. At the same time, recycling rates are expected to grow at an accelerated pace, driven by regulatory push and sustainability demand. The two effects will increase the MSW market value from EUR ~160 bn today to ~860 bn by 2050 (annual growth of ~6%).

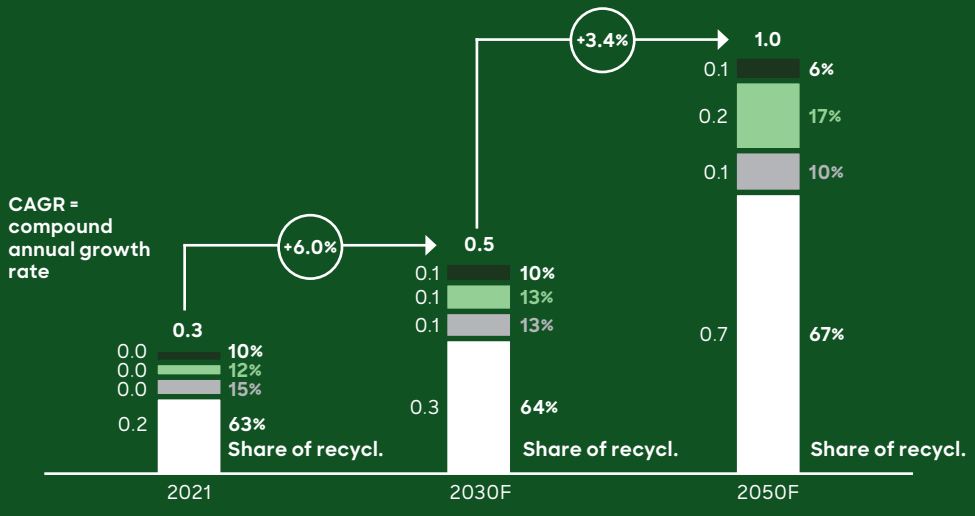
The **inappropriate disposal of MSW** can have a significant adverse environmental impact, releasing potent gases into the air, such as methane and CO2 emissions from the open burning of waste or failure to capture the landfill gas, and in the form of leakage into the environment as leachate (with effects on soil, water, ecosystems, etc.). Consequently, municipal authorities and the private sector have increasingly focused on improvements in waste management, improving arrangements for collection, sorting, recycling / recovery, and managing residual waste. As a result, MSW recycled volumes have ramped up in the past 30 years, already achieving, for instance, a blended global recycling rate of ~40% for the key four recyclables (plastics, glass, fibers, and metals).

D Recycling rates & resulting recycled volumes of key recyclables in MSW: glass, metal, plastic and fibers

Key recyclables outlook, recycling rates [%]



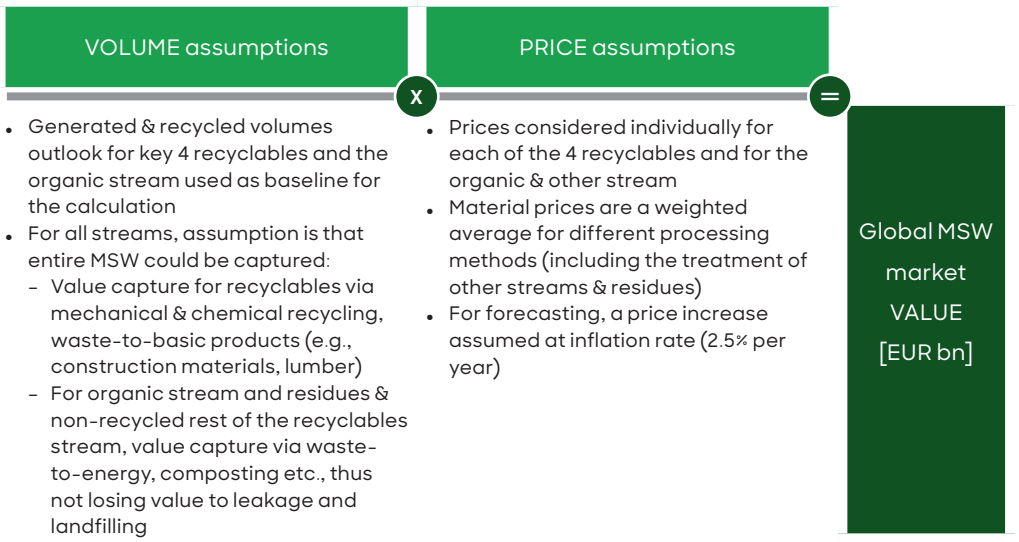
Key recyclables outlook, recycled volumes [billion metric tons]



Source: OECD, World Bank, Plastics Europe, PRE, Roland Berger

We anticipate the overall **recycling rate of the four recyclable materials** (fibers, metal, plastic, glass) to increase to around 70% (blended rate) by 2050 as a consequence of increased regulation and policy advancements, increased consumer demand for sustainability-based products and packaging, and virgin material substitution. This evolution would lead to a potential increase in the volume of recyclates for the primary four recyclable materials (fibers, plastic, metal, and glass), from ~300 m tons to ~1 bn tons (equivalent to an annual growth rate of ~4%).

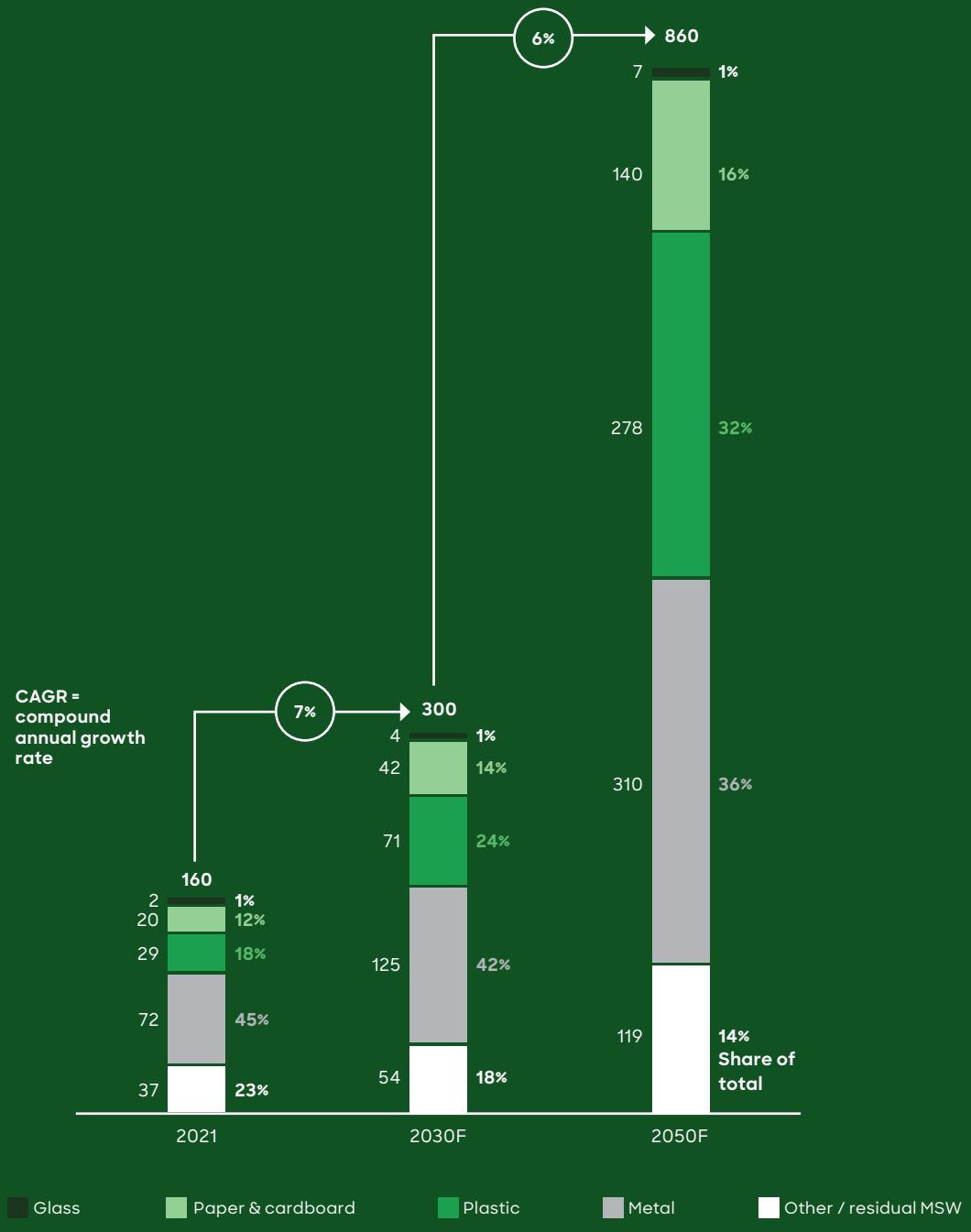
E Methodology Box for MSW market value estimation



Source: OECD, World Bank, Plastics Europe, PRE, Roland Berger

The resulting **total MSW market value** (recyclables and organic streams) **is estimated to grow by 6-7% CAGR, from EUR ~160 bn in 2021 to EUR 860 billion by 2050,** driven mainly by volumes and, to a lesser extent, by price increases of recyclates. As recyclate volume supply is expected to close today's gap to recyclate demand in the long term, we envisage only a slow recyclate price growth rate in the long term (~2.5% blended price CAGR by 2050, in line with inflation). In parallel, we expect an increase in the recyclate quality (e.g., food-grade or similar use) with an increasing share of source separation (even in developing countries), thus an overall long-term price decrease for the same quality levels, as global recyclate demand and supply are assumed to balance each other.

F MSW global market value today and 2050 outlook, by key components [EUR bn]



Source: OECD, World Bank, Plastics Europe, PRE, Roland Berger

Plastic: A valuable MSW component with high “visibility” rising fast since the 1960s

3

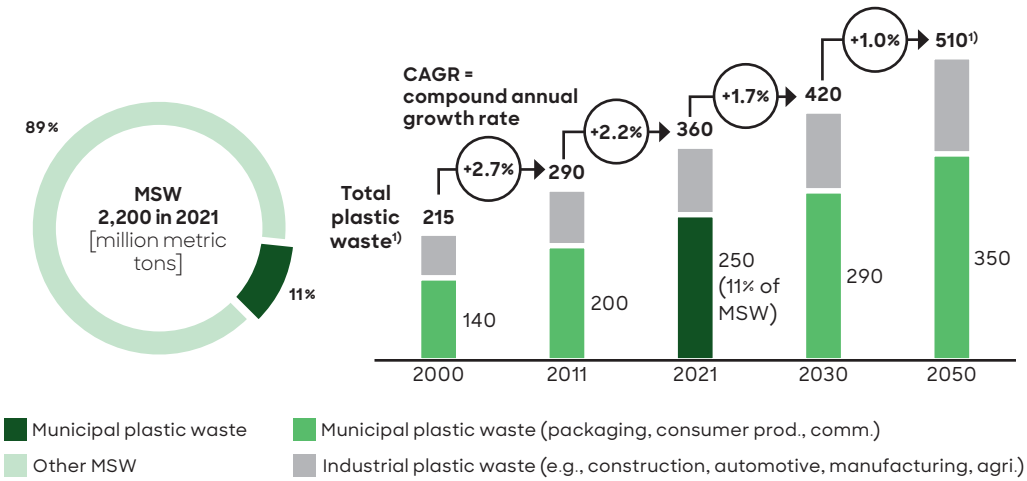
Summary: Plastic generation remains correlated with the increase in consumption. Therefore, plastic waste volumes will continue to increase over the next decades, but at a much slower pace (1%) than historically.

Municipal plastic waste volumes account for ~11% of the annual generated MSW volumes, with ~250 m tons generated annually. In addition to the ~250 m tons of municipal plastics (mainly packaging, toys, and other consumer and household products), there are another ~110 m tons of industrial plastic waste volumes generated by industrial-related activity (e.g., from construction, automotive, other manufacturing, and agricultural activities). Given that this study focuses on the end-of-life / recycling solutions for all plastic waste streams, we will consider **all 360 m tons of plastic waste (from both municipal and industrial waste) generated today for the purpose of the report.**

Plastic has emerged since the 1960s, shifting consumer products and packaging from heavier and less functional (protective) materials to plastic. Mass consumption was only possible with the emergence of plastic resolving the limitations in product expiration dates and logistics inefficiencies. Consumer markets were highly localized before the emergence of plastic. On the other hand, plastic waste has been an increasing environmental challenge due to its long decomposition time (hundreds of years), the effect of microplastics on wildlife, and its toxicity when openly burnt.

Plastic waste volumes have increased in developed countries at an annual double-digit growth rate between the 1960s and 1990s, with a slowdown of the volume growth rate only in the past 25 years. Developing and emerging countries have followed a similar trend (with a lag of 30-40 years). For instance, in the past 10-15 years, plastic waste volumes generated in Asia and Africa have increased at 4-5% per year, while in Europe or the US at 1% or less, thus resulting in a blended global growth rate of plastic waste generated of 2-3%.

G Global plastic waste volumes in the context of MSW volumes, 2050 outlook [million metric tons]



1) Incl. MSW plastic (e.g., packaging, consumer & institutional products, transportation packaging) & non-MSW plastic (i.e., electronics, building & construction, agriculture, automotive, industrial)

Source: OECD, World Bank, Plastics Europe, PRE, Roland Berger

We expect the slowdown in plastic waste generation to continue the trend seen in the past 15 years because of the pressure from various stakeholder categories (authorities, NGOs & consumers) to reduce volumes produced (mainly non-recyclable plastics). Nevertheless, recyclable plastic is superior to most others (from a functional and environmental perspective - Its substitution with other materials would eventually result in a higher environmental impact). We thus envisage a long-term annual growth projection of 1-1.5% until 2050, which will result in ~510 m tons of total plastic waste generated in 2050 (~350 m municipal plastic waste and ~160 m industrial plastic waste).

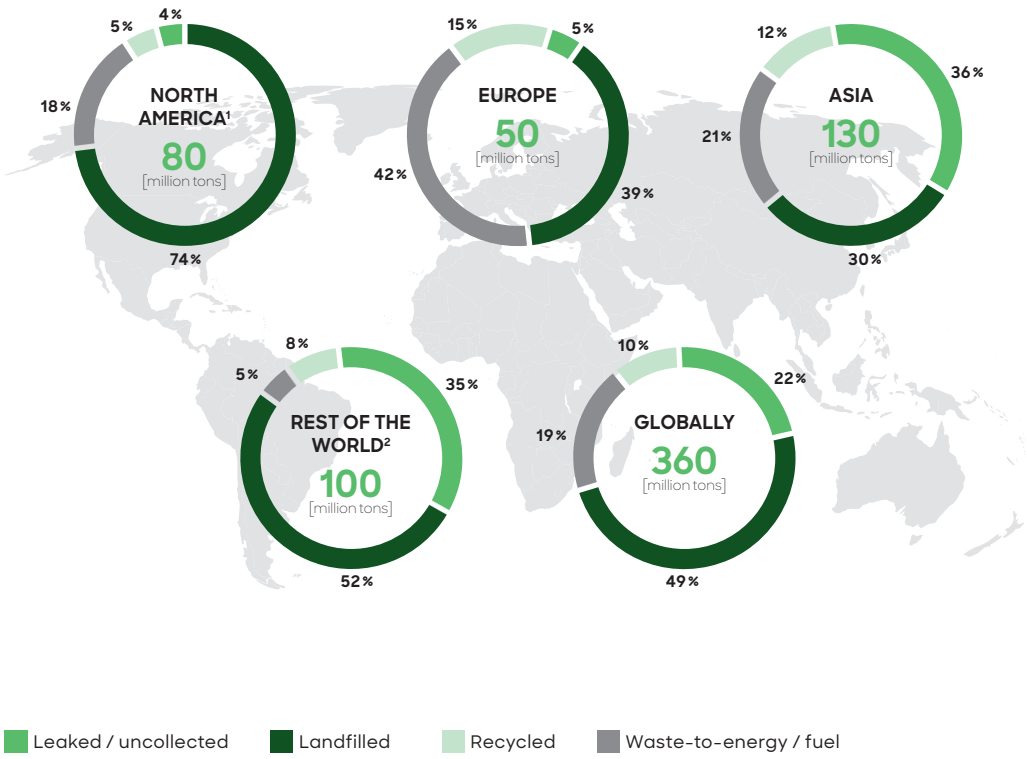
Plastic recycling becoming a key long-term investment opportunity

4

Summary: The current global total plastic waste recycling rate is at ~10% and is estimated to increase up to ~45% by 2050, mainly driven by sustainability demand, regulatory pressure ,and market forces (value of recycled plastic as substitute to virgin plastic). Mechanical & chemical recycling have excellent long-term growth perspectives (~5% and ~14% CAGR, respectively); waste-to-basic products (e.g., construction, furniture, lumber, etc.) to grow mainly in developing / emerging countries.

Currently, **globally, only ~10% of total plastic waste is recycled** (~15% of municipal plastic waste). 90% of total plastic waste volumes generated annually are either landfilled, incinerated (WtE), or leaked into the environment and openly burned (70 m, or ~20% of total).

H Global total plastic waste volumes end-of-life, by region, today



1) United States and Canada; 2) Africa, South and Central America, Middle East, Oceania, Non-EU Europe, Eurasia; 3) Total plastic waste includes both MSW plastic and non-MSW plastic waste; 4) Including chemical & mechanical recycling, waste to basic products (construction materials, lumber, fuel)

Source: OECD, World Bank, Plastics Europe, PRE, Roland Berger

Europe is the global leader in plastic waste recycling, with a recycling rate of approximately 15% in 2021. This percentage is expected to rise further as the European Union strengthens regulatory efforts to combat pollution and waste while setting ambitious targets for packaging and other waste categories such as WEEE and textiles.
There are three main drivers for the accelerated growth of recycling rates in the future: regulation, ESG / circularity targets of the private sector, and the intrinsic value of plastic waste as substitute raw material for virgin plastic:

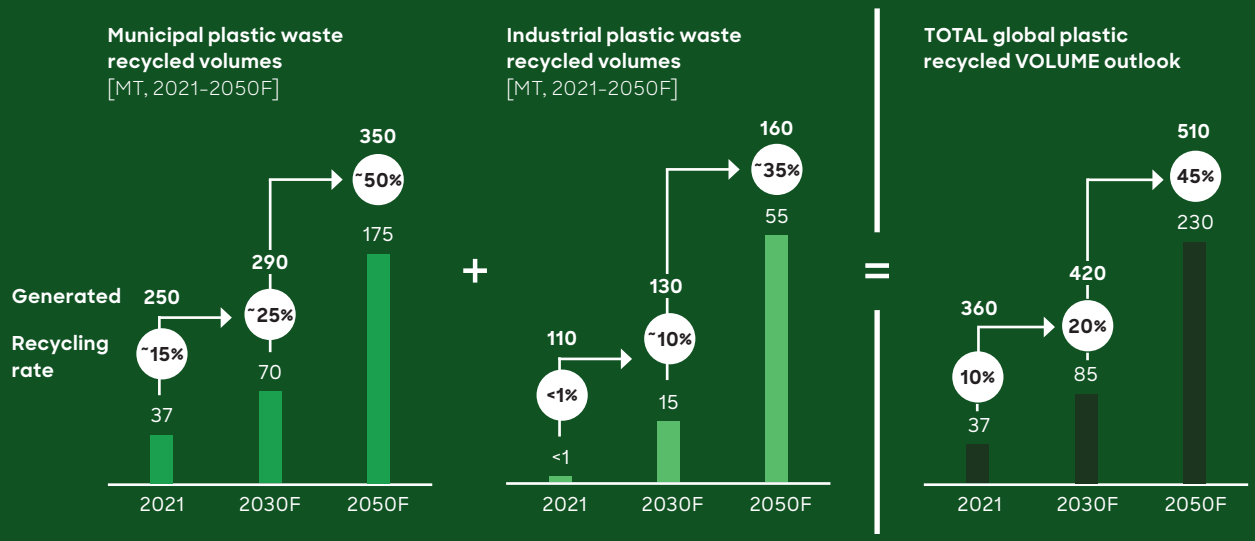
- **Regulation** is the central catalyst of recycling rates in the upcoming decades, in the form of policy support for infrastructure build-up (subsidies, min offtake price guarantees), setting of mandatory targets (for collection, recycling), the introduction of Extended Producer Responsibility (EPR), deposit schemes for beverage packaging (DRS) or by stimulating demand via recycled content requirements / targets and enforcing recyclability guidelines.

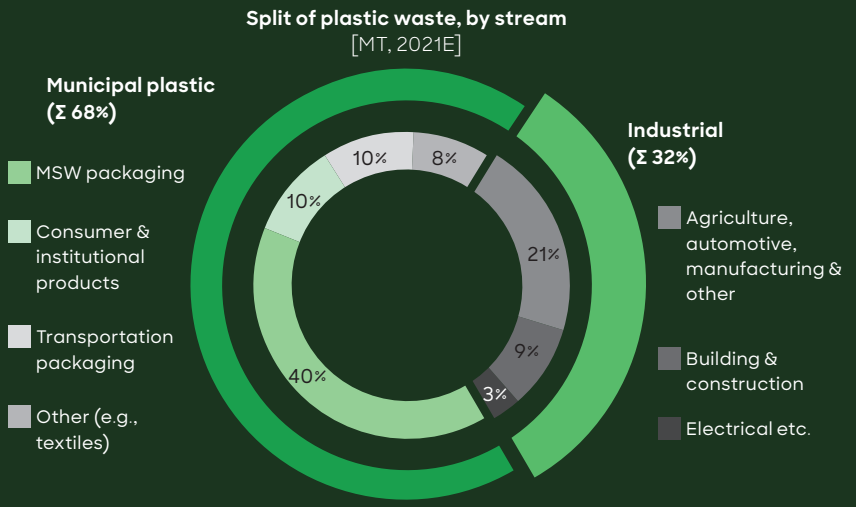
- **Individual company / industry level targets** (reflecting the end-consumer demand for sustainability), beyond regulatory targets, are also key in driving recycling rates, in particular in the countries where regulation on the matter does not exist (most countries across the world); this typically takes the form of efforts to support existing local initiatives, transfer expertise, and kick-start more significant investments; eventually, policy support needs to kick-in, to accelerate the evolution of the systems.

- **Market forces represent the 3rd driver of recycling targets**, relevant in particular for the high-value plastic streams (e.g., PET, HDPE, commercial film stream); these streams represent, however, only a minority share of total plastic waste; therefore, market forces are typically less relevant when it comes to driving recycling rates for other plastics (e.g., LDPE, PP, etc.).

From a **market value perspective**, we estimate the market for total plastic waste across all value chain segments (collection-sorting-recycling) to grow more than 12-fold from EUR ~30 bn today to EUR ~370 bn in 2050, driven by the increase of recycled volumes, both from the municipal and the industrial streams. Global prices of plastic recyclates are expected to stabilize long-term at the level of inflation, as the current recyclate demand gap will be closed (assuming the increase of plastic waste feedstock supply at 45% recycling rate by 2050).

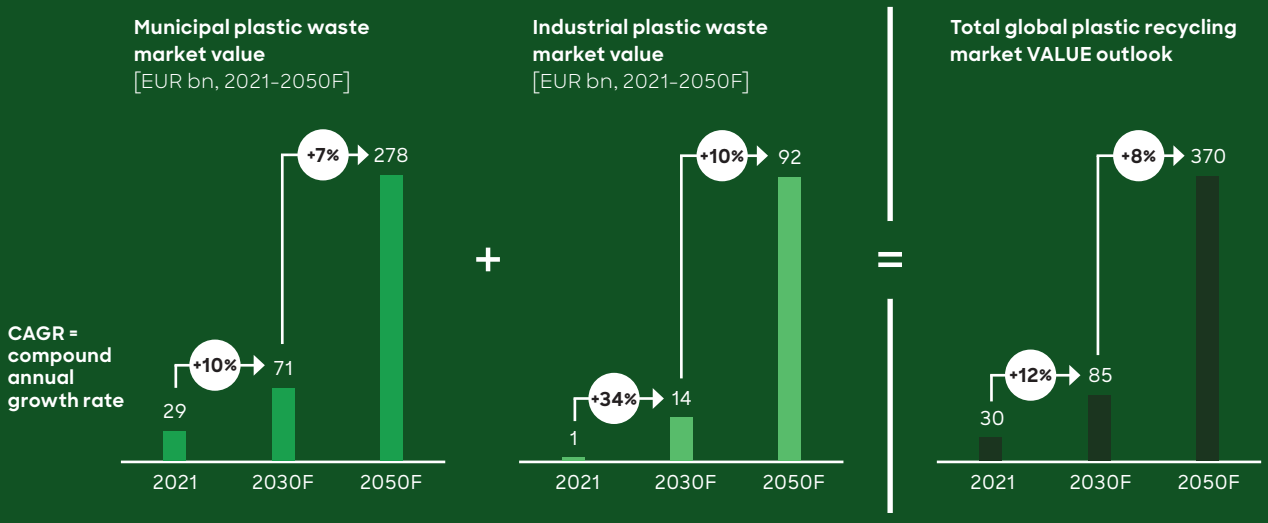
Global plastic waste volumes & value outlook, generation & recycling, split by stream (municipal vs. industrial)





Key observations

- Recycling rates of municipal plastic waste are substantially higher today, given the focus of regulations
- Recycling rates of industrial plastic waste expected to increase by 2050 at accelerated pace, driven by regulations and their fit for recycling (lower contamination levels vs. municipal stream)



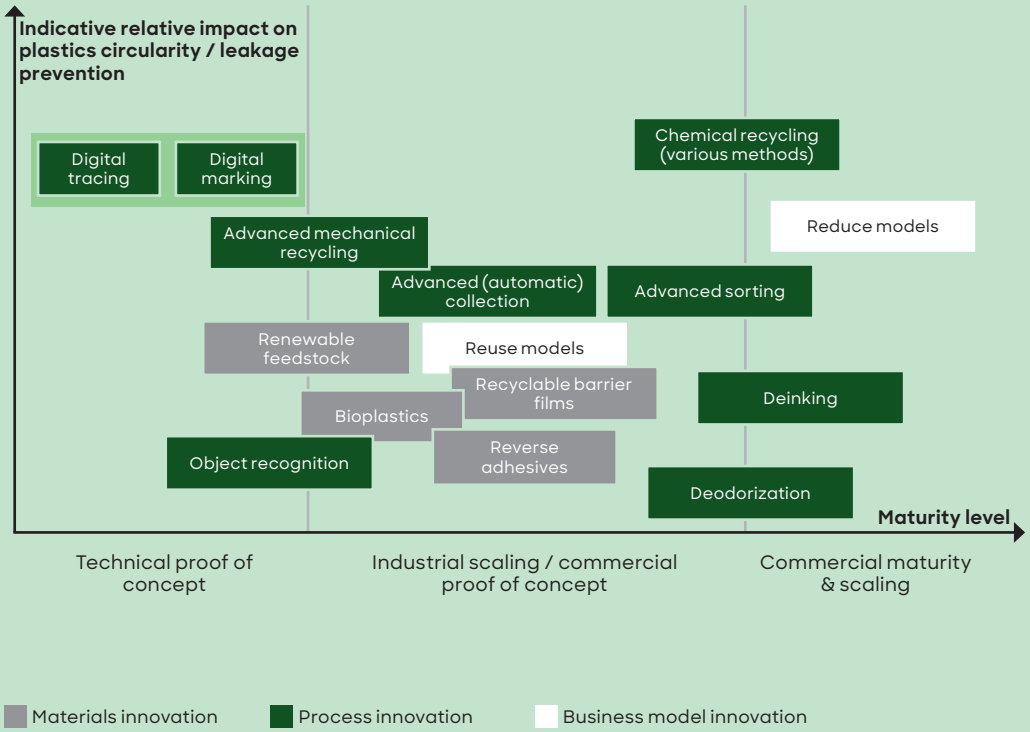
Source: OECD, World Bank, Plastics Europe, PRE, Roland Berger

The **value of the market** today is mainly split between collection and mechanical recycling, which we expect to remain the key buckets of value creation in 2050. We see, however, a slight shift in value creation from collection to sorting as investments in the Global South and technological innovation in developed systems are ramping up. We also expect a shift from waste-to-basic products (construction, furniture) to chemical recycling on the back of accelerated growth in the latter across all types of systems (both mature and less developed).

Investors consider both regulatory certainty and feedstock volumes, but also the **price of recyclate** when assessing the financial viability of plastic waste collection, sorting, and recycling. Recyclate prices are volatile and highly correlated with virgin plastic prices (with a typical premium of 5-30% on top of virgin prices) and are similarly exposed to transnational waste trade flows. The European plastic recycling sector's recent challenges, in the context of recyclate prices decreases impacting profit margins and loss of market share to imported recyclates, provide evidence of these exposures to prices and trading flows.

Innovation and technology are key catalysts for the assumed accelerated growth in the global plastic waste market. In this context, we see three types of innovation acting as enabling factors: chemical industry-driven innovation (new types of plastics, targeting a lower environmental impact), process / technical innovation (focused on improving cost efficiency and productivity / yields), and business model innovation (with the key objective to reduce the overall plastic waste generated).

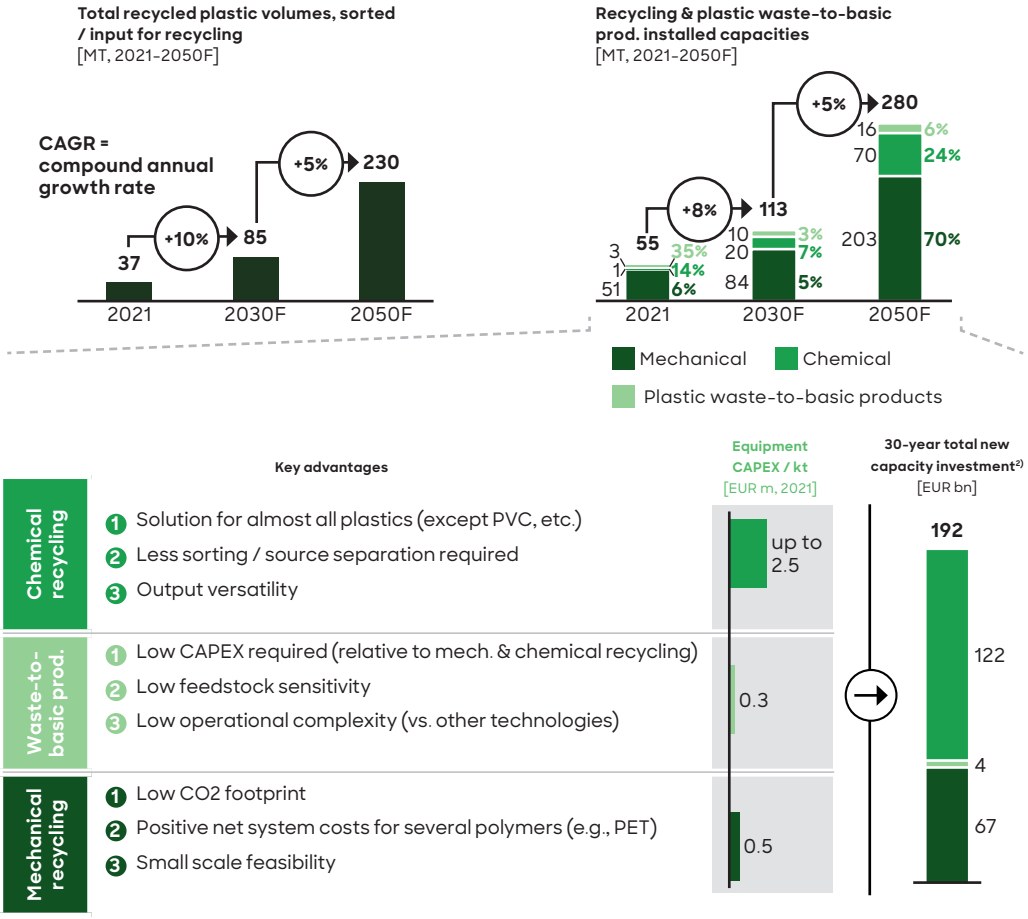
J Innovation as key enablers - Selected examples (non-exhaustive)



Source: Alliance to End Plastic Waste, Roland Berger

Chemical recycling will increase its importance in managing plastic waste, especially in large, urbanized countries with sufficiently concentrated feedstock (scale required for the economic viability of chemical recycling at ~50 kt / plant). The global chemical recycling capacity is expected to increase from ~1 MT in the present to 70 MT by 2050 (24% share of total recycling), driven mainly by the lesser requirements from sorting and the output versatility.

K Zoom-in on key plastic waste recycling by type



1) 192 bn. EUR total investment over 29 years, annualized; 2) On top of new capacities investment, there is also substantial additional amount of replacement / large maintenance investment, not considered here

Sources: OECD, World Bank, Plastics Europe, PRE, Alliance to End Plastic Waste, Roland Berger

Mechanical recycling keeps the advantage of a lower environmental impact and economic viability even at a lower scale, for specific high-value polymers. Therefore, mechanical recycling is expected to grow at a steady pace of 5-6% CAGR per year globally.

Processing of plastic waste-to-basic products (e.g., lumber, construction materials, furniture, etc.) is expected to also play a role in the overall recycling mix, particularly in developing / emerging countries, given the low CAPEX requirements and limited feedstock limitations.

Overall, we expect **capacities for plastic waste recycling (mechanical, chemical, and plastic waste-to-basic products) to increase more than 5-fold between 2021 and 2050,** thus requiring a total investment of ~EUR 190 bn over the next decades, i.e., EUR ~6 bn / year.

Policy frameworks are key waste recycling & recovery catalysts

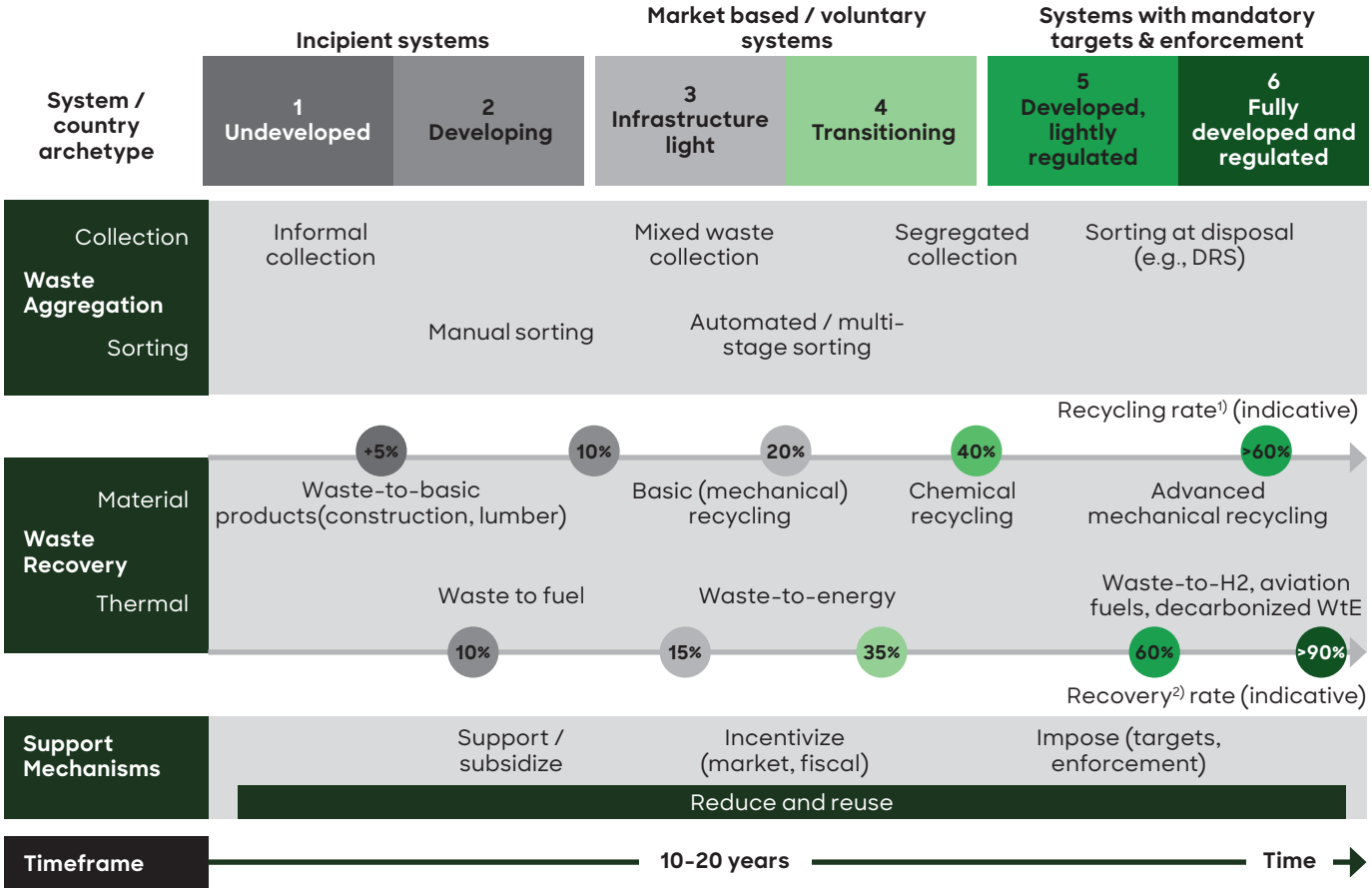
5

Summary: Policy frameworks are key drivers of recycling / recovery rates – depending on the maturity stage of each waste management system, a different set of policies is the best fit to drive system evolution. Next to policies, funding, innovation, and ecosystem development are also enablers of system evolution.

From an environmental and economic perspective, policy frameworks are the central pillar to drive waste recycling & recovery. Depending on the maturity stage of the waste management systems, in terms of infrastructure, market functionality, and stakeholder awareness, policies do act as support mechanisms to support, incentivize, and enforce a certain pressure on the waste (eco)system. Policies addressing overall reduction and reuse of plastics, in the areas where this makes sense from environmental and functional perspective, can be successfully promoted in all system archetypes.

Based on the **framework developed by the Alliance to End Plastic Waste and Roland Berger** on the evolution of municipal solid waste management systems over time, we typically see recycling & recovery rates correlated with the infrastructure development levels across the key segments of the value chain (collection-sorting-recycling / recovery) and the policy frameworks in place. A typical evolution of systems over time requires 10-20 years and is only sometimes linear.

L Roland Berger and Alliance to End Plastic Waste Municipal Solid Waste Management Framework



1) Recycling rate = material recovery, i.e. recycling and waste-to-basic products; 2) Recovery rate = material + thermal recovery
Source: Roland Berger, Alliance to End Plastic Waste

From a policy perspective, several elements have a structural impact on the evolution of waste management systems: disposal management (at the collection and landfill level), targets and incentives (along the value chain and for all key stakeholder categories), and enforcement.

Next to the **policy framework,** we also define a set of additional enablers that are essential in driving waste recycling & recovery rates:

- Developing the waste **ecosystem** in terms of data, guidelines, alignment of stakeholder incentives and behaviors, and expertise.
- **Funding** (from private and public or combined sources) in terms of ease of access, capital cost, and effectiveness.
- **Innovation** in terms of process automation and digitalization, materials, and business / operational models.

The long-term outlook for plastic waste management is positive, driven by environmental and economic considerations. A market expected to increase with double-digit growth rates over the next 30 years is poised to attract substantial investments, which may further benefit the innovation spiral and accelerate its development. The 2050 global MSW market outlook assumes that the waste management framework pillars will be successfully employed at national and supra-national levels (e.g., regional or UN). Evidence of this framework being deployed in practice over the past 50 years across 30-40 countries (in Europe, Japan, South Korea, or Canada) provides some assurance that this evolution will be repeated within the next three decades globally, resulting in the forecasted recycling & recovery rates and corresponding monetary value.

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