Building a bridge strategy for residual waste

Material Recovery and Biological Treatment to manage residual waste within a circular economy

Policy briefing

June 2020 – Zero Waste Europe

Index

Executive summary

"Addressing today's obligations and goals,
with no prejudice for tomorrow's ambition"

The *EU Landfill Directive* [1] requires the pre-treatment of waste before it is sent for landfilling. This is aimed at minimising the impacts of landfilling, but it causes an important side effect, in that it increases the cost of final disposal.

Incineration itself may be considered as a pre-treatment (as also mentioned amongst the possible treatments in the *EU Landfill Directive*), given that it leaves behind ashes and slags that (at least in part) need landfilling. Incineration, though, creates a lock-in effect which often prevents proper recycling, due to the need to continually feed incinerators with a given tonnage, ensuring the pay-back of investments and eventual profits.

There is a need to define suitable pre-treatment in a way that, whilst ensuring the negative impacts of landfills are reduced, keeps the flexibility required to continuously improve the performance of waste management systems, adapting equipment and operations to increasing amounts of clean materials (dry recyclables and biowaste) generated by separate collection. With regards to this, a "Material Recovery and Biological Treatment (MRBT)" system that combines biological treatment and sorting equipment allows us to "stabilise" the organics that are included in residual waste, so as to minimise their impact once buried in a landfill, while also helping to recover materials such as metals, plastics, paper that are still included in residual waste after separate collection. While pursuing the goals of the *EU Landfill Directive*, this option also embeds the needed equipment and processing systems that may support an ever-increasing amount of separately collected materials for recycling, as required by the ambitious mid and long-term targets of the EU's *Waste Framework Directive* [2].

[1] ec.europa.eu/environment/waste/landfill_index.htm
[2] ec.europa.eu/environment/waste/framework

Waste management in the circular economy age

Through the *Circular Economy Package* [3], the European Union (EU) has adopted an advanced roadmap on waste management. The EU has created a framework for Member States where waste management becomes a tool to help maximise efficient management of resources, whilst continuing to pursue environmental sustainability through the minimisation of waste and the maximisation of reuse and recycling.

The EU's *Circular Economy Package* has seen a number of positive developments in the following areas:

- A reduction in the extraction and importing of primary raw materials from other regions of the world, at a time when the world is urgently confronted with the scarcity of resources and the need to remain within planetary boundaries;
- Increases in the efficiency of our production and consumption model;
- The creation of new jobs, for example in separate collection, recycling and reuse activities, as well as through the adoption of new business models e.g. based on "*product as a service*", redesigning of production and goods for better reusability and recyclability, etc;
- Shifting costs of waste management from rewarding capital expenditures, to remuneration of workers.

With the points listed above in mind, the circular economy vision is all about preserving materials and resources in the system, minimising the so-called "leakages", such as landfilling and Waste-to-Energy (WtE). Indeed, energy recovery from waste (through incineration or co-incineration) destroys vast amounts of resources, requires the extraction of new primary raw materials, perpetuates a linear economic model and releases greenhouse gases (GHG) from fossil-based materials (e.g. mostly of plastics and artificial textiles). This practice clearly undermines the efforts of the European Union, which seeks to decarbonise the economies of Member States. Furthermore, it is an ineffective way of producing energy, with a higher unit emissions of fossil CO_2 per kWh than conventional fossil fuel power stations [4].

Whilst pointing towards the reduction of waste and maximisation of reuse and recycling, the *Circular Economy Roadmap* also requires proper consideration for the management of residual waste. As a matter of fact, options for managing residuals may influence the performance of waste management systems in two fundamental ways:

1. They may directly contribute to inflate the "burdens" of the system, from an environmental, climatic, economic and operational perspectives. For instance, as mentioned above, burning fossil-based materials may be a contributor to total GHG emissions from the waste management system [5];
2. But also, and even more importantly, it may affect the evolution of the system, when any waste related infrastructure helps create a *lock-in* situation [6] and impairs, or slows down, efforts towards waste reduction,

[3] ec.europa.eu/environment/circular-economy

[4] It has been calculated by ISPRA (Italian EPA) that in 2018 Italian incinerators emitted 554,2 g CO_2-eq/kWh (relative to gross production of energy, and including electricity and heat) while in the National Energy Mix the unit emission of fossil CO_2 per kWh was already as low as 281,4 g CO_2-eq/kWh.
The trend, as reported by EEA, is clearly towards further reduction of specific emissions from the energy mix, on account of a larger reliance on renewable sources in the future, which will make incineration a less and less favourable option. See also the Zero Waste Europe Report: zerowasteeurope.eu/library/klaipeda

[5] The EU Plastic Strategy mentions incineration in a negative way, remarking the massive release of fossil CO_2 from incineration of plastics: eur-lex.europa.eu/legal-content/EN/TXT

[6] "Lock-in" defines the problems in modifying a given scenario, due to past choices and investment: in waste management, the need to secure a fixed tonnage of waste so as to secure a pay-back of investments in technologies for managing it. It is particularly remarkable in the case of incineration:

and the maximisation of material recovery beyond the minimum recycling targets (65% preparation for reuse and recycling by 2035)

It is therefore of utmost importance to define a solid "transitional strategy" for the management of residual waste. A strategy which goes hand in hand with the transition from the current situation towards the full potential of the circular economy, so that **compliance with the regulatory obligations for disposal is ensured and, at the same time, lock-in is avoided by being flexible. This "bridge strategy" should also support the national strategies, local schemes and the EU waste management system as a whole, while working collaboratively towards waste reduction, increasing reuse, recycling and minimising disposal.**

The regulatory context: an assessment of requirements of the Landfill Directive

Recently updated through the *Directive (EU) 2018/850* of the European Parliament and of the European Council [7], the *Landfill Directive* (*Council Directive 1999/31/EC*), includes two key requirements:

- Minimisation of biodegradable waste to landfills with specific phased targets, and
- An obligation for pre-treatment of Municipal Solid Waste (MSW) prior to landfilling[8].

Thanks to the obligation to pretreat waste before landfilling, the Directive works towards the following strategic goals:

- Minimisation of environmental impacts from landfill sites,
- Increase of the cost of landfilling[9].

While infringement procedures [10] have rightly ruled that waste landfilled without pre-treatment does not comply with the obligation stipulated by the *EU Landfill Directive*, some industries have misleadingly argued that "*this implies the need to build incinerators*".

What the *EU Landfill Directive* defines as "treatment", in Article 2:

h) "Treatment" means the physical, thermal, chemical or biological processes, including sorting, that change the characteristics of the waste, in order to reduce its volume or hazardous nature, facilitate its handling or enhance recovery.

Hence, as much as "thermal treatment" (i.e. incineration or co-incineration) is included amongst eligible types of treatment, it is not the only one, nor is it compulsory to consider it. Other types of treatment are equally suitable, provided they ensure the goal to "*reduce the volume or hazardous nature of waste, facilitate handling or enhance recovery*".

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many areas which invested in high incineration capacities, currently show recycling rates that are stagnating or whose increase is particularly slow, which ultimately undermines the Circular Economy Roadmap.
See e.g. zerowasteeurope.eu/2019/08/nordic-countries-have-to-steer-away-from-incineration

[7] The new *EU Landfill Directive* also includes a Target, from 2035 onward, of maximum 10% MSW in landfills "in any given year". For a critical assessment of the target and related consequences, see the specific Zero Waste Europe policy briefing.

[8] Although there are possible relaxations, to be codified for specific cases such as for waste for which "*treatment does not contribute to the objectives of this Directive (...) by reducing the quantity of the waste or the hazards to human health or the environment*"). This may apply e.g. to areas with a very high capture of biowaste and minimised percentages of it in residual waste, hence reduction of fermentability may not be required.

[9] With the obligation to pre-treat, the cost of pretreatment adds on top of the cost of landfilling.

[10] See e.g. the "Malagrotta judgement" curia.europa.eu/juris/liste.jsf?language=en&num=C-323/13 and the EU-PILOT 2018/9328 against Spain.

Misleading requirements in national enforcements: the calorific value and related problems

Some EU Member States have adopted supplementary requirements to define the acceptance of waste at landfill sites. In particular, many countries have defined maximum calorific values for waste to be landfilled. This was first defined in Germany in the "Final Disposal Ordinance" (*Ablagerungsverordnung,* 2001 [11]) which stipulated that only waste with a calorific value lower than 6000 kJ/kg could be finally disposed of in landfills. Such regulatory requirements were first adopted before climate change policy was fully defined, and are based on the assumption that it is better to burn waste than to landfill it, even if the carbon footprint (with all emissions are considered) of generating energy with this feedstock is considerably worse than gas and clearly heavily polluting, in a scenario now that is dominated by renewable energy sources.

Similar provisions were subsequently adopted, albeit with different threshold values, in other Member States (e.g. Austria, Italy, Slovenia). It must be noted, though, that many decision-makers erroneously think that the threshold on calorific value is regulated by the *EU Landfill Directive*. This is not the case in fact, an approach, such as the one adopted in Germany before the C*ircular Economy Package*, may cause distorted effects that deviate from the circular economy agenda - in particular in those Member States where infrastructural plans for the effective management of residual waste, and related investments, are still being defined. Indeed, we see this type of requirement:

- Drives early investments towards incineration, since it is "needed to comply". Building capacities for incineration takes time, hence plans to comply with regulations are typically defined way in advance of the given deadline;
- Compels to plan and fund capacities aimed at burning plastics and other materials with high calorific value, which are still included in residual waste (e.g. non-packaging plastics which are not targeted by Extended Producer Responsibility - EPR - and related separate collection schemes). This contravenes, though, the principles to minimise the release of fossil fuel based CO2 emissions. A longer term climate and circular economy strategy for governments would instead consider reducing and redesigning the production of those materials, and increase recycling (these are the principles of the EU Plastic Strategy [12]).

In the short-term, a requirement on the maximum calorific value of residual waste to be landfilled could also undermine the efforts to separate organics and, particularly, food waste. One of most notable effects of the separate collection of biowaste is a remarkable increase of calorific values of residual waste (many districts where captures of food waste are maximised, get often well above 15.000 kJ/kg). Therefore, some regions and municipalities in Europe may delay programmes for separate collection of biowaste to avoid incurring the increase of calorific value, until there are capacities to burn residual waste.

Such contradictions, and their combinations, were the reason why Governments have repeatedly adopted temporary derogations, postponing its entry into effect (as in the Czech Republic), or finally repealed the threshold (as in Italy). Derogations and postponements, though, are far from providing clarity to decision-makers and stakeholders.

Above all, with such a requirement concerning the calorific value, local plans must be designed so as to comply with both what's strictly required by the *EU Landfill Directive* (pre-treatment) and also national requirements (maximum calorific

[11] Ordinance on the Environmentally Compatible Storage of Municipal Waste and on Biological Waste Treatment Facilities ("*Abfallablagerungsverordnung*").
[12] ec.europa.eu/environment/circular-economy/pdf/plastics-strategy-brochure.pdf

values). Consequently, once a derogation or postponement applies to a domestic regulation, which is not stipulated by the Directive, and related options are delayed, this also implies a postponement of compliance with the EU Directive.
This seems to be the case to explain the still missing capacities for an effective pre-treatment of MSW in many parts of Europe [13].

The most sound approach is therefore avoiding those problems from the start, refraining from considering additional requirements which are not included in the *EU Landfill Directive* and may become contradictory to the other goals and objectives of the circular economy agenda.

How to define "pre-treatment" appropriately

The goals of the *EU Landfill Directive* can be summarised as the minimisation of landfilling (quantity and capacity of landfill sites) and its related environmental impacts. The minimisation of the number and capacity of landfills in Europe should primarily be ensured through the reduction of waste and increasing diversion towards reuse, recycling and composting [14] while, the minimisation of negative impacts should primarily consider the reduction of biodegradability.

Indeed, it is biodegradability of MSW that causes:

- Fermentation of waste,
- Release of methane (which is only partly captured through gas wells and flaring systems [15]),
- Release in leachates of organic acids and other compounds that increase the potential of leachates to extract other hazardous compounds from the waste mass,
- Odours, and
- Attraction of birds, insects, pests.

With that in mind, the definition of "acceptable pre-treatment" should primarily consider *a* significant reduction in fermentability.

Germany was the first Member State where a definition of "acceptability" was adopted, with the *Technisches Anleitung Siedlungsabfaellen* (TASi, Technical Guidelines on Household Waste, 1993 [16]). The German guidelines, which were adopted before the *EU Landfill Directive*, defined the threshold in terms of volatile solids, which basically defines the organic content in residual waste. The very low acceptable threshold, though, fixed at 3% (on weight basis), could be met, but only by the ashes from incineration. The subsequent need for investments in incineration, and contradiction to other goals of waste management strategies, caused a later revision of the requirement, with the introduction of the previously mentioned *Ablagerungsverordnung* (Ordinance on final disposal, 2001). The Ordinance introduced the concept of "equivalency" of treatments (*Gleichwertigkeit*), that makes biological stabilisation "equivalent", provided it meets a

[13] In Italy, the threshold on the Calorific Value for waste in landfills, originally stipulated in 2003, was repealed in late 2015, after its entry into force had been repeatedly postponed for the contradictory effects to increased recycling rates, to diversion of biowaste through separate collection, and to the need to prioritise investments for recycling and composting. The Scottish Executive lately postponed a similar regulation until 2025: the Scottish "Landfill Ban" is actually a wider ban for waste landfilled with no prior pretreatment, but distorted effects are equally caused by the formerly planned need for more incineration capacity, and the subsequent need to wait until that capacity is available; intuitively, this implies many more years of untreated waste going to landfills.
[14] For a structured review of requirements of the *EU Landfill Directive*, and evidence on the importance of ZW programmes to minimise landfilling, avoiding options such as incineration that may cause lock-in, see the ZWE paper on the Landfill Target,
[15] Estimated captures of landfill gas for landfills in operation range from 10 to 80%: www.tandfonline.com/doi/abs
[16] *Technische Anleitung zur Verwertung, Behandlung und sonstigen Entsorgung von Siedlungsabfällen.*

"respirometric test". The test must demonstrate that the biodegradable part of waste has undergone a consistent mineralisation, hence a reduction of fermentability.

After the German Ordinance, other national regulatory frameworks have properly considered the definition of "effective pre-treatment" and acceptance through tests on fermentability. This may be tested through "respirometry tests" (such as SOUR[17] and DRI[18]) which assess the oxygen uptake by microbes as an index of residual fermentation potential[19], or through tests of potential methane production, which similarly, assesses how much of the remaining organic matter is likely to produce methane in anaerobic conditions such as those occurring in a landfill [20]

To summarise, the correct way to define "acceptance" and implement strategies devised by the *EU Landfill Directiv*e must be to test the fermentability of the waste mass after pre-treatment.

As we will better analyse further on, testing the fermentability of the waste mass after pre-treatment would help in several ways. Firstly, it helps achieve - and is consistent - with the overarching goals of the *EU Landfill Directive.* Secondly, it meets the key requirement to minimise fermentability of materials in landfills. Thirdly, it minimises the release of greenhouse gases [21], while also leaving room for flexible operational solutions that do not cause lock-in or prevent high performing recycling and composting systems. As we will explain further on, biological treatment is inherently flexible, since its processes may also be used, at a later stage, for clean materials derived from separate collection (composting of organic waste).

[17] ec.europa.eu/environment/waste/compost/presentations/stentiford.pdf
[18] ec.europa.eu/environment/waste/compost/presentations/adani.pdf
[19] This approach was included e.g. in German, Austrian, Italian Landfill Regulations.For a comprehensive review of ways to define acceptance at landfills through residual fermentability, see Müller, W. and Bulson, H., 2005: *Stabilisation and Acceptance Criteria of Residual Wastes - Technologies and their Achievements in Europe*. Proc. ORBIT Conference "The future of residual waste management in Europe, Future Challenges Regarding Climate Change and Sustainable Material Flow Management", Luxembourg, 2005.
[20] This was an approach originally included in the UK LATS (Landfill Allowances and Trading Scheme)
[21] In a nutshell, biological stabilisation degrades a large part of biodegradable organic matter, releasing biogenic (hence, climate neutral) CO2 from biogenic materials such as food scraps, which prevents later formation of methane after landfilling, minimises odours and attraction of pests, reduces the chemical strength of leachates. At the same time, fossil carbon of materials as plastics and artificial textiles is not turned into fossil CO2, which would otherwise constitute a net CO2 burden that exacerbates global warming.

Residual waste: just a load of valueless stuff?

Zero waste programmes [22], which are the perfect toolkit to turn the circular economy vision into an operational reality, have showcased and emphasised the importance of taking a deeper look into residual waste.

As a matter of fact, the composition of residual waste is a valuable source of information to assist with:

- Comparing and combining percentages in residual waste with tonnages of separately collected materials, which helps us to calculate the rates of recyclable and compostable materials
- Informing decision making on priority actions and strategies to be considered, in order to:
    - Improve the capture of materials that may be recycled/composted,
    - Redesign materials that cannot be recycled or composted, so as to make them reusable, recyclable or compostable, if not then to fully design them out of the production cycle,
- Visualising which types of materials may be worth targeting for further recovery before final disposal.

With regards to the last point, one must note that the separate collection rates which are being promoted in the EU's *Circular Economy Package*, cause a consistent reduction of residual waste, and imply a significant concentration of materials which are not yet captured through separate collection[23]. These include materials not currently targeted by separate collection, such as non-packaging plastics which are not covered by EPR schemes, but also materials which should be collected separately, but may erroneously be delivered with residual waste.

Following a similar pattern, plastics tend to show a particularly remarkable "concentration effect" as previously described, related above all to non-packaging plastics which ordinarily are not targeted by separate collection schemes triggered by Extended Producer Responsibility (EPR).

In order to assess the nature of residual waste after the implementation of advanced separate collection systems, as foreseen in the *EU Circular Economy Package*, one may consider the composition of residual waste in areas where a separate collection for main materials to be targeted (packaging waste and biowaste) has already been successfully implemented. In particular, it is important to see the effect on residual waste, in those areas where the specific obligation for separate collection of biowaste (which is stipulated by article 22 of the new *Waste Framework Directive*, with a deadline by 31 Dec 2023) has already been enacted.

Table 1a and 1b report on the average composition of residual waste in 2019 in the City of Milan (Pop. 1,35 M), and in 2016 and 2017 in the Slovenian capital Ljubljana (pop, 300.000); in both situations, kerbside collection includes food waste for both large producers (HoReCa sector, greengrocers etc) and households, and separate collection rates of 65-70% have been met overall [24].

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[22] zerowastecities.eu

[23] By way of an example, we may consider the concentration of paper in residual waste, assuming we start from approximately 25% of paper in MSW (or some 100 kg/person, assuming a specific MSW production of 400 kg/person in a given area per year); even with comparatively high collection rates of paper (for example, 80%), still 20 kg/person.year of paper will end up in residual waste. In circumstances where 75% of MSW is separately collected, residual waste is as little as 100 kg/person.year (25% of 400 kg). Hence, the "concentration effect" would finally determine a percentage of paper in residual waste as high as 20% (20 kg/person of paper out of 100 kg/person residual waste), which is not a negligible percentage.

[24] Milan, as a large, densely populated city was considered on purpose, so as to check what the effects may be also in situations where operational implementation of separate collection, in particular of biowaste, may be made more difficult by underlying housing conditions.

The analysis of residual waste in Milan and Ljubljana shows two important factors to be considered when contemplating MRBT:

1. A relatively intriguing percentage of fibers[25] and plastics (to a minor extent, metals) which may be worth considering for further recovery of materials;
2. A comparatively low percentage of biowaste (when compared to MSW), which should make residual waste less "dirty" (and sticky), a precondition to make any equipment adopted to process waste into different streams more efficient.

MATERIAL	MILAN (Average 2019)
WEEE, HHW	0.1%
Paper and cardboard	29.3%
Other paper	3%
Plastic tableware	1.1%
Plastic packaging	13.1%
Other plastic	2.2%
Textiles, leather & rubber	6.6%
Iron	3.6%
Aluminum	0.8%
Multi-layer	1.1%
Bio waste	11.1%
Glass	5.8%
Nappies	6%
Fines <20	13.1%
Garden waste	3.1%
Total	100%

***Table 1**: Composition of residual waste in the City of Milan (pop. 1,35 M) after separate collection of packaging waste and biowaste, achieving 60-65% separate collection (personal communication, data from 2019).*

[25] "Fibers" are commonly used to comprehensively address cellulosic materials as paper and cardboard.

MATERIAL	LJUBLJANA (average 2017)
WEEE, HHW	0.87
Paper and cardboard	21.5%
Other paper	3.88%
Plastic (LD-PE, PP.PET,HD-PE)	10.08%
Other plastic	11.79%
Textiles, leather & rubber	7.67%
Iron	2.53%
Other metals	2,31%
Biowaste	10.91%
Glass	2.29%
Nappies	10.34%
Fines <20	10.91%
Treated wood	1.83%
Other waste (bones, ceramics, stones...)	2.11%
Tetrapak	0.99%
Total	100%

***Table 2**: Composition of residual waste in 2017 in the City of Ljubljana (pop. 300.000) after separate collection of packaging waste and biowaste*[26].

[26] ebm.si/zw/wp-content/uploads/2018/04/ZW_porocilo_MOL_2018.pdf

The concept of Material Recovery and Biological Treatment (MRBT)

A "bridge" strategy for residual waste management should be designed in a way that simultaneously:

1. Compliance with the obligation on pre-treatment to ensure the consistent reduction of negative impacts, with specific regards to fermentability of biodegradable materials, as we have discussed in previous sections;

2. A reduction of the total volume/weight of materials being subsequently landfilled [27];

3. Above all, while pursuing goals 1 and 2, any effective residual waste management strategy should keep the needed operational flexibility within the system. This is to avoid any potential lock-in of the need for waste to be continually generated, ensuring that the designed system may flexibly adapt to increasing amounts of separately collected materials and subsequent decreasing amounts of residual waste.

With regards to the last goal, options to process residual waste should include equipment which may be used, at a later stage, to deal with separately collected materials. An incinerator can only burn materials (apart from marginal recovery of metals) and turn them into energy, which would contravene the overarching principle of circular economy of keeping *materials* in the loop. The same principle applies to the traditional concept of MBTs (mechanical-biological treatment sites [28]). MBT sites use specific equipment to produce RDF (Refuse-Derived Fuel) from the burnable fractions, such as paper and plastics. This equipment can't be adapted either to process clean, separately collected materials, since making them into RDF would contradict the goal itself of separate collection (which is aimed at recovering materials).

If one considers, though, replacing the RDF-production units in MBT plants with equipment to sort residual waste and recover the materials which are worth recovering (see previous section) this could help ensure the:

1. Reduction of the negative impacts at landfills, due to the biological treatment of the dirty organics;

2. Sufficient diversion of materials from landfills, due to process losses [29] from biological stabilisation and the recovery of some of the other materials [30];

3. Flexibility of the operational lay-out, given that the sorting systems may similarly be used with materials from kerbside programmes for further separation of different metals, different polymers and different paper grades after separate collection, to help enhance the effectiveness of collection and subsequent recycling systems.

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[27] This should better be assessed, though, in terms of total tonnages (or kg/person, to make it comparable across districts with different demographic conditions) that a certain area is finally delivering to a landfill. In other words, it is not that important the percentage of residual waste that gets finally landfilled after pretreatment, but the tonnage that percentage applies to. See also the ZWE paper on the Landfill Target (and keep in mind its key message that 10% of a cake is way more than 100% of a biscuit).

[28] A traditional MBT scheme includes a biological treatment section to stabilise the fermentable part of waste, and a section that mechanically processes dry fractions into a material with a high calorific value, called Refuse Derived Fuel.

[29] "Process losses" refer to the release of biogenic CO_2 and water vapour during stabilisation of the biodegradable part of waste.

[30] In a long-term vision to minimise landfilling, it is not the percentage of recovery that matters, but the number of tonnages it refers to. Hence, the flexibility of the system becomes the overarching goal, while efficiency of recovery from residuals may be considered as a "coordinated goal", although not the most important one.

The combination of these operational goals can be described as "Material Recovery and Biological Treatment" (MRBT [31]). This is key as it distinguishes the differences from old-fashioned MBT [32] to emphasise the intended goal of merging the recovery of some waste materials and the biological stabilisation of fermentable materials before landfilling.

When discussing and examining MRBT, one key operational principle must be considered throughout:

Biological stabilisation of organics included in residual waste is only aimed at reducing fermentability and related impacts when landfilled. It is not an option for producing compost, nor should it ever be considered for that.

The foregoing takes into account the contamination of organics with other materials from the mechanical separation of waste. There is overwhelming evidence [33] that showcases the efficiencies of separate collection as a precondition, in order to ensure the quality of composted materials, thereby maximising the benefits of this procedure and avoiding any potential negative impact.

In fact, this was translated into one of the key provisions of the EU's Circular Economy Package, the newly revised Waste Framework Directive, which stipulates:

> *(art. 22) Member Member States shall ensure that, by 31 December 2023 (...) bio-waste is either separated and recycled at source, or is collected separately and is not mixed with other types of waste.*
>
> and
>
> (art. 11a) As *from 1 January 2027, Member States may count municipal bio-waste entering aerobic or anaerobic treatment as recycled only if, in accordance with Article 22, it has been separately collected or separated at source.*

Article 22 requires separate collection as the **prerequisite** to have composted materials that are suitable for use on land without any detrimental effect. Article 11a, instead, has often been interpreted as a "ban on Mechanical-biological Treatment," and thus a driver towards incineration; in fact, Article 11a only stipulates that "compost-like outputs," which have been described sometimes as "mixed MSW compost," may not be counted as "recycled". *Biological stabilisation may, though, still be considered as a way of pre-treating waste before landfilling*, with related benefits in terms of reduced impacts and flexibility.

[31] See also here for an introductory analysis of environmental performances of MRBT zerowasteeurope.eu/2013/05/what-to-do-with-the-leftovers-of-zero-waste
[32] The key difference being the fact that MBT includes equipment to produce RDF, while MRBT replaces it with systems to recover materials.
[33] ec.europa.eu/environment/waste/compost/pdf/hm_finalreport.pdf

Possible structure and operational goals of MRBT

Keeping in mind the operational goals of pre-treatment within a sustainable, flexible and adaptable strategy, MRBT should basically include three sections:

- **A section to separate dry materials from organics.** The easiest way to accomplish this is to install primary screens after bag openers. Primary screens allow most dry materials, such as paper, plastics, metals, and cartons, to end up with the larger, more coarse materials, while most organics will get diverted into the smaller materials.

- **A "mechanical sorting" section.** This is for the coarse, dry materials that are separated from the organics at the beginning, with the combination of many or all of the following equipment:

    - Ballistic separators: these sort materials into 2D/3D streams, hence they may select materials such as plastic films from bottles;
    - Optical sorters: these help the separation of materials based on color, shape, structural properties and chemical composition, sorting for example different polymers or different paper grades;
    - Magnets: to separate ferrous metals;
    - Eddy current separators: to separate non-ferrous metals;
    - Extruders: which may increase the total recovery rates, by making mixed low-grade polymers into new aggregates.

  The combination of different processes and related equipment may be designed in order to recover specific materials of interest. These could be defined as the materials with the highest percentages within the residual waste, their value on the market or the related cost of separation and cost of landfilling.

- **A biological treatment section** for mechanically separated organics, which should operate a "composting-like" process, designed to reduce fermentability and achieve "stability" of the organics. For example, this could be a marked reduction of the biochemical activity, so as to minimise the related impacts once landfilled. Such a section should be based on similar operational principles to composting, such as:

    - Forced aeration to supply oxygen and drain excess heat out of the system;
    - Turning, if/when needed, so as to make the mass more dense again and conductive to forced aeration;
    - An odour treatment section, including at least biofiltration (which is the most effective odour abatement system, in the case of exhaust air from biological treatment and composting) coupled with wet scrubbing in most sensitive locations.

One may also consider including anaerobic digestion in the scheme, so as to improve the energy balance and retain biogenic carbon, in the form of methane, in order to use it as a renewable replacement for fossil fuels. Anaerobic digestion should, though, be followed by final aerobic biological stabilisation of the digestate to minimise the fermentability of waste before landfilling.

The combined effects of the 3 aforementioned sections of structuring an MRBT means that the system is able to achieve, at the same time:

- An increased biochemical stability of fermentable materials, helping to minimise the negative impacts once such materials are buried in landfill;
- A reduction in total weight of landfilled waste, thanks to both:
  - Process losses (i.e. CO2 and water) from biological stabilisation,
  - Recovery of materials (metals and/or plastics and/or paper);
- Increased flexibility and adaptability within the system to:
  - Increase the amount of clean organics which can be processed separately, in order to produce compost (the system must be designed so that it can be run in a modular way),
  - Increase the volume of dry recyclables from separate collection, operating on different working shifts for separate collection and for mechanical treatment of residual waste.

In a zero waste oriented approach, it would be of fundamental importance to also include a **dedicated area where a permanent "Zero Waste Research Centre on hard-to-recycle goods and materials" should be hosted**. This would focus on items in residual waste which may be addressed through redesigning or new business models so as to make them reusable/recyclable. Such models have already been shown to be successful in addressing materials that were not recyclable, and were subsequently redesigned through the involvement of the industrial responsibility [34], or targeted by new business models based on "product as a service" (as e.g. in the case of cloth nappies with a centralised washing service).

Ideally, such a Zero Waste Research Centre should involve Universities, designers and all those having skills and expertise on problematic materials, related problems in recycling operations, product design and innovative business models.

As regards to the "recovery potential" of MRBT sites, this varies depending on the composition of residual waste and operational designs that are adopted. It is important to note here that:

1. Recovery of materials from residual waste is adopted, with various degrees of complexity, at different sites. Certainly, the efficiency of material recovery in MRBT systems cannot be equal to the efficiency of recovery from separately collected materials, which is the key reason why EU strategies and zero waste schemes prioritise separate collection. However, it may still deliver material streams that can be recycled and marketed.

[34] See e.g. this article on actions undertaken after research on residual waste by Zero Waste Italy, which eventually involved producers of coffee capsules to have them redesigned for recyclability www.zerowasteitaly.org/the-open-case-study-of-the-zero-waste-research-center-of-capannori-lucca-on-the-lavazza-coffee-pods-starts-delivering-results

2. The simplest of the approaches is the separation of metals (ferrous and/or non-ferrous) which is ordinarily practised also at old MBT sites [35]. Today, an increasing number of sites have also adopted separation of plastics, cartons and fibers [36].

3. The rates of material recovery highly depend on two underlying conditions:

    - The composition of residual waste, which is connected to the evolution and structure of separate collection. For example, at the highest separate collection rates, plastics tend to concentrate in residual waste, particularly for the "non-packaging plastics" that are not targeted by separate collection;

    - A large influence is exerted by the percentage of organics in residual waste. A low percentage increases efficiency of sorting equipment and value of recovered materials, since residual waste looks less dirty/sticky, and behaves better through sorting systems [37]. While high percentages of organics in residual waste (as those that may be typically found in schemes where separate collection of food waste hasn't been implemented, yet) may allow for some recovery of metals and plastics, when the concentration of organics gets minimised a more aggressive separation may be included at this stage, helping to enlarge the scope of the targeted materials to recover, such as fibers;

4. There may be some interest to further increase the recovery of plastics, through such processes as extrusion, which may blend various polymers into heterogeneous aggregates for durable applications. Much as extrusion may definitely be labelled as a "downcycling" option, hence hanging at lower tiers of the waste hierarchy, still it may meet relevant technical standards for various applications, such as pallets, tiles, drainage pipes, etc.

5. As already noted, the landfill diversion through material recovery is complemented by the diversion that comes from process losses, which are achieved through stabilising the fermentable part of the waste mass.

All duly considered, MRBT may be designed in a way that meets different desirable levels of diversion and material recovery, depending on the value of materials, the cost of landfilling, and how important it is to achieve a higher percentage of diversion.

Table 3, in the next page, reports various levels of diversion, and the way they may be combined.

[35] Typically, at most MBT sites material recovery options are combined with RDF production so as to maximise diversion from landfills; percentages of RDF on the total mass balance, though, become marginal (hence, may finally be dismissed) at sites where material recovery options target various materials.

[36] www.avr.nl/en/plastic-separation-from-residual-waste-bag and docplayer.net/34604553-Materials-recovery-from-municipal-solid-waste-ecoparc-4-barcelona-a-case-study.html

[37] It must be noted that consistent diversion of organics will soon be the ordinary situation across Europe, on account of the obligation for separate collection and management of biowaste as stipulated in article 22 of the Directive. This highlights a remarkable cross-consistency between advanced CE scenarios, and adoption of treatment systems for residual waste based on recovery of materials.

TYPE OF DIVERSION / TARGETED MATERIAL	POTENTIAL DIVERSION[38]	AFFECTING FACTORS (IN ORDER OF IMPORTANCE)
Process losses from biological stabilisation	10-20%	Dependant on: 1. Percentage of organics in residual waste 2. Duration of stabilisation (usually the best trade-off between length and costs of the process and achieved stability is met around 4-5 weeks; this may ensure some 40-50% mass loss from stabilised materials, depending also on the degree of moisture)
Metals (Fe and non-Fe)	2-6%	Dependant on percentage of metals and whether separation targets ferrous, non-ferrous or both
Plastics	5-25%	Dependant on: 1. Percentage of plastics in residual waste 2. Number of optical sorters 3. Adoption of extrusion to maximise recovery 4. Adoption of hand-sorting for 2D plastics (films)
Fibers (paper, cardboard)	5-15%	Dependant on: 1. Percentage of fibers in residual waste 2. Percentage of organics in residual waste (affects practicability of recovery operations) 3. Number of optical sorters 4. Adoption of hand-sorting for e.g. cardboard

Table3: *a schematic list of different contributions in terms of mass balance to diversion from landfills through MRBT for residual waste.*

The most important factor to consider throughout is the possibility to keep the system flexible, ensuring the ability to adapt to dwindling tonnages of residual waste as progress is made towards a circular economy. The reduction of tonnages of residual waste may be compensated by the increasing amounts of separately collected materials, still keeping an operationally/financially viable situation, and avoiding any tension at the interface between separate collection, circular economy and the need to use the installed capacities, designed at a time when residual waste was significantly more relevant.

[38] As a percentage of input materials to the MRBT site. Needless to say, the highest percentages are competing with each other, since the higher the presence of any given material, the lower the presence of others. Highest recovery rates are currently around 30-35% of residual waste, which may be complemented by a further 10% process loss from stabilisation.

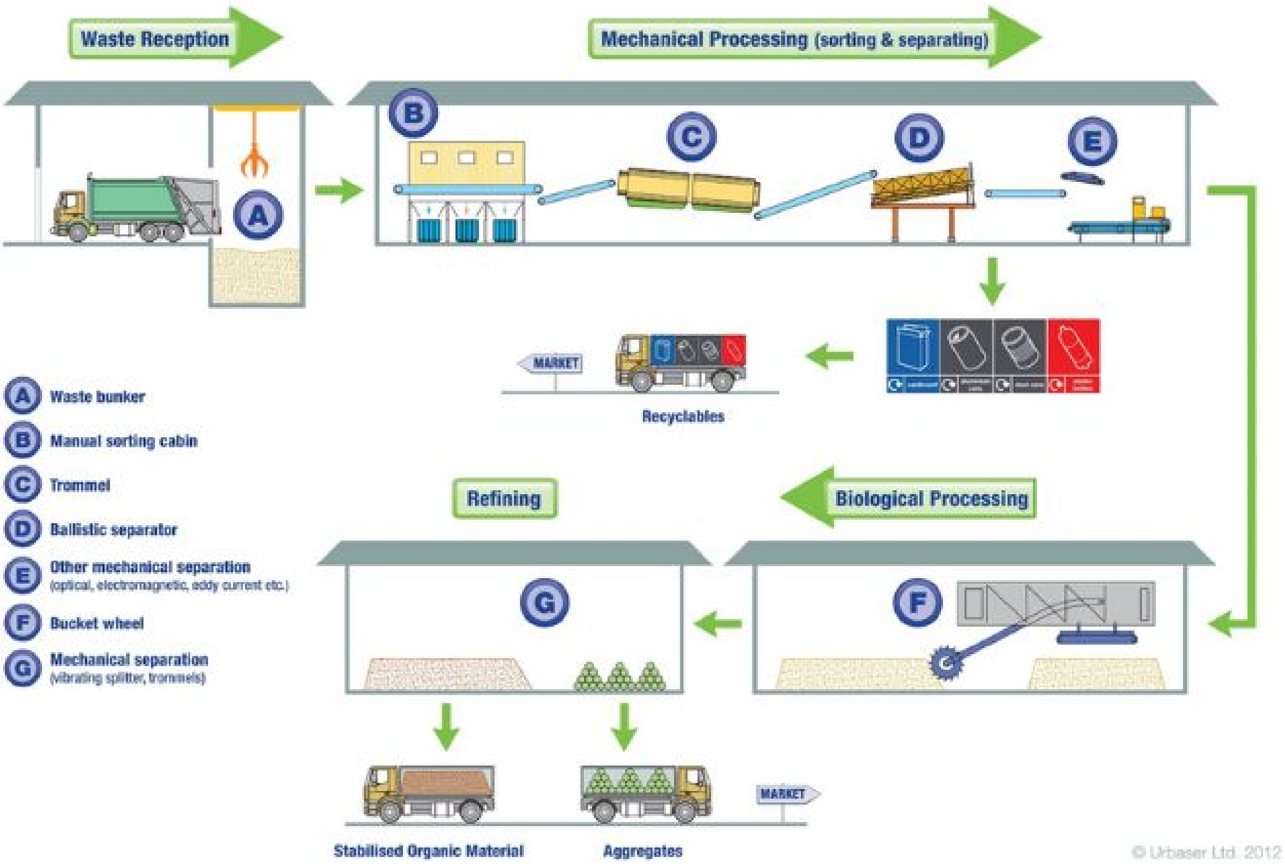

***Figure 1**: a schematic lay-out (slightly modified) of an MRBT site (source: Morris et al: What is the best disposal option for the "Leftovers" on the way to Zero Waste?, Eco-Cycle, www.ecocycle.org/specialreports/leftovers).*
The lay-out is schematic and only intended to visualise main operational sections (separation, material recovery, biological stabilisation). As explained in the text, the combination and sequence may vary depending on local needs and conditions.

Why a bridge strategy for residual waste: the benefits of MRBT

The starting point in this paper regarding a bridge strategy for residual waste has been the regulatory context, helping ensure that the pre-treatment of residual waste meets the requirements of the European Union's *Landfill Directive*. The obligation for pre-treatment has been one of the most important drivers to improve waste management across the EU, due to the fact this minimises the negative impact of landfills, whilst simultaneously increasing the costs for disposal, therefore making reduction, reuse and recycling more attractive.

The pre-treatment obligation does impose a need for immediate and appropriate investment based on current levels of residual waste, even though with time these levels are bound to decrease.

Therefore, a key aspect to reiterate and prioritize throughout is the flexibility of the residual waste management system. Options for residual waste must be designed in a way that, while they seek to minimise impacts of landfills (in the spirit of the *EU Landfill Directive*) they also keep the system adaptable to work on increasing tonnages of separately collected materials, while decreasing amounts of residual waste.

Treatment options for residual waste based on the MRBT concept show various advantages compared to incineration and co-incineration:

- MRBT-types of treatments are remarkably more **scalable** (i.e. able to be adopted at different sizes of operational capacities) than incineration. MRBT is based on biological stabilisation and mechanical sorting systems, which are inherently modular. While Best Available Technology (BAT) incinerators incur significant diseconomies of scale, as well as being less effective, at less than 100.000-150,000 t/year,[39] MRBT may work at much less than 100.000 t/year (many biological treatment sites operate at less than 50.000 t/year).
  Therefore MRBT could better address the proximity principle[40], and make various districts totally autonomous for residual waste management.

- Sites designed to operate through biological stabilisation and material recovery, are markedly **cost competitive** with incineration. Capital expenditure (capex) at a BAT level may be in the range of EUR 200-400 per t/year of installed capacity[41], while BAT incinerators typically are around EUR 1000 per t/year and more[42].
  This implies a lower use of financial resources for residual waste management, and a larger part of the budget may be dedicated to separate collection, reuse and recycling.

- MRBT types of installations are typically **faster to implement** than incinerators. Planning, procurement, permitting, construction and approval may typically take two years, which is much less than the time taken to have an incinerator up and running.
  This means "saving time" in terms of compliance with the *EU Landfill Directive*, and in terms of getting ready to ensure pre-treatment while minimising the negative impacts of landfills.

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[39] Eunomia et al: Costs for Municipal Waste Managementin the EU - Final Report available at: ec.europa.eu/environment/waste/studies/eucostwaste.pdf

[40] The "proximity principle", as defined in EU waste policy, states that *wastes should be disposed of as close to the source as possible*. Available at: ec.europa.eu/environment/archives/enlarg/handbook/waste.pdf

[41] Arcadis et al: Assessment Of The Options To Improve The Management Of Bio-waste In The European Union, Final Report, Annex E, Approach to estimating costs available at: ec.europa.eu/environment/waste/compost/pdf

[42] The parameter herewith discussed is unit investment cost (unit CapEx). Operational costs may differ with regards to a few key parameters, such as the local cost of manpower, cost of energy and fuels, and, above all, gate fees for rejects to landfills, etc. Typically, OpEx with a landfill fee of around Eur 60/t, may be in the range of Eur 60-65/t, including the final disposal in landfills.

- MRBT types of installations are **climate-friendly**, since through biological stabilisation they only degrade biogenic materials and recover fossil-based materials (or finally landfill them, sequestering carbon) whilst fossil-CO2 would get released through incineration and co-incineration (which burns RDF, a large part of which is made of plastics and other fossil-based materials as artificial textiles). This is of particular importance, given the ongoing decarbonisation of the EU economy and energy production, which implies the need to reduce GHG emissions progressively and steadily to achieve net zero by 2050 or sooner.

- The most important operational aspect of MRBT is its inherent flexibility. MRBT is made **adaptable** by the fact it includes:

    - Process systems for biological stabilisation, which may modularly be adapted to process also clean organics from dedicated separate collection schemes.

    - Equipment for optical, ballistic, magnetic separation, which may be used on different working shifts also for increasing amounts of dry recyclables from kerbside schemes.

From a strategic standpoint, having in mind the flexibility needed by ambitious goals defined in the EU circular economy agenda, **this is probably the most important competitive edge compared to both incineration and co-incineration**[43].

[43] RDF production at old-style MBTs requires density refiners, which are not suitable for sorting various types of recyclables from separate collection into recyclable streams.

Policy recommendations

This paper has highlighted the importance of adopting Material Recovery and Biological Treatment as a strategy for the management of residual waste in the circular economy. This will ensure the cross-consistency between on the one hand, the need to comply with the *EU Landfill Directive* and, on the other hand, the need to refrain from options that may cause lock-in and get in the way of the ambitious circular economy roadmap.

With this in mind, Zero Waste Europe calls for a dedicated EU strategy for the management of residual waste. This should include the following in order to consolidate key messages and political directions:

- An European Commission (EC) Communication on the role of Landfilling in a circular Europe. This action would be similar to the EC communication on Waste-to-Energy[44] (Jan 2017) and it may include the following key messages:

    1. The role of landfills should be residual, capacities should not be overly sized.
    2. It should remind that pre-treatment of residual waste is a precondition.
    3. Definition of the key goals of the *Landfill Directive* (minimisation of impacts) and the way to codify related "acceptance" at landfills.
    4. Mention possibilities to recover materials from residuals.
    5. It should also include some key messages on biological treatment, in order to avoid misunderstandings around "MBT being banned soon".

- A common EU-wide approach should be defined, including the codification of "pre-treatment" and the goals of biological treatment. This new approach should get rid of misleading parameters such as the one on the calorific value; it should emphasise the importance of stability and list possible ways to have it codified (or even mandate an EU standard to be codified by CEN).

- Compile an EU-wide survey on technologies that may be used to recover materials from residual waste, and related applications of recovered materials, current initiatives, best practices and biological treatment sites that are already turned into compost sites (fully or in part).

- Support, with dedicated funding programmes, transformation of existing MBT into MRBT sites, and further revamping (partial or total, depending on situations) of both into compost sites and clean Material Recovery Facilities in order to provide capacities for processing clean organics (which will be generated from the dissemination of separate collection of biowaste as mandated by article 22 of the *Waste Framework Directive*) and dry recyclables.

[44] ec.europa.eu/environment/waste/waste-to-energy.pdf

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Zero Waste Europe, 2020

Zero Waste Europe is the European network of communities, local leaders, businesses, experts, and change agents working towards the same vision: phasing out waste from our society. We empower communities to redesign their relationship with resources, to adopt smarter lifestyles and sustainable consumption patterns, and to think circular.

Zero Waste Europe gratefully acknowledges financial assistance from the European Union. The sole responsibility for the content of this event materials lies with Zero Waste Europe. It does not necessarily reflect the opinion of the funder mentioned above. The funder cannot be held responsible for any use that may be made of the information contained therein.