Processing of mixed plastic packaging waste to maximise recycling yields for high quality output

In a nutshell

Summary overview

It is best practice to process separately collected mixed plastic packaging waste in individual material streams that can be transformed into valuable high-quality secondary raw materials and recycled products. The process encompasses the following steps:

- sorting flexible plastic packaging waste from the rigid items (film sorting) by using film grabbers, air drum or ballistic separators followed by a manual quality assurance step;
- sorting plastic bottles and other rigid items by polymer and colour with optical sorting systems;
- reducing sorted film and residual rigid items (as separate flows) in flakes by using granulators;
- cleaning flaked plastic packaging using friction cleaning (dry or wet grinding systems);
- separating and washing flaked plastic packaging by polymer and colour by using optical sorting systems or density separation technologies;
- extruding flaked material into pellets.

Waste management area

Cross-cutting	MSW - strategy	MSW - prevention	MSW - collection	MSW - EPR	**MSW - treatment**	CDW	HCW

Applicability

Good waste collection systems and the good quality of the collected materials need to be assured in order for the recycled output to be suitable for the market. Current market trends towards more complex multi-layer and multi-material plastic products also make mixed plastics sorting and reprocessing much more difficult. As with the previous best practice, there are no general barriers to building and operating such a plant. However, careful planning and determination of the optimal plant capacity are important.

Specific environmental performance indicators

- Plant processing rate (weight %), calculated as the annual quantity of materials sent for recycling divided by the annual quantity of mixed plastic packaging waste processed.
- Energy efficiency (kJ/t), calculated as the annual total energy consumption of the plant divided by the quantity of mixed plastic packaging waste processed.
- GHG emissions (t CO_2e/t), calculated as the annual total CO_2 equivalent emissions (scope 1 and 2) of the plant divided by the quantity of mixed plastic packaging waste processed.
- Water use (m^3/t), calculated as the annual total water used on site divided by the quantity of mixed plastic packaging waste processed

Benchmark of excellence
Plastic recovery facilities processing mixed plastic packaging waste have a plant processing rate of at least 60 %.

Description

The term "mixed plastic packaging waste" covers all plastic packaging waste sourced from the domestic waste stream and includes rigid and flexible plastic items of various polymer types and colours that are typically generated by households. It usually excludes non-packaging items, even though in some EU countries some non-packaging items are starting to be admitted in the recyclables collection bin. Based on available domestic waste assessments, the share of plastic in the household waste ranges from 8 % to 12 % by weight, and, assuming an average value of 9 %, bottle plastics account for 2.4 %, non-bottle plastics including films, bags and other packaging comprise 5.2 %, with the remaining 1.4 % represented by the non-packaging fraction (WRAP, 2008). When this collected waste stream enters material recovery facilities (MRFs), plastic bottles and containers of the different polymer types can be efficiently separated, but the rest of this flow (about 6.6 % of the total) largely remains as a residual component that is commonly sent to final disposal or energy recovery or, in the best case, at least partly down-cycled.

The major challenge in producing valuable recyclate (i.e. materials resulting from the processing of plastic waste, such as pellets, granules and flakes) from mixed plastic packaging waste is that most plastic types are inherently immiscible at the molecular level and have different processing requirements. Furthermore, when plastic is contaminated, or of a limited quantity or with a varied composition, recycling is more difficult. Therefore, to achieve efficient mechanical recycling, mixed plastic packaging waste should be processed as far as possible into clean single types (Plastics Recyclers Europe, 2013).

The route that household plastic waste takes for separation and reprocessing depends on how it is collected (WRAP & Zero Waste Scotland, 2012):

- Plastic packaging waste from multi-stream systems is typically baled at a transfer station or depot and sent directly to a so-called plastics recovery facility (PRF), i.e. a facility set up specifically to sort plastics by polymer type and/or colour.
- Materials collected co-mingled usually pass through a material recovery facility (MRF), where the co-mingled stream is separated into material types. Some MRFs also separate one or more of the more abundant and higher value plastic bottle streams, typically PET and HDPE, but most of them concentrate on separating mixed plastic bottles for further sorting at a specialist PRF.

In both cases, the different plastic packaging polymers sorted at the PRFs are sent to plastics reprocessors that convert them, through mechanical recycling steps, into raw materials (pellets, granules, flakes) that can be used to manufacture new plastic products.

There are six main polymer types in the household waste stream, which account for around 75 % of the demand from converters. Table 1 shows these main types and the related recycled products with well-established markets (Plastics Recyclers Europe, 2013).

Table 1. Main polymer types in the household waste stream and related recycled products

Polymer type		Recycled products
LDPE	Low-density polyethylene	Bin liners, carrier bags, agricultural film mulch, agricultural film sheet, construction film, tubes, cling film, flexible packaging, heavy-duty sacks
HDPE	High-density polyethylene	Tubes, sewer pipes, pallets, boxes, buckets, bottles for detergents, construction, food product packaging, toys, cable insulation
PP	Polypropylene	Pipes, pallets, boxes, buckets, furniture, car parts, pots of yoghurt/butter/margarine, fibres, milk crates
PS	Polystyrene	Clothes hangers
PVC	Polyvinyl chloride	Sewer pipes, window frames, construction, flooring, wallpaper, bottles, car interiors, medical products packaging
PET	Polyethylene terephthalate	Bottles, sheets, strapping (e.g. carpets, clothing automotive parts), food and non-food packaging, films and fibres

Source: Plastics Recyclers Europe, 2013

To recover high-quality recyclable materials from the household mixed plastic packaging waste and transform them into valuable raw materials and recycled products, the following sorting and reprocessing steps are needed (WRAP, 2008; Reclay StewardEdge, 2013):

1. sorting flexible plastic packaging waste from the whole rigid items (film sorting) by using film grabbers, air drum or ballistic separators followed by a manual quality assurance step;
2. sorting plastic bottles and whole rigid items by polymer and colour by using optical sorting systems;
3. reducing sorted film and residual rigid items (as separate flows) in flakes by using appropriate granulators;
4. cleaning flaked plastic packaging using friction cleaning (dry or wet grinding systems);
5. separating and washing flaked plastic packaging by polymer and colour by using optical sorting systems or density separation technologies;
6. extruding flaked material into pellets.

The first two sorting steps are generally performed at PRFs, but the most advanced MRFs also include mixed plastics sorting lines featuring partial sorting steps, as described in the best practice related to the sorting of co-mingled light packaging waste. The other steps are commonly featured at plastic reprocessing plants, but some PRF operators have invested in downstream reprocessing capacity in order to produce high-grade recycled polymers (WRAP & Zero Waste Scotland, 2012). This best practice deals with plastics sorting and processing facilities able to maximise the recovery of the different plastic materials collected from municipal solid waste, by polymer and colour, including films and flaked plastics, thus enhancing the overall recycling rates from the mixed plastic packaging waste flow.

Given the current state-of-the-art of mixed plastics sorting and reprocessing technologies, even in the most advanced PRFs some challenges still remain, mainly regarding two critical plastic fractions: black polymers and biodegradable plastics. Black or dark plastic packaging wastes are not recognised by optical sorters and generally end up in the residual waste fraction of the PRFs (WRAP, 2008a; Chacón et al., 2016), while the presence of biodegradable plastics in the sorted polymer flows could lower the quality of the recyclates (Plastics Recyclers Europe, 2013). Recent research has demonstrated that innovative technologies and equipment can effectively recognise and also sort these critical fractions (Hollstein F. et al., 2013; BP sorting, 2014; Filmsort, 2015; Chacón et al., 2016) and specific sorting machines are starting to become commercially available. Future perspectives as to the advanced sorting techniques are also offered by robotic technologies; these use multiple sensors and artificial intelligence software to monitor and analyse the waste stream in real time and industrial robotic arms to pick up waste fractions of various shapes and sizes quickly and accurately. Interesting robotic waste sorting solutions are already applied at the pilot scale (Sadako Technologies, 2016) or at the full industrial scale for particular waste flows (Zenrobotics, 2016).

Environmental benefits

As in the case of the previous best practice about sorting of co-mingled lightweight packaging, the main environmental benefit of this best practice is related to the substitution of virgin plastic materials with those recovered through the sorting and reprocessing of the collected mixed plastic packaging waste.

Lots of studies based on life cycle assessments have demonstrated that recycling is generally an environmentally preferable option compared to other waste management alternatives. In the case of plastic recycling, the energy savings with respect to plastic production from virgin materials are in the order of 80–90 % (Plastics Recyclers Europe, 2013). A major review of LCAs carried out by WRAP in 2006 and updated in 2010 (WRAP, 2010) concluded that mechanical recycling is the best alternative regarding the climate change potential, depletion of natural resources and energy demand and that the environmental benefits are mainly derived from the avoided material production. In order to maximise the benefits, emphasis should be put on recovering good-quality material with a high purity (to limit the rejected fraction) that, once recycled, can replace virgin plastics at a high ratio (1 to 1).

Some figures showing the relative benefits of recycling the different plastic polymers, taken from a recent study carried out by Eunomia (2015), are provided in Table 2.

Table 2. Selected values – Impacts of recycling dense plastic

Data source	Impacts (tonnes CO2 equivalent per tonne of aluminium recycled)
Association of Plastics Manufacturers in Europe (in WRATE)	Mixed plastic -1.04
	Bottle plastics -1.15
US EPA (2002/6)	HDPE -1.40
	LDPE -1.71
	PET -1.55
AEA (2001)	HDPE -0.53
	PET -1.80
APME (2005)	HDPE -1.90
WRAP (2006)	Average -1.08 (of landfill scenarios)1
ERM (2006 a)	-2.32
ERM (2006 b)	1.82 (lumber) / -0.85 closed loop
Prognos / IFEU (2008)	-0.16 – -1.72
SCM (2013)	-0.578
Franklin Associates (2010)	PET -1.98 HDPE -1.2
Notes: 1. Unlike the other studies referenced above, WRAP's values included the benefits associated with avoided residual treatment; these are, however, likely to be minimal for landfilled plastic. 2. Depending on production process and polymer mix	

Sources: AEA Technology (2001) Waste Management Options and Climate Change: Final Report, European Commission: DG Environment, July 2001; ERM (2006 a) Impact of Energy from Waste and Recycling Policy on UK Greenhouse Gas Emissions, Final Report for Defra, January 2006; ERM (2006 b) Carbon Balances and Energy Impacts of the Management of UK Wastes, December 2006; APME data cited here from http://www.plasticseurope.org ; USEPA (2002) Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks, EPA530-R-02-006, May 2002; Prognos / IFEU / INFU (2008) Resource Savings and CO2 Reduction Potential in Waste Management in Europe and the Possible Contribution to the CO2 Reduction Targets in 2020, October 2008; WRATE database; Zero Waste Scotland (2013) The Scottish Carbon Metric: Technical Report, October 2013; Franklin Associates (2010) life cycle inventory of 100% postconsumer HDPE and pet recycled resin from postconsumer containers and packaging, Report for The plastics division of the American chemistry council, inc., July 2010

Considering the processing of mixed plastic packaging waste in advanced PRFs in more detail, an in-depth analysis is provided in the WRAP report "LCA of Management Options for Mixed Waste Plastics" (2008b), which shows the results of an environmental life-cycle assessment (LCA) study of a range of recycling technologies and includes a comparison with a selection of alternative disposal options for domestic mixed plastic waste. The basis for the comparison between the various recycling technologies and alternative disposal routes is the recycling, reprocessing or disposal of one tonne of mixed plastic arising as waste from a typical UK material recovery facility (MRF). For each recycling scenario, the boundaries of the LCA study range from the point at which this mixed plastic waste leaves the MRF through to the production of granulate material ready to be made into "new" products. Non-recycled fractions are modelled up to the point at which the material is considered to be disposed of (e.g. in landfill) or to the point where it can substitute a primary material (e.g. after the agglomeration process for producing a redox agent for blast furnace injection). In the case of recycled/recovered products the assessment also includes the avoided production of material or energy from primary sources. It should be noted that the chosen study boundaries mean that the process of collecting the mixed plastic waste is not included in the assessment.

The following impact categories have been assessed:

- global warming potential (GWP);
- solid waste arisings (solid waste);
- primary energy consumption (energy);
- photochemical ozone creation potential (POCP);
- eutrophication potential (EP);
- acidification potential (AP);
- human toxicity potential (HTP);

- ozone layer depletion potential (OLDP);
- abiotic depletion potential (ADP).

The alternatives analysed are shown in Table 3 and the results of the comparison are illustrated in Figure 1.

Table 3. Key processes included in the modelled mixed plastics sorting facilities

Scenario	Key processes
A	■ Landfill (all materials)
B	■ Municipal incineration with energy recovery (all materials)
C	■ Near infra-red (NIR) sorting (Titech) ■ Conversion to solid recovered fuel (SRF) for cement kilns (non-PVC fraction) ■ Mechanical recycling of PVC fraction
D	■ Film removal (Stadler) ■ NIR sorting of rigids (Titech) ■ Pyrolysis of PP and PE fractions (BP polymer cracking process) ■ Mechanical recycling of PVC and PET fractions
E	■ Film removal (Stadler) ■ NIR sorting of rigids (Titech) ■ Pyrolysis of PP, PE and PS fractions (Ozmotech process) ■ Mechanical recycling of PVC and PET fractions
F	■ Film removal (Stadler) ■ NIR sorting of rigids (Titech) ■ Conversion of PE and PP fractions for use as redox agent in blast furnace ■ Mechanical recycling of PVC and PET fractions
G	■ Film removal (Stadler) ■ NIR sorting of rigids (Titech) ■ Mechanical recycling of PE, PP, PET and PVC fractions
H	■ Film removal (Stadler) ■ NIR sorting of rigids (Pellenc) ■ Mechanical recycling of PE, PP, PET and PVC fractions
I	■ Film removal (Stadler) ■ NIR sorting of rigids (Qinetiq) ■ Mechanical recycling of PE, PP, PET and PVC fractions
J	■ Film removal (Stadler) ■ NIR sorting of rigids (Sims) ■ Mechanical recycling of PE, PP, PET and PVC fractions
K	■ Film removal (KME) ■ NIR sorting of rigids (Titech) ■ Mechanical recycling of PE, PP, PET and PVC fractions
L	■ Film removal (Stadler) ■ Density separation (TLT) ■ Mechanical recycling of PE and PP fractions
M	■ Sorting and cleaning PE and PP fractions (Swiss Polymera) ■ Mechanical recycling of PE and PP fractions (Swiss Polymera)
N	■ Sorting and cleaning PE and PP fractions (B+B) ■ Mechanical recycling of PE and PP fractions
O	■ Film removal (Stadler) ■ Density separation (Herbold) ■ Mechanical recycling of PE and PP fractions
P	■ Film removal (Flottweg) ■ Density separation (TLT) ■ Mechanical recycling of PE and PP fractions

Source: WRAP, 2008b

	High priority	←			→			Low priority
Scenario	**Global Warming Potential**	**Solid Waste**	**Energy**	**Human Toxicity Potential**	**EUtrophication Potential**	**Photochemical Ozone Creation Potential**	**Acidification Potential**	**Abiotic Depletion Potential**	**Ozone Layer Depletion Potential**

Scenario	Global Warming Potential	Solid Waste	Energy	Human Toxicity Potential	EUtrophication Potential	Photochemical Ozone Creation Potential	Acidification Potential	Abiotic Depletion Potential	Ozone Layer Depletion Potential
A (Landfill)	15	16	16	16	16	16	16	16	16
B (Incineration)	16	1	8	15	10	15	15	15	2
C (SRF)	11	2	1	14	2	12	11	1	10
D (BP pyrolysis)	14	12	4	2	8	13	13	14	3
E (Ozmotech pyrolysis)	13	15	3	3	1	11	12	13	1
F (Redox agent)	12	4	2	4	13	14	14	5	9
G (Stadler & Titech)	1	5	5	5	3	6	4	3	6
H (Stadler & Pellenc)	4	7	7	11	5	8	8	7	4
I (Stadler & Qinetiq)	7	14	10	13	7	10	10	12	5
J (Stadler & Sims)	2	6	6	6	4	7	5	4	7
K (KME & Titech)	5	8	9	12	6	9	9	9	8
L (Stadler & TLT)	6	10	12	8	11	3	2	6	11
M (Swiss Polymera)	3	3	11	1	9	1	1	2	13
N (B+B)	9	13	14	10	14	5	6	10	14
O (Stadler & Herbold)	10	11	15	9	15	4	7	11	15
P (Stadler & Flottweg)	8	9	13	7	12	2	3	8	12

rank 1=best,

rank 16=worst

green=top 25%,
red=bottom 25%

Source: WRAP, 2008b

Figure 1. Results of LCA comparison of alternative disposal or sorting options for mixed plastic waste, *showing the relative ranking of the scenarios against each impact category*

From Figure 1 it is clear that scenario A (landfill) is the option with the least favourable environmental performance followed by B (incineration) – although interestingly incineration has the best performance for solid waste arisings, the impact category ranked second. The recycling scenarios (G to P) tend to have the best environmental performance if all impact categories are taken into account, but if only global warming potential, primary energy consumption and solid waste arisings are studied then C (conversion of mixed plastics in solid refuse-derived fuel) ranks in the middle of the recycling options.

Side effects

The cross-media effects are fundamentally the same as in the case of the previous best practice related to sorting of co-mingled lightweight packaging: electricity consumption, emissions of dust and odour, and safety and health of workers performing manual sorting. For PRFs using wet grinding systems and density separation technologies for cleaning and sorting plastic flakes, water consumption and discharges are a significant environmental impact as well. When this is the case, closed-loop water use is recommended for reducing water consumption and the need for effluent treatment.

As for the energy consumption in the sorting processes, i.e. film separation and sorting of plastic bottles and whole rigid items per polymer and colour, it can be assumed that the figures are the same as those reported for MRF consumption in table 5 of the previous best practice about sorting of co-mingled lightweight packaging.

As for the energy and water consumption in the reprocessing steps, i.e. plastic flakes cleaning, separating and washing, some reference figures are provided in Table 4 with reference to the secondary production of PET and HDPE. These figures are related to the whole process for producing one kg of recycled PET or HDPE (Rigamonti L. et al., 2014).

Table 4. Input material for the secondary production of PET and HDPE (expressed per kg of recycled PET or HDPE)

Consumption	Unit	Average	Std. dev.	Min.	Max.
		RECYCLED PET			

Electricity	kWh	0.32	0.10	0.24	0.47
Methane	MJ	2.56	0.31	2.29	2.90
Water	kg	2.96	-	-	-
RECYCLED HDPE					
Electricity	kWh	0.44	0.17	0.20	0.56
Methane	MJ	0.51	0.21	0.27	0.65
Water	kg	1.78	-	-	-

Source: Rigamonti L. et al., 2014

Applicability

As to the applicability of this best practice, there are no legal or country-specific barriers to building and operating integrated mixed plastic sorting and reprocessing plants, but some constraints exists with reference to the economic feasibility and related optimal plant capacity and feedstock availability.

The challenge for integrated PRF operators is that their customers (plastics converters) demand large quantities of recycled plastics, manufactured to strict specifications at a price that has to be competitive with virgin plastic. Technical requirements can vary greatly depending on the end use required by the buyer. Meanwhile, the quantities available to PRF operators and tonnages of recyclate produced can be of varying quality as there is no EU-wide certification in place. The market for recovered plastics is still small in comparison with virgin plastics, and subject to the broader economic climate as well as several other factors that can be volatile in nature. Since recyclates aim to partly replace virgin polymers in existing applications, their market value is directly linked to virgin plastic prices, which depend heavily on volatile oil prices (Plastics Recyclers Europe, 2013).

In this context, the first prerequisite for the applicability of the best practice is that good waste collection systems for household post-consumer plastic packaging are put in place and the good quality of the collected materials is assured through effective household communications. And going back in the plastic value chain, it is also important to somehow limit, as far as possible, the market trends in plastic applications towards more complex multi-layer and multi-material products, which make mixed plastics sorting and reprocessing much more difficult.

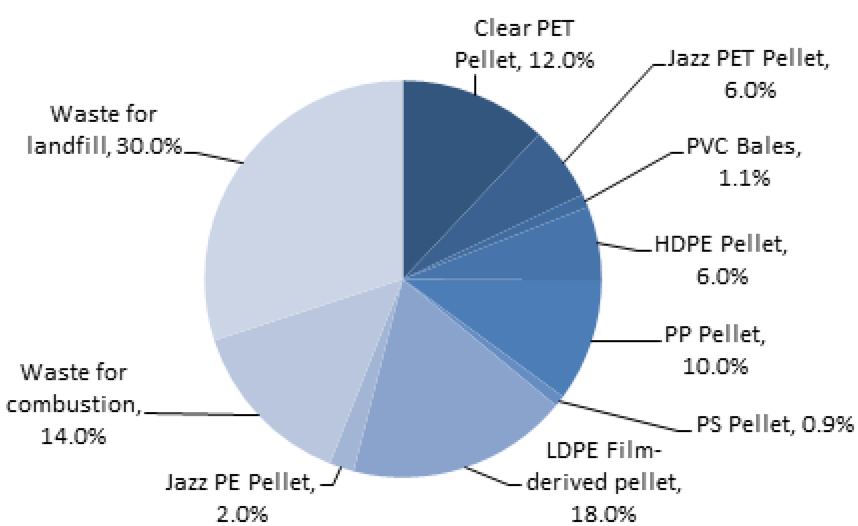
Given these framework conditions, the critical issue regarding the best practice applicability is related to the optimal plant capacity, as in the case of sorting co-mingled packaging waste in MRFs. The elements that need to be taken into account are exactly the same as for MRFs. As explained in detail in Economics below, an integrated mixed plastic sorting and reprocessing plant should generate a profit at a throughput of around 80 000 t/year.

Economics

The costs and benefits of this best practice are highly dependent on the quality of the materials recovered and on the market value of such materials. As in the case of MRFs, economies of scale play a relevant role in determining the economic feasibility of PRFs: the financial assessment of recycling mixed plastics realised by WRAP (2009) points out that a fully integrated plastics recovery and reprocessing facility producing high-grade clear PET and natural HDPE and industrial-grade PE, LDPE, coloured PET, PS and PP appears to be able to generate adequate investor returns at a scale of about 80 000 t/year. The financial assessment developed by WRAP provides a detailed analysis of the expected economic viability of a PRF, based on the financial modelling of an integrated mixed plastics sorting and reprocessing facility with a capacity of 80 000 t/year (24 000 t/year of plastic film and 56 000 t/year of rigid plastic) including the following elements:

- A semi-automated PRF section, where plastic films are removed by hand at the start of the sorting process and then rigid PET, HDPE, PP, PS and PVC containers are identified and separated automatically by NIR sorting technology. The PRF section produces separated rigid container fractions (including bottles) and a film fraction for further processing within the integrated PRF and reprocessing facility, plus a baled PVC fraction for sale.
- A flake washing plant which dry-cleans and granulates segregated rigid plastics from the PRF section and then washes and separates the material further to produce clean washed single polymer flake fractions for further processing.
- An extrusion section which melts and vacuum degasses (where appropriate) the clean washed flake to produce food-grade natural PET, food-grade natural HDPE, and non-food-grade but high-quality PP, PS, mixed colour (Jazz) PET and Jazz PE pellet products for sale.
- A NIR film sorting section which separates the film fraction produced by MRFs.
- A film washing, agglomeration and extrusion section which produces clean low-density polyethylene (LDPE) pellets for sale.

The product yields foreseen for the plant are shown in Figure 2. The recovery rate of the plant is 56 % of the mixed plastics input flow.



Source: WRAP, 2009

Figure 2. Product yields from the modelled PRF

As the financial model was created by WRAP in 2009, the assumptions about costs and revenues for input and output materials, capital costs and labour costs are not up-to-date and must be considered with caution. But, besides the exact values for the PRFs' expected cash flow, the results of the financial assessment and sensitivity analysis provide the following reliable conclusions:

- A stand-alone mixed plastics sorting and reprocessing plant should generate a profit at a throughput of around 80 000 t/year (24 000 t/year of mixed films plus around 56 000 t/year of other mixed rigid plastic and bottles).

- The business would be significantly more robust to increases in feed costs or reductions in selling prices if the plant could be built with a capacity of at least 100 000 t/year (30 000 t/year of films plus 70 000 t/year of rigid plastics).
- The commercial viability of the facility is particularly sensitive to the price of recycled pellets and to the yield of useful plastic that is extracted from the feed material.
- Variations in labour and utility cost have less impact on commercial viability than product price and yield factors.
- Variations in capital costs have a significant impact on investor returns. Grant support to reduce effective capital costs or use of second-hand equipment where feasible will improve project viability.
- A mixed plastics sorting and reprocessing plant processing only other rigid plastics where clear PET and natural HDPE have already been removed should be commercially viable as a stand-alone venture or as an addition to an existing reprocessing facility for HDPE and PET, provided the additional facility is built at a scale of at least 80 000 t/year.
- The assumptions used in this model indicate that film processing should be commercially viable, both as part of an integrated facility and as a stand-alone business. The viability of this option is sensitive to the cost of the delivered mixed film feed material.

Besides the results of this financial analysis, in its previous report about “Domestic mixed plastics packaging waste management options”, WRAP (2008a) also developed a preliminary assessment of the economic viability of the process designs defined in the study. On the basis of the analysis carried out and given the model assumptions, processes appeared to generate attractive internal rates of return.

Driving forces for implementation

As in the case of sorting of co-mingled lightweight packaging waste, the most important driving force for sorting of collected mixed plastic packaging waste has been the European Packaging Directive (1994/62/EC; 2004/12/EC amended) and the related extended producer responsibility (EPR) regulations introduced by Member States, subsequently reinforced by the recycling targets and landfill bans set by the EU’s Waste Framework Directive (2008/98/EC), and more recently by the proposal for reinforcing these targets introduced in the EU's Circular Economy Package. The pull mechanisms for the creation of well-functioning secondary raw materials markets (i.e. economic incentives, Green Public Procurement) are also relevant drivers, but still need to be reinforced.

In the case of plastic sorting, a further driving force consists of the need to sort plastics as far as possible into single polymer types to obtain efficient mechanical recycling and thus a higher economic value from the plastic materials recovered. This need becomes particularly relevant in the territories where the collection schemes include all plastic packaging or all plastic waste in the sorting guidelines, in order to ease sorting for inhabitants. Indeed, most plastic types are inherently immiscible at the molecular level and have different processing requirements. For example, a small amount of PVC contaminant present in a PET stream will degrade the recycled PET resin and vice versa. The cleaner and the fewer different types of plastic, the less mechanical treatment is required and the higher the quality of the recycled plastic products (Plastics Recyclers Europe, 2013).

Reference organisations

Advanced sorting of mixed plastic packaging waste is much less developed than advanced co-mingled sorting and currently there are only a few integrated PRFs sorting and reprocessing mixed plastics, as described in the previous paragraphs, operating in Europe. Examples of best performing integrated PRFs are provided below:

- Montello SPA, Italy: advanced integrated PRF located in Montello (province of Bergamo, Italy), with a capacity of 150 000 t/year, performing advanced sorting of mixed post-consumer packaging waste followed by reprocessing steps for some of the recovered plastic waste flows (production of PET flakes; LDPE, HDPE and PP granules, polyolefin granules and Geomont® dimpled sheet. Further information on the company website http://joomla.montello-spa.it/en/index.php. The company also produced a video describing the sorting and recycling process, available at https://www.youtube.com/watch?v=w8_CvCM-85Y.

- Biffa Polymers, UK: mixed plastic sorting and washing facility, applying a flake separation technology, opened by Biffa in 2011 at Redcar and upgraded in 2013. The PRF currently sorts and reprocesses a pre-sorted polypropylene (PP) packaging input stream, consisting of pots, tubs and trays from the household waste stream, producing high-quality washed PP flake outputs. Some of the output is processed through Biffa's food-grade HDPE recycling facility at the same site and go back into the manufacture of new milk bottles. A video describing the sorting process is available at https://www.youtube.com/watch?v=z_dIogMIz5A.
- ALBA Group, Germany: in Eisenhüttenstadt, ALBA operates a plant that mechanically recycles used plastic packaging. Here, as well as state-of-the-art sorting and washing processes, the used packaging undergoes a treatment process specially developed in-house. Using fusing and compression, the plastics are converted into an innovative resin that can be used to manufacture brand new plastic products. The company also produced a video describing the recycling process, available at https://www.youtube.com/watch?v=0rsidi-2gnk.
- SUEZ, France: in its plant in Rochy-Condé, in 2015, SUEZ inaugurated a new plastics processing line capable of separating and grinding all types of plastic resins into flakes or aggregate, transforming plastic waste into high-quality granulate that is reused in the composition of make-up palettes, vehicle headlights, gutter ducts or even textiles. The site has a total capacity of 105 000 t/year and 4 000 t/year for the plastic processing including 1 500 t/year for the grinding. The company also produced a video describing the sorting and recycling process, available at https://www.youtube.com/watch?v=_n_VMt9UZw8.

It is more common for advanced PRFs to just perform the sorting steps of the household plastic packaging waste fraction, recovering a high number of plastic grades (by polymer type and colour), as in the case of Veolia's UK Rainham plant, known as the Parrot POLY-mer separation facility, which has the capability to separate up to nine different grades of plastic, ranging from bottles, yoghurt tubs and trays, with a sorting capacity of 50 000 t/year.

As described in the best practice on sorting of co-mingled lightweight packaging waste, some advanced MRFs are also equipped with plastic sorting units for polymer type and colour. The SUEZ MRF plant located in Rotterdam is particularly interesting, as it efficiently sorts from a co-mingled packaging input, including plastic and metals, different grades of plastics that are then reprocessed by QCP (Quality Circular Polymers), a new plastics recycling facility realised in partnership with SUEZ (see related videos at https://www.youtube.com/watch?v=Xjot6NpySac - https://www.youtube.com/watch?v=gfVHQ9EvU4Q).

It is finally worth noting, considering the innovation trends, that some promising technological solutions are emerging for sorting black polymers, film plastics including biodegradable films, or for applying robotic arms in the sorting process. Reference organisations working on these solutions are as follows:

- SADAKO Technologies, Spain: a Barcelona-based start-up that has developed a high-speed industrial robotic arm (Wall-B) with a grasping-by-suction system plus a state-of-the-art computer vision system that can overhang conveyor belts. The robotic arm is already used at two processing plants near Barcelona (https://www.youtube.com/watch?v=-BN18Re0g00).
- ZenRobotics, Finland: a high-tech company specialised in Artificial Intelligence (AI)-controlled robotic systems that has developed robotic solutions for sorting waste streams; these are already commercially available for sorting CDW and under development for other waste streams (http://zenrobotics.com/).
- Steinert, Germany: Steinert recently developed the UniSort BlackEye technology, a sensor-based sorting machine that has the ability to classify plastics according to their polymer group categorisation, enabling also the recovery of black or dark plastics (http://www.steinertglobal.com/fileadmin/user_upload/global/download-area/EN/UNI_blackeye_EN.pdf), and the Unisort Film machine, for sorting buoyant objects such as conventional PVC film, bio-based film or biodegradable film (http://www.steinertglobal.com/de/en/products/unisort/unisort-film/).

Literature

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