REPORT

Study about Plastic Sorting and Recycling

prepared for:

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Leoben, 04.1.2019

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Abbreviations

PO	Polyolefins
PE	Polyethylene
LDPE	Low Density Polyethylene
HDPE	High Density Polyethylene
PP	Polypropylene
PS	Polystyrene
PET	Polyethyleneterephthalate
PVC	Polyvinylchloride
PA	Polyamide
PC	Polycarbonates
RDF	Refuse-derived fuel
UV	Ultraviolet
VIS	Visible spectroscopy
NIR	Near-infrared
XRF	X-Ray Fluorescence
XRT	X-Ray Transmission
LIF	Laser-induced fluorescence
LIBS	Laser-induced breakdown spectroscopy
SDG	Sustainable development goal

1 PREAMBLE

1.1 GENERAL

COWI A/S (COWI) has been commissioned by the Danish Environmental Protection Agency to carry out an inventory of the framework conditions and the business and development potential for Danish plastics converting companies and of existing sorting, recycling and recovery technologies.

COWI A/S (COWI) has contracted Ingenieurgemeinschaft Innovative Umwelttechnik GmbH (IUT) for the preparation of basic data for the elaboration of the study.

IUT has subcontracted their long-term partner institute Montanuniversity of Leoben / department waste treatment technologies and waste management to support IUT in the preparation of the necessary data and documents.

The scope of IUT/MUL is described in chapter 1.2 of this report.

1.2 SCOPE OF WORKS BY IUT/MUL

The scope for IUT/MUL has been defined by COWI by using the descriptions and tables included in this chapter.

The overall scope has been split into two main activities:

- Market catalogue
- Technology catalogue

1.2.1 Market catalogue

This catalogue will have 3 chapters:

- Chapter 1 will cover 3-5 different source separated mixed plastics from various sources.

COWI will prepare this chapter.

- Chapter 2 will cover 6-10 different fine sorted plastics fractions (polymers) of various qualities.
  IUT/MUL will prepare this chapter.
- Chapter 3 will be on 6-10 granulates/flakes from recycled plastics.
  IUT/MUL will prepare this chapter.

IUT/MUL will deliver following data and documents for the market catalogue:

- 1 filled table (as per example below) for each investigated polymer type
- Material requirements for sorted polymers and recyclates
- Pricing for sorted polymers and recyclates
- Quality assurance on sorted polymers and recyclates
- Trends in polymer and waste sector
- Catalogue of recycling plant in the countries Germany, Netherlands, Austria and United Kingdom indicating the processed polymer type and capacity, if available in public data or provided by the plant operators during the E-Mail survey.

The design concept for the tables in the catalogue to be delivered by IUT/MUL can be seen below. The 3rd column is for guidance and will be removed in the final catalogue.

Plastic type	Fine sorted HDPE	A name for the plastic type to be send to next step/market
Polymertype	HDPE + impurities	Specific information about the polymer in question. Could be transparent or color.
Purity	94%	Referring to German DSD standards for recycled packaging plastic waste
Expected impurities	Max 3 % PP/other plastics, max 3% other materials	A description of the allowed impurities
Market price (EU/ton)	XX to XX EUR/ton	A range and perhaps a link/name to see the current market price of this specific polymer/fraction.

Amount from DK potentially available	Xxxx ton	COWI will provide this number
Possible customers	XXX (xx ton/year, DK), YYY (yy ton/year, DE),	Companies that buy this material, and the amount that they are capable/interested in buying pr. year, (approximate number)
Next step in value chain possible treatment **(a)**	Manufacturing of secondary plastic (flakes/granulate) Further fine sorting and production of pellets after further washing and cleaning.	This field can be repeated several times if different next treatments are possible in the market. The next steps should be compatible with the technologies described in chapter 2 of the technologies catalogue. Indicate the name of the technology and a 1-2 lines description of the next step
Next step in value chain possible treatment **(b)**		If other further treatment technologies are possible include them also as b, c, d ….
Possible factors significantly reducing the value of the material	e.g. Contaminations with sand or glass. Other factors or challenges (labels etc.)	Describe if specific factors will reduce the quality or value or loss of the material significantly.
Challenges in the market		Trend or situations, which influences the market (size and value)
Sources of information		Central or local sources for the above information

Table 1: Pattern for market catalogue provided by COWI

1.2.2 Technologies catalogue

This catalogue will have 2 chapters

- Chapter 1 - Technical concepts for sorting facilities
- Chapter 2 – Technical concepts for secondary plastic processing plants

1.2.2.1 Chapter 1 - Technical concepts for sorting facilities

This chapter shall cover 4-5 technical concepts for sorting facilities, aimed at specific types of mixed plastics.
IUT/MUL will identify and describe the relevant different concepts.

The descriptions will include a flow/box diagram and a dictionary/catalogue that explains briefly (2-4 lines a) the important steps/components of the facility.

COWI will, based on information from IUT/Leoben, prepare this chapter.

1.2.2.2 Chapter 2 – Technical concepts for secondary plastic processing plants

This chapter shall cover 3-5 secondary plastic processing plants (all relevant polymers to be covered).
IUT/MUL will identify and describe the relevant different concepts.

IUT/MUL will deliver following data and documents for this chapter:

- 1 filled table (as per example below) for each investigated polymer type

The design concept for the tables in the catalogue to be delivered by IUT/MUL can be seen below. The 3rd column is for guidance and will be removed in the final catalogue.

Technology	Manufacturing of secondary plastic (flakes/granulate)	Name of the technology
Description of the technology	Fine-sorted plastic polymers of high purity is further processed	10-15 lines of text describing how such a facility is designed

	via additional sorting as well as washing and other cleaning process to create a completely pure plastic raw material that is extruded into granulate/pellets. [Figure showing a typical facility layout/design]	and operates, in easy understandable text for non-technology experts
Development status	Mature and in operation many places, (considerations on further development to be added)	Status on the development and areas where further development is taking place
Input material for the facility	Presorted PET, HDPE, LDPE or PP (PS) in DSD quality	List all types of polymers accepted at this type of facilities. These should as far as possible fit the materials in the chapter 2 of the market catalogue
Variable OPEX (EUR/ton)		e.g. electricity, water, heat; but also wages of employees handling the waste (i.e. employment that scales with input in tons) Electricity may be given in kWh/ton or similar Employees may be given in working hours/ton
Total CAPEX (mill. EUR)		e. g. construction costs, machines, equipment; before amortization. Items that are locally dependent (e.g. land costs)

		may be omitted and replaced with a notice that they are not included. Include instead e.g. land needs (square meters)
Annual fixed OPEX (mill. EUR/year)		e.g. maintenance, insurance, employees independent of production volume (e.g. bosses) Maintenance may be given in % of CAPEX/year instead of money Employees may be given in count instead of wage sum
Output	PET, HDPE, LDPE or PP (PS?) pellets (or flakes) of xx quality/purity	Description of output of each polymer the technology is suitable for treating. (e.g. flakes, pellets, food quality, other qualities). These should as far as possible be compatible with the materials in chapter 3 of the market catalogue
Process efficiency (% of input recycled - output/input)	?? % for all polymers (if this varies)	% of input recycled - output/input. If process efficiency varies, for e. g. 2D/3D or object size or other factors.
Energy consumption / ton	XX kWh/ton electricity, XX MJ heat/ton	
Employed staff	Xx/1000ton	

Companies	Companies in the requested countries	A list of companies the perform this kind of treatment in northern Europe
Rejects	XX% of input sent to waste incineration plant (or other destination)	Rejected materials from the processing (type and amount (per ton input) and method of handling and disposal (e.g. as RDF?
Specific challenges	Handling contaminations with impurities, labels etc.	If the technology has specific challenges, e. g. impurities that it cannot handle
Sources of information		Central sources for the above information

Table 2: Pattern for technology catalogue for recycling plants provided by COWI

2 MARKET CATALOGUE

2.1 GENERAL

The following plastic types are being investigated in the study:

- Low-density polyethylene (LDPE) foils
- High-density polyethylene (HDPE) hollow bodies
- Polypropylene (PP) hollow bodies and dimensionally stable PP (bucket, canister, emptied),
- Polystyrene (PS) hollow bodies
- Polyethylene terephthalate (PET) bottles

All relevant stakeholders along the value chain from plastic wastes to the finished products are shown in Figure 1. This figure also shows all the terms used in this study along the presented value chain (Friedrich et al., 2019).

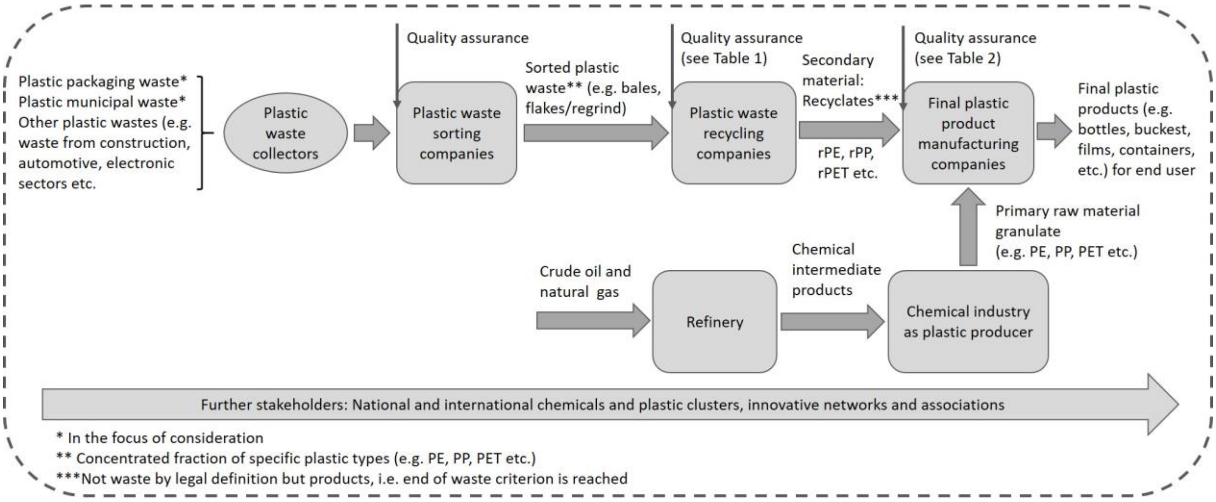

FIGURE 1: STAKEHOLDERS ALONG THE VALUE CHAIN FROM PLASTIC WASTE TO FINAL PLASTIC PRODUCTS (FRIEDRICH ET AL., 2019)

A market analysis of secondary plastic granulates was conducted to identify the quality benchmark in plastic recyclates, performed by observing the development of pricing, identifying drivers to the increase or decrease of value and verifying whether the value depends on recyclate quality or on other economic features.

To analyze the correlation between price and quality, several packaging plastic waste processing companies and plastic waste recycling companies were provided with a specially designed assessment guide. In addition to personal discussion with plastic waste recyclers and the plastic waste processing industry in Austria, the plastics recyclers in Germany, Netherlands, Austria and UK was approached with short and targeted e-mail questions.

About 240 e-mails were sent to plastics recyclers, resulting in a return rate of only approximately 5% (15 companies have generally replied, but just 12 have provided data for the study).

2.2 MATERIAL REQUIREMENTS

2.2.1 Sorted polymers

In Germany, quality standards for sorted plastic waste applied in the plastic waste recycling companies have evolved within the plastic industry (Grüner Punkt, 2019), summarized in Table 1.

Sorted plastic wastes	Metal items [w%]	Other plastic particles [w%]	Other residues 1) [w%]	Dimensionally stable PE articles [w%]	Foamed plastics incl. EPS* [w%]	Plastic Foils [w%]	PVC [w%]	Dimensionally stable PP [w%]
Plastic Foils (mostly LDPE)	< 0.5	< 4.0	< 4.0	-	-	-	-	-
Plastic hollow body (mostly HDPE)	< 0.5	< 3.0	< 3.0	-	-	-	-	-
PP	< 0.5	-	< 3.0	< 1.0	< 0.5	< 2	-	-
PET bottles	< 0.5	< 2.0	< 2.0	-	-	-	< 0.1	-
PE	< 0.5	-	< 3.0	-	< 0.5	< 5.0	-	< 3.0
PS	< 0.5	< 4.0	< 2.0	-	< 1.0	-	-	-
Compostable waste (foods, garden rubbish) * EPS: expanded polystyrene								

Table 3: Quality standards for sorted plastic wastes for recycling (Grüner Punkt, 2019)

2.2.2 Recyclates

Provided specification sheets or datasheets of produced recyclates include limit ranges (see Table 4) for the following properties:

- The density of non-cellular plastics (DIN EN ISO 1183-1)
- Melt volume-flow rate (MVR), melt-mass flow rate (MFR) and flow rate ratio (DIN EN ISO 1133-1)
- Tensile properties, in particular, modulus of elasticity (E-Modul) (DIN EN ISO 527-1)
- Notch impact strength (DIN EN ISO 179/1eA)

Properties	LDPE	HDPE	PP	PET	PS
Density [g/cm³]	0.920 - 0.945	0.940 - 0.970	0.895 - 0.920	1.360 - 1.390	1.050 - 1.290
Melt-mass flow rate (MFR) [g/10 min]	0.5 – 0.9(1)	0.1 - 30.0(1)	0.1 - 30.0(2)	20.0 - 30.0(3)	2.3 - 8.2(4)
Tensile properties (modulus of elasticity) [MPa]	220 - 380	1 170 - 1 350	850 - 1 450	3 400 - 3 700	3 000 - 3 400
Notch impact strength [kJ/m²]	8.00 - 15.00	4.85 - 5.15	3.00 - 5.50	2.00 - 4.00	8.0 - 12.0
(1) 190° C | 2,16 kg (2) 230° C | 2,16 kg (3) 280° C | 5,00 kg (4) 200° C | 5,00 kg					

TABLE 4: PHYSICAL, CHEMICAL AND RHEOLOGICAL PROPERTIES OF THE INVESTIGATED RECYCLATES (GRÜNER PUNKT, 2019)

2.3 Pricing

2.3.1 General

The plastic trading market is currently shifting and increasingly developing into a buyer's market. A high dollar exchange rate (1,1008 $/€ on 24-Sept-2019) (Wallstreet-online, 2019) and weak crude oil prices (62.90 $/barrel on 24-Sept-2019) (Tecson, 2019) result in a preference for primary raw material over recyclates.

Moreover, the European plastic market has changed due to the ban of exports to China that has previously been one of the largest importers of European plastic waste. 56% of all plastic waste worldwide and 87% of all European plastic waste has been sent to China in recent years. (Uken, 2018). The plastic waste streams, which are heavily contaminated and poorly sorted are most seriously affected. As a result, there is an oversupply of this plastic wastes in the European plastic recycling market. It follows that the plastics processing industry will favor high quality of plastics available.

Plastic wastes with low extraneous and pollutant contents and lower humidity are demanded. This oversupply of polluted plastic waste enables customers to select highest-quality plastic waste, ultimately affecting the pricing. Low-quality plastic waste losing market shares used to a great extent for thermal treatment or recovery (Sarc et. al., 2019).

2.3.2 Bales and Regrinds

The price developments for HDPE and LDPE (A), PP (B), PET (C) and PS (D) regrinds (thick-walled 3D-plastics e.g. from electronic equipment waste) and bales over the last years are shown in figure 3. The average selling price for regrinds of commodity plastics (e.g. PE, PP, PET, PS) is about 538 €/t, varying by 92 €/t (Plasticker, 2019).

For the PE types, it is stated that the average regrind price is very similar for HDPE and LDPE with approximately 0.6 €/kg (Plasticker, 2019). The HDPE regrind price fluctuated significantly more than

LDPE in the years 2014 to 2017. The LDPE regrind price is on average three times higher than the prices for the LDPE bales. This can also be observed for PP and PET. At 0.56 €/kg, the average regrind price for PP is 2.5 times higher than for PP bales, and at 0.37 €/kg, the average regrind price for PET is 1.9 times higher. (Plasticker, 2019) The reason for this is the higher processing depth and the associated higher costs for the production of regrinds compared to bales. The different price differences between regrinds and bales of the plastic types can be explained by the different processing costs.

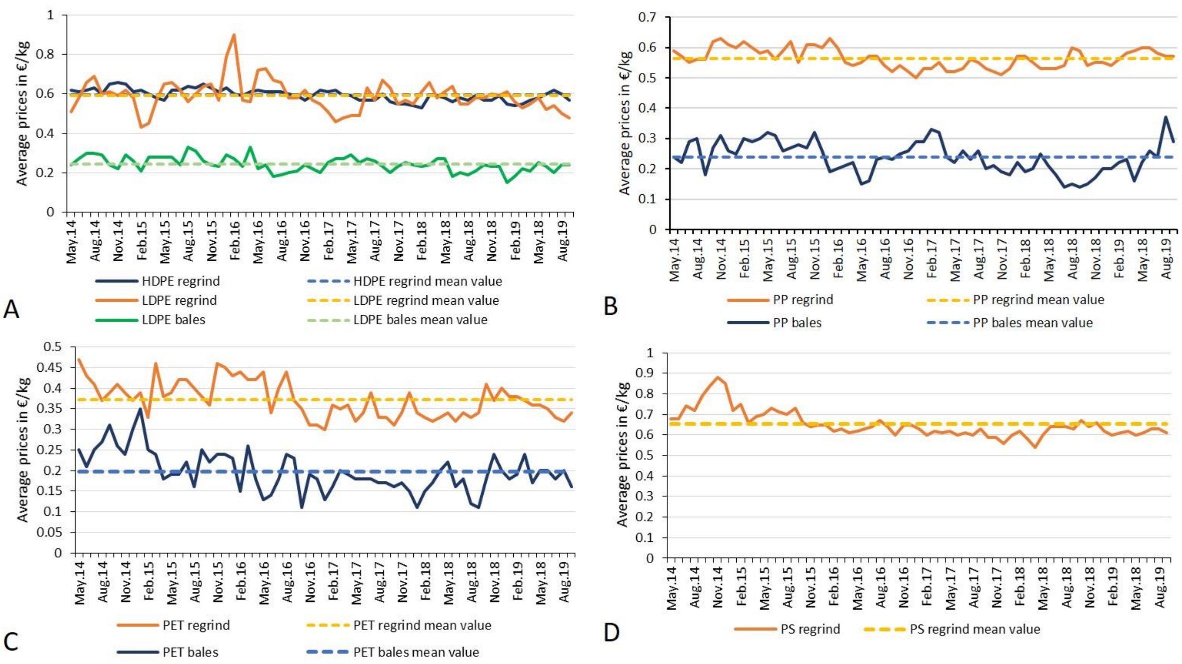

FIGURE 2: PRICE DEVELOPMENT FOR REGRINDS AND BALES OF PE TYPES (A), PP (B), PET (C) AND PS (D) (PLASTICKER, 2019)

The prices provided by the above mentioned internet platform have to be considered on an upper level price range. The price ranges provided in the chapter 2.6 are given by plant operators and experience over the last years and can be considered as more realistic for calculation of potential business cases.

2.3.3 Recyclates

The price developments for LDPE (A), HDPE (B), PP (C) and PS (D) granulates of primary raw materials and recyclates are shown in figure 3. No reliable price development could be collected for PET. The average selling price in July 2019 of primary raw material granulates of standard plastics (e.g. PE, PP, PS, PET) was around 1.17 €/t and 0.537 €/t (Plasticker, 2019) was the average selling price of recyclates of standard plastics. This means that granulates produced of primary raw material are on average twice as expensive as recyclates.

A comparison of the price developments of the primary raw materials with those of recyclates shows that there is a certain dependency between both price developments. If the price of a primary raw material rises or falls, the recyclate price of this plastic type also reacts with a price rise or fall. This fact can be seen for example well for LDPE in figure 3 (A).

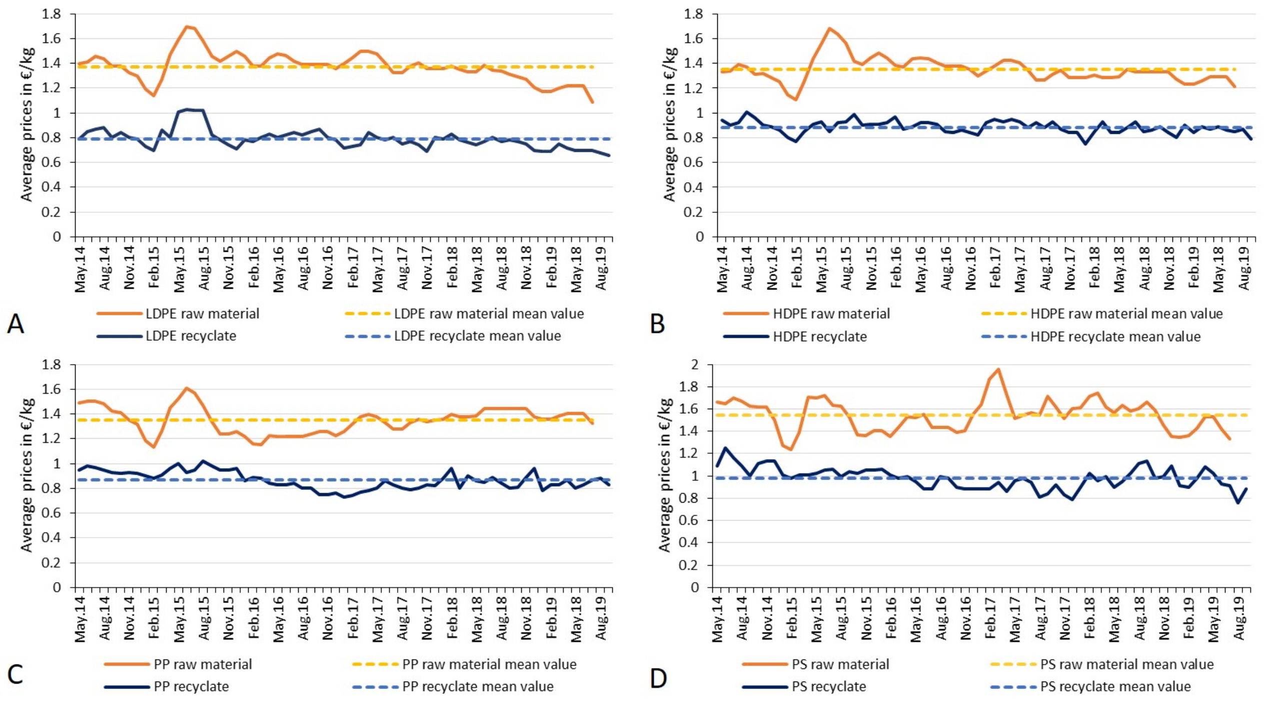

FIGURE 3: PRICE DEVELOPMENT FOR PRIMARY RAW MATERIAL AND RECYCLATES OF LDPE (A), HDPE (B), PP (C) AND PS (C). (PLASTICKER, 2019)

2.4 QUALITY ASSURANCE

2.4.1 Sorted polymers

The key competence in the quality assurance process of the delivered mixed plastic waste material to the plastic waste sorting plant is found with the material acceptance staff. Based on their experience, the quality of supplied plastic waste bales can be assessed by visual inspection. Attention is paid to coarse impurities. The collective experience of the stuff is decisive.

An essential part of the input control is the color distribution of the bale because a majority of pure plastics is a requirement for the production of high-quality recyclates and their use in new products.

Furthermore, the origin of waste affects the assessment of the sorted plastic waste quality. Hence, the material flow can be assessed using empirical values depending on the origin.

There are interesting arguments why deliveries of sorted plastic waste bales are rejected. Cartridges for sealing compounds repeatedly lead to rejection. The moisture of bales is another argument. Increased moisture can affect the surface of the particles and foaming processes during injection molding may occur.

Basically, however, non-conformity with quality requirements usually leads to a price reduction. If the content of contaminants is too high, the processing is impaired (material variations).

2.4.2 Quality assurance for re-granulate

The quality of random samples of recyclates is controlled in a laboratory. The physical, rheological and mechanical properties of the recyclates are of great interest.

The following characteristics are analyzed in the course of a random sample inspection:

- physical properties
    - density determination (DIN EN ISO 1183-1)

- rheological properties
    - melt-mass flow rate (MFR) (DIN EN ISO 1133-1)
- mechanical properties
    - tensile properties, especially modulus of elasticity (DIN EN ISO 527-1)
    - notch impact strength DIN EN ISO 179/1eA

Frequently, further parameters of the recyclates are determined. These include:

- melting temperature
- color distribution and color composition
- size and form of the granulated material (e.g. lenses, cylinder)
- moisture content
- filtration fineness
- ash content
- heavy metal content

In addition, there is often a continuous control of recyclates and an inspection for any specks, gas emissions, mechanical values and the color of the recyclates.

The hardness of recyclates allows initial prediction of the foreign plastic content, the shape of the granulates and the bulk density indicating potential gas inclusions or vacuoles.

The color and odor of granulates may indicate previous thermal degradation of the material.

The following devices or test methods are frequently used in quality assurance refers to the previously mentioned standard specifications:

- Melt index testers
- differential scanning calorimetry (DSC)
- ash furnaces
- residual moisture scales
- density analyzers
- capillary rheometers
- tensile testing and notched-bar impact test machine

Basically, the market mechanisms of supply and demand apply. In addition, the following criteria were identified for pricing recyclates:

- Purity: the purer a material, the broader its range of application and the higher the price potentially achieved
- Color purity: the purer the color of recycled material, the broader its range of application and the higher the price potentially achieved
- A function of the primary raw material prices: Pricing polymer types is a function of the respective commodity price. If the price of primary raw material decreases, the price of polymers will drop as well. Recyclate prices are usually following the trend.

Other pricing contributors are melt filtration in the context the lower the melt filtration (measured in µm), the higher the quality and cost supplement for masterbatches. When plastic is dyed, a certain amount will be charged for this procedure, raising the price.

2.4.3 Quality benchmark in plastics recyclates

The surveys indicated that the quality standards for recyclates from Grüner Punkt (2019) are considered as a benchmark in the industry.
For the recyclate quality, two levels are distinguished: mean quality for standard products like flower pots or buckets in 'standard plants' and high-quality surpassing defined threshold values from Grüner Punkt (2019).

The demand for plastic recyclates is higher now than the recycling market is able to provide. As depicted in Figure 3 where market prices and their trends are shown, primary raw plastic granulates are 40-60% more expensive than plastic recyclates. The quality of recyclates is below that of primary raw plastic granulates regarding material properties but the consumers would tolerate it for the sake of sustainability.

Better recyclability of plastics might reduce the market value of plastic recyclates. As best plastic recyclate quality, i.e. the benchmark, is met by plastic recyclates applied to food packaging like 'cap-to-cap' or 'bottle-to-bottle' production referring to the surveyed plastic processing companies.

2.5 TRENDS AND MARKET ACTIVITIES THAT INFLUENCE PLASTIC WASTE MANAGEMENT

2.5.1 European strategies

The most important action in European waste management was adoption of Circular Economy Package in 2018 with, among others, https://ec.europa.eu/environment/circular-economy/:

- A Europe-wide **EU Strategy for Plastics in the Circular Economy** and annex to transform the way plastics and plastics products are designed, produced, used and recycled. By 2030, all plastics packaging should be recyclable.
- A **Monitoring Framework on progress towards a circular economy at EU and national level**. It is composed of a set of ten key indicators which cover each phase – i.e. production, consumption, waste management and secondary raw materials – as well as economic aspects – investments and jobs - and innovation.

The revised legislative framework on waste has entered into force in July 2018. It sets clear targets for reduction of waste and establish an ambitious and credible long-term path for waste management and recycling. Key elements of the revised waste proposal include:

- A common EU target for recycling 65% of municipal waste by 2035;
- A common EU target for recycling 70% of packaging waste by 2030;
- There are also recycling targets for specific packaging materials:
    - Paper and cardboard: 85 %
    - Ferrous metals: 80 %
    - Aluminum: 60 %
    - Glass: 75 %
    - Plastic: 55 %
    - Wood: 30 %
- A binding landfill target to reduce landfill to maximum of 10% of municipal waste by 2035;
- Separate collection obligations are strengthened and extended to hazardous household waste (by end 2022), bio-waste (by end 2023), textiles (by end 2025).

- Minimum requirements are established for extended producer responsibility schemes to improve their governance and cost efficiency.
- Prevention objectives are significantly reinforced, in particular, requiring Member States to take specific measures to tackle food waste and marine litter as a contribution to achieve EU commitments to the UN SDGs.

EU Strategy for Plastics in the Circular Economy (EC, 2018) gives definition for:
"A vision for Europe's new plastics economy"
A smart, innovative and sustainable plastics industry, where design and production fully respect the needs of reuse, repair, and recycling, brings growth and jobs to Europe and helps cut EU's greenhouse gas emissions and dependence on imported fossil fuels."

Among others, following information and data from the Strategy is relevant for present report:

- Plastics and products containing plastics are designed to allow for greater durability, reuse and high-quality recycling. By 2030, all plastics packaging placed on the EU market is either reusable or can be recycled in a cost-effective manner.
- Recycling of plastics packaging waste achieves levels comparable with those of other packaging materials.
- By 2030, sorting and recycling capacity has increased fourfold since 2015.
- Thanks to improved separate collection and investment in innovation, skills and capacity upscaling, export of poorly sorted plastics waste has been phased out. Recycled plastics have become an increasingly valuable feedstock for industries, both at home and abroad.
- The plastics value chain is far more integrated, and the chemical industry works closely with plastics recyclers to help them find wider and higher value applications for their output. Substances hampering recycling processes have been replaced or phased out.

Specifically, key players should work together to:

- improve design and support innovation to make plastics and plastic products easier to recycle;
- expand and improve the separate collection of plastic waste, to ensure quality inputs to the recycling industry;
- expand and modernize the EU's sorting and recycling capacity;
- create viable markets for recycled and renewable plastics.

2.5.2 International trends

Next, selected relevant international trends as well as market activities are summarized and discussed:

2.5.2.1 Globalization

https://www.un.org/development/desa/en/news/intergovernmental-coordination/new-globalization-report.html

Speaking before the UN General Assembly's Second Committee on 13 October 2017, Mr. Liu highlighted three mega-trends related to globalization:

- Shifts in production and labor markets;
- rapid advances in technology; and
- climate change.

These trends are expected to shape and influence our future. The first mega-trend refers to the impact that production changes have had on labor markets, including through outsourcing and mechanization, which have spurred job losses, particularly in manufacturing sectors. These trends in labor markets are associated with higher rates of income inequality, which has increased in a majority of countries across the globe.

The second mega-trend is closely connected to the first, as it relates to the fast-moving development and advancement of new technologies, including in information and communications and artificial intelligence, that have also affected the world of work. While these innovations can act as catalysts for sustainable development, countries that do not have access to them are at risk of being left behind.

Globalization and its effect on climate change are the third emerging mega-trend. The report highlights that many trends closely linked to globalization, including economic activity, lifestyle changes and urbanization, all have an impact on our environment and may contribute to climate change. "The report of the Secretary-General emphasizes that globalization can be a powerful driver of economic growth, but to achieve sustainable development, globalization must work for all," Mr. Liu said, stressing also that "global agreements can play a key role in strengthening the benefits of globalization." Such global agreements are already in place with the 2030 Agenda for Sustainable Development, the Addis Ababa Action Agenda on Financing for Development and the Paris Agreement on climate change.

Additionally, at this point it has to be mentioned, that 17 Sustainable Development Goals (SDGs) play one very important international role. Latest information and status for every single SDG is given in the Report of the United Nations: The Sustainable Development Goals Report 2019: https://unstats.un.org/sdgs/report/2019/The-Sustainable-Development-Goals-Report-2019.pdf

2.5.2.2 Increase in Population

https://yaleglobal.yale.edu/content/world-population-trends-signal-dangers-ahead
https://www.worldometers.info/world-population/
https://population.un.org/wpp/Download/Standard/Population/

Global population achieved a milestone in 2011, hitting the 7 billion mark. Currently at 7.2 billion, the world is projected to increase by almost another billion people, climbing to 8.1 billion by 2025. The population is older. Countries continue to age substantially, with those aged 60 or older the fastest growing segment. In developed countries, almost one in four is an older person, with more older people than children.

Life expectancy is higher in most countries due to systematic progress against mortality. One can expect to live to age 77 in developed countries and to age 67 in developing countries. The world is more urbanized.

A tremendous change occurred with the industrial revolution: whereas it had taken all of human history until around 1800 for world population to reach one billion, the second billion was achieved in only 130 years (1930), the third billion in 30 years (1960), the fourth billion in 15 years (1974), and the fifth billion in only 13 years (1987).

- During the 20th century alone, the population in the world has grown from 1.65 billion to 6 billion.
- In 1970, there were roughly half as many people in the world as there are now.
- Because of declining growth rates, it will now take over 200 years to double again.

World population forecast:

- World population is expected to reach 8 billion people in 2023 according to the United Nations (in 2026 according to the U.S. Census Bureau).
- World population is expected to reach 9 billion in the year 2037.
- The United Nations projects world population to reach 10 billion in the year 2057.

2.5.2.3 Municipal and Packaging waste rise in quantity

https://ec.europa.eu/eurostat/statistics-explained/index.php/Municipal_waste_statistics#Municipal_waste_generation
https://ec.europa.eu/eurostat/statistics-explained/index.php/Packaging_waste_statistics#Waste_generation_by_packaging_material

Presented article shows trends in municipal waste generation and treatment in the European Union (EU) from 1995 to 2017. There is a very distinct trend towards less landfilling as countries move steadily towards alternative ways of treating waste. Municipal waste accounts for only about 10 % of total waste generated when compared with the data reported according to the Waste Statistics Regulation. For 2017, municipal waste generation totals vary considerably, ranging from 272 kg per capita in Romania to 781 kg per capita in Denmark.
Development of all packaging waste generated, recovered and recycled, EU 2007 – 2016; In 2016, 169.7 kg of packaging waste was generated per inhabitant in the EU-28. This quantity varied between 54.9 kg per inhabitant in Croatia and 220.6 kg per inhabitant in Germany.

2.5.2.3.1 Situation in Germany (UBA, 2018)

https://www.umweltbundesamt.de/publikationen/aufkommen-verwertung-von-verpackungsabfaellen-in-11

Umweltbundesamt (2018): Aufkommen und Verwertung von Verpackungsabfällen in Deutschland im Jahr 2016 [Generation and Recovery of Packaging Waste in Germany in 2016]. Project number: 66835/Z 6-30 727/45; UBA-FB 002670.

In recent years, there has been a steady increase in the consumption of plastic packaging. There are several trends that favor or compensate for this increase.

Favorable trends:

- Increasing consumption of plastic beverage bottles,
- Increasing consumption of packaged products for immediate consumption,
- Increasing consumption of blister packs,
- Increasing consumption of plastic retail packaging and
- Tendency towards bulk packaging of portioned units.

Opposing trends:

- decreasing weight for dimensionally stable plastic packaging,
- slightly decreasing weights in films and
- The sharp decline in consumption of plastic carrier bags.

The opposite trends have a much lower impact on consumption than favorable trends, which is why further increases of packaging waste are expected.

2.5.2.3.2 Situation in Germany, France, Italy, Spain and the UK – which represents 70% of the plastic waste generated in Europe (Deloitte Sustainability, 2017)

https://www2.deloitte.com/my/en/pages/risk/articles/blueprint-for-plastics-packaging-waste.html

Deloitte (2017): Deloitte Sustainability – Blueprint for plastics packaging waste: Quality sorting & recycling – Final Report.
The study presents a quantitative and a qualitative analysis of the main packaging resins (PET, HDPE, LDPE, PP) based on the flows in France, Germany, Italy, Spain and the UK, which represent 70% of the plastic waste generated in Europe. The analysis revealed significant areas of improvement

particularly in relation to the collection rate of PET and polyolefins which are currently as low as 53%. The collection rates vary significantly between the different resins and shapes (between 0% for PET household films and 80% for household PET bottles).

The performance of sorting and recycling varies greatly from country to country, as this step is particularly affected by the quality and output of the collection schemes and the level of contamination of the collected waste.

The study also develops a 2025 forecast under which the 55% recycling target is implemented within the EU (the recycling performance reaches 65% if the extra-EU exports are included). Achieving a 55% recycling target in 2025 means that more than 10 Mt of recycled material need to be absorbed by the end-markets. Compared to 2014, this corresponds to more than twice the amount of the total recycled material and to about one third of the plastic used in the different end-markets. For the absorption of the additional tonnages, the identification of new markets is required. These markets are mainly the sectors with a high demand of plastics and a low use of recycled material.

The impact assessment carried out in the present study shows that the implementation of the 55% target by 2025 is expected to generate significant environmental benefits, as well as to create jobs within the EU territory.

2.5.2.4 Plastic Waste Situation

https://ec.europa.eu/commission/sites/beta-political/files/plastics-factsheet-challenges-opportunities_en.pdf
https://ec.europa.eu/environment/waste/studies/pdf/plastics.pdf
https://www.ciel.org/wp-content/uploads/2019/05/Plastic-and-Climate-FINAL-2019.pdf
https://www.dw.com/en/the-plastic-crisis-isnt-just-ugly-its-fueling-global-warming/a-48730321

Recent case studies have shown that the average weights of individual items of packaging have been decreasing. Drinks bottles made of plastic have dropped in weight by 7.5% and plastic film contains on average 11-15% less material. Despite this, per capita quantities of packaging are increasing across the EU-27 Member States.

The World Economic Forum (WEF) projects that plastic production and use will grow 3.8 percent per year through 2030. WEF assumes this rate of growth will slow to 3.5 percent per year from 2030 through 2050.

2.5.2.5 Activities at companies' level

https://www.csreurope.org/coca-colas-progress-against-world-without-waste#.XdwhMK8xnIU

Coca Cola is committed to creating a World Without Waste by taking responsibility for the packaging they introduce to markets and working to reduce ocean pollution. Below are a few highlights of progress that they have made this year (status: 10.10.2018):

- DESIGN: Aspires to create packaging that contains at least 50% recycled material by 2030, and continues pursuing the goal to make all consumer packaging 100% recyclable by 2025.
- NEW TECHNOLOGIES: Coca Cola´s R&D team continues to evaluate new technologies, and in summer they joined DEMETO's, developers of the gr3n technology for chemical recycling, Industrial Advisory Board. Unlike mechanical recycling, DEMETO's technology allows a complete recovery of PET plastic without any degradation of the material.
- BOTTLE-TO-BOTTLE: In Mexico, their bottled water brand, Ciel, is now available in a 100% recycled plastic bottle (rPET). This builds on the extremely strong collection and conversion infrastructure that their system has financed over the past decade. The percentage of recycled material they are using in their packaging throughout Latin America is growing: 42% in Colombia; 25% in Costa Rica, Ecuador, El Salvador, Honduras, Nicaragua and Panama; 10.8% in Guatemala; Their Mount Franklin water brand in Australia is also now available in 100% rPET.
- COLLECT: Reduce waste by collecting and recycling a bottle or can for every one we sell by 2030.
- Further highlights: "From Plastic to Furniture; Drop Box Program; No Package, No Problem; Industry Partners etc.

Five companies leading the movement to go plastic free
http://www.climateaction.org/news/5-companies-leading-the-movement-to-go-plastic-free

ASDA

Earlier this year, it set out plans to immediately reduce plastic use by 10 percent in 2018, which will require the replacement of 2.4 million drinking straws. All of its stores will also remove single-use cups and cutlery by 2019. In the long-term, it set out ambitions to make all its branded packaging recyclable by the mid-2020s. As the company currently serves 18 million people a week, the potential for changing consumer behavior is high.

McDonalds

"As the world's largest restaurant company, we have a responsibility to use our scale for good to make changes that will have a meaningful impact across the globe," Francesca DeBiase said recently, McDonald's Chief Sustainability Officer. She was commenting on the company's landmark decision to ensure 100 percent of its packaging comes from renewable, recycled or certified sustainable sources within the next eight years.

Costa Coffee

However, it is the decision to pay waste collectors £70 for every ton of used cups which is a real game changer. By 2020, the company is targeting an astonishing half a billion recycled cups, the equivalent of its current annual sales in the UK.

Evian

By 2025, the French company has made the pledge to only produce bottles which are 100 percent recycled.

Tottenham Hotspur

Once the new 62,000 seated venue has been opened at the end of 2018, it banned all single-use plastics across the whole club, including VIP areas. Fans are sold disposable cutlery, straws and stirrers from day one.

What are supermarkets doing to fight plastic? List of supermarkets and programs against plastic (status: 14.01.2018):

https://www.bbc.com/news/science-environment-42652937

- **TESCO**: By 2025, Tesco wants all its packaging to be recyclable or compostable and its total packaging weight to be halved compared to 2007. It has removed all polystyrene from its fish packaging, and claims that more than 78% of its packaging is recyclable, though this depends on the type of material accepted by local authorities.
- **SAINSBURY´S**: Sainsbury's has set a target to reduce packaging by a half by 2020, compared to 2005.
- **ASDA**: Asda has reduced the weight of its packaging by 27% since 2007, partly by introducing "skin" packaging on some of its meat products.
- **MORRISONS**: Morrisons recycles its carrier bags and uses "returnable bins" for fish products to reduce the use of poly boxes.
- **ALDI**: Aldi wants to source all its pulp-based packaging from certified forests by 2020 and has seen a relative 11% reduction in packaging of 11% between 2012 to 2015.
- **Co-Op**: Co-Op aims for 80% of its products to have "easily recyclable" packaging by 2020.
- **LIDL**: Lidl says it is in the process of setting targets for plastic waste. It removed microbeads from all its cosmetic and household products last year, and has also committed to switching to biodegradable cotton buds. For the last 24 years it has charged for plastic carrier bags, and it stopped selling single-use bags last year.

Other Market-Activities: Adidas, Colgate-Palmolive, IKEA, Philips etc.:

https://www.adidas-group.com/en/media/news-archive/press-releases/2019/adidas-to-produce-more-shoes-using-recycled-plastic-waste/

https://www.packaging-gateway.com/news/colgate-palmolive-reduce-plastic-packaging/

https://www.theguardian.com/business/2018/jun/07/ikea-commits-to-phase-out-single-use-plastic-products-by-2020

https://www.philips.de/a-w/ueber-philips/nachhaltigkeit/sustainable-planet/circular-economy/recycle.html

Ikea Group (Ingka Holding B.V. and its controlled entities) invested in Morssinkhof Rymoplast Group (2017)
https://www.retaildetail.eu/en/news/furniture/ikea-acquires-stake-plastic-recycling-plant
https://www.morssinkhofplastics.nl/english/
https://plasticker.de/news/shownews_en.php?nr=31843&nmin=0&div=n&special=&select=&sort=&begriff=ikea&nmax=1&stag=&smon=&sjahr=&etag=&emon=&ejahr=&backto=/news/searchnews2_en.php
Morssinkhof Rymoplast Group will start to build a state-of-the-art plastics recycling plant in Heerenveen. The plastics recycling plant will be realized at Ecopark De Wierde in Heerenveen, next to the plastic sorting plant currently being realized by Omrin, HVC and Midwaste. Morssinkhof Rymoplast will process sorted plastic waste from the plastic sorting plant into high-quality secondary raw materials. In addition to the plastic packaging waste from the plastic sorting plant, comparable plastic flows from other Dutch and foreign collection systems will be purchased for processing. The investment from Ikea Group (Ingka Holding B.V. and its controlled entities) in Morssinkhof Rymoplast Group in 2017 supports the realization of the plastics recycling plant.

BOREALIS acquired Ecoplast (2018) and mtm-Plastics (2016)
https://www.borealisgroup.com/news/borealis-to-acquire-austrian-plastics-recycling-company-ecoplast-kunststoffrecycling-gmbh
Borealis, a leading provider of innovative solutions in the fields of polyolefins, base chemicals and fertilizers, acquired 100% of the shares in Ecoplast Kunststoffrecycling GmbH ("Ecoplast"), an Austrian plastics recycler. Based in Wildon, Austria, Ecoplast processes around 35 000 tons of post-consumer plastic waste from households and industrial consumers every year, turning them into high-quality LDPE and HDPE recyclates, primarily but not exclusively for the plastic film market.

GreenCycle, a Schwarz Group company acquired the Porta Westfalica-based Tönsmeier Group (2018)
https://www.euwid-recycling.com/news/business/single/Artikel/lidl-to-acquire-toensmeier.html
Europe's largest retail group, the Schwarz Gruppe acquired Tönsmeier, the fifth largest waste management company in Germany. With the acquisition via its subsidiary GreenCycle GmbH, Schwarz – the parent company of the Lidl and Kaufland grocery chains – is substantially expanding its waste management and recycling business.

LyondellBasell and SUEZ begin Jointly Operating Plastics Recycling Venture (2018)
https://www.prnewswire.com/news-releases/lyondellbasell-and-suez-begin-jointly-operating-plastics-recycling-venture-300613780.html
LyondellBasell, one of the largest plastics, chemicals and refining companies in the world, and SUEZ, a global leader in smart, sustainable resource management, announced the successful completion of a transaction making each company a 50 / 50 partner in Quality Circular Polymers (QCP), a premium plastics recycling company in Sittard-Geleen, the Netherlands.

Veolia acquired French plastic recycling joint venture from Plastic Omnium and Derichebourg (2018)
https://www.euwid-recycling.de/news/international/einzelansicht/Artikel/veolia-uebernimmt-kunststoffrecyclingaktivitaeten-von-derichebourg-und-plastic-omnium.html
https://www.plasteurope.com/news/VEOLIA_t239224/
Plastic Omnium (Levallois / France; https://plasticomnium.com/en) and Derichebourg (Paris / France; www.derichebourg.com) are divesting their joint venture, Plastic Recycling (Saint-EusÃ¨be / France; www.plasticrecycling.fr). The buyer is recycling group Veolia (Paris / France; www.veolia.com), which acquired German films recycler Just Kunststoff in autumn 2017.

2.5.2.6 Activities at international level – China – green fence politics etc.

http://advances.sciencemag.org/content/4/6/eaat0131
https://www.nationalgeographic.com/news/2018/06/china-plastic-recycling-ban-solutions-science-environment/
The rapid growth of the use and disposal of plastic materials has proved to be a challenge for solid waste management systems with impacts on our environment and ocean. While recycling and the circular economy have been touted as potential solutions, upward of half of the plastic waste intended for recycling has been exported to hundreds of countries around the world. China, which has imported a cumulative 45% of plastic waste since 1992, recently implemented a new policy banning the importation of most plastic waste, begging the question of where the plastic waste will go now. We use commodity trade data for mass and value, region, and income level to illustrate that higher-income countries in the Organization for Economic Cooperation have been exporting plastic waste (70% in 2016) to lower-income countries in the East Asia and Pacific for decades. An estimated 111 million metric tons of plastic waste will be displaced with the new Chinese policy by 2030. As

89% of historical exports consist of polymer groups often used in single-use plastic food packaging (polyethylene, polypropylene, and polyethylene terephthalate), bold global ideas and actions for reducing quantities of non-recyclable materials, redesigning products, and funding domestic plastic waste management are needed.

https://recyclingnetwerk.org/2019/05/16/new-un-rules-on-plastic-waste-exports-following-chinas-bans/

After importing the world's plastic waste for decades, China decided to ban the import of plastic waste at the start of 2018. The ban concerns lots of different types of plastic, PET, PE, PVC, PS, "other" plastics, textiles and unsorted paper waste. The Chinese ban led to a waste crisis all over the world. It has led to waste stockpiling up in the US and Europe, illegal waste burning in Poland, and encourages the European Commission to push on with the Plastic Strategy and the Single-Use Plastics Directive. Netherlands and Belgium are among the world's top exporters of plastic waste. In 2016, they both had a part of 4 percent of the world's export, according to the Harvard University's Atlas of Economic Complexity.

The Chinese ban meant that waste traders started looking for new places to easily get rid of the worthless piles of plastic waste. Countries in South-East Asia such as Indonesia, Thailand, Vietnam and Malaysia became alternative destinations. The new UN rules try to prevent the dumping of plastic waste in these countries.

2.6 CATALOGUE PER EACH CONSIDERED POLYMER TYPE

2.6.1.1 LDPE clear (transparent)

Plastic type	LDPE
Polymertype	LDPE foils clear (transparent)
Purity	- >92% by mass as per specification sheet No. 310 "Grüner Punkt" - Recycling plant operators are preferably demanding >95% by mass
Expected impurities	Plastic impurities (<4 % by mass as per "Grüner Punkt"): - Colored LDPE - Other polymers - Multilayer foils Metallic impurities (<0.5 % by mass as per "Grüner Punkt") Other impurities (<4 % by mass as per "Grüner Punkt") - Paper and cardboard, beverage cartons, etc. - Aluminized plastics - Inerts (stones, ceramics, glass) - Organic impurities, etc.
Market price (EU/ton)	120 – 200 €/t (11/2019, Basis Austria)
Amount from DK potentially available	To be answered by COWI
Possible customers	Operators of LDPE recycling plants with processes as indicated in chapter 3.2.1.2.1 An overview of operators of LDPE recycling plants in D, NL, A and UK is provided in the charts in the Annex of this report.
Next step in value chain possible treatment	LDPE recycling plants with processes as indicated in chapter 3.2.1.2.1

Possible factors significantly reducing the value of the material	- Lower purity as indicated at row "Purity" - Critical impurities such as PVC, Silicone, etc. - Glass, sand and organic and fiber impurities
Challenges in the market	- High volatility of the prices - Intercontinental legal requirements (China ban, etc.) - Recycling targets (push factor) and requirements/definitions for the usage of secondary raw materials (pull factor)
Sources of above mentioned information	Expertise and interviews with sorting plant operators

Table 5: Market catalogues table – LDPE clear

2.6.1.2 LDPE color

Plastic type	LDPE
Polymertype	LDPE foils colored
Purity	- >92% by mass as per specification sheet No. 310 "Grüner Punkt" - Recycling plant operators are preferably demanding >95% by mass
Expected impurities	Plastic impurities (<4 % by mass as per "Grüner Punkt"): - Colored LDPE - Other polymers - Multilayer foils Metallic impurities (<0.5 % by mass as per "Grüner Punkt") Other impurities (<4 % by mass as per "Grüner Punkt") - Paper and cardboard, beverage cartons, etc. - Aluminized plastics - Inerts (stones, ceramics, glass) - Organic impurities - etc.
Market price (EU/ton)	0 – 50 €/t, Tendency to pay for disposal (11/2019, Basis Austria)
Amount from DK potentially available	To be answered by COWI
Possible customers	Operators of LDPE recycling plants with processes as indicated in chapter 3.2.1.2.1 An overview of operators of LDPE recycling plants in D, NL, A and UK is provided in the charts in the Annex of this report.
Next step in value chain possible treatment	LDPE recycling plants with processes as indicated in chapter 3.2.1.2.1
Possible factors significantly reducing the value of the material	- Lower purity as indicated at row "Purity" - Critical impurities such as PVC, Silicone, etc. - Glass, sand and organic and fiber impurities

Challenges in the market	- High volatility of the prices - Intercontinental legal requirements (China ban, etc.) - Recycling targets (push factor) and requirements/definitions for the usage of secondary raw materials (pull factor)
Sources of above mentioned information	Expertise and interviews with sorting plant operators

Table 6: Market catalogue table – LDPE color

2.6.1.3 HDPE

Plastic type	HDPE
Polymertype	HDPE hollow bodies, volume <5l
Purity	- >94% by mass as per specification sheet No. 329 "Grüner Punkt" - Recycling plant operators are preferably demanding >95-98% by mass
Expected impurities	Rigid PP items (<3 % by mass as per "Grüner Punkt") Plastic films (<5 % by mass as per "Grüner Punkt") Foamed plastics (<0.5 by mass % as per "Grüner Punkt"): Metallic impurities (<0.5 % by mass as per "Grüner Punkt") Other impurities (<3 % by mass as per "Grüner Punkt") - Paper and cardboard, beverage cartons, etc. - Aluminized plastics - Inerts (stones, ceramics, glass) - Organic impurities - etc.
Market price (EU/ton)	180 – 250 €/t (11/2019, Basis Austria)
Amount from DK potentially available	To be answered by COWI
Possible customers	Operators of HDPE recycling plants with processes as indicated in chapter 0 An overview of operators of HDPE recycling plants in D, NL, A and UK is provided in the charts in the Annex of this report.
Next step in value chain possible treatment	HDPE recycling plants with processes as indicated in chapter 0
Possible factors significantly reducing the value of the material	- Lower purity as indicated at row "Purity" - Critical impurities such as PVC, Silicone, etc. - Glass, sand and organic and fiber impurities
Challenges in the market	- High volatility of the prices - Intercontinental legal requirements (China ban, etc.)

	- Recycling targets (push factor) and requirements/definitions for the usage of secondary raw materials (pull factor)
Sources of above mentioned information	Expertise and interviews with sorting plant operators

Table 7: Market catalogue table – HDPE

2.6.1.4 PP

Plastic type	PP
Polymertype	PP hollow bodies, volume <5l
Purity	- >94% by mass as per specification sheet No. 324 "Grüner Punkt" - Recycling plant operators are preferably demanding >95-98% by mass
Expected impurities	Rigid PE items (<1 % by mass as per "Grüner Punkt") Plastic films (<2 % by mass as per "Grüner Punkt") Expanded plastics (<0.5 by mass % as per "Grüner Punkt") Metallic impurities (<0.5 by mass % as per "Grüner Punkt") Other impurities (<3 % by mass as per "Grüner Punkt") - Paper and cardboard, beverage cartons, etc. - Aluminized plastics - Inerts (stones, ceramics, glass) - Organic impurities - etc.
Market price (EU/ton)	100 – 150 €/t (11/2019, Basis Austria)
Amount from DK potentially available	To be answered by COWI
Possible customers	Operators of PP recycling plants with processes as indicated in chapter 0 An overview of operators of PP recycling plants in D, NL, A and UK is provided in the charts in the Annex of this report.
Next step in value chain possible treatment	PP recycling plants with processes as indicated in chapter 0
Possible factors significantly reducing the value of the material	- Lower purity as indicated at row "Purity" - Critical impurities such as PVC, Silicone, etc. - Glass, sand and organic and fiber impurities
Challenges in the market	- High volatility of the prices - Intercontinental legal requirements (China ban, etc.)

	- Recycling targets (push factor) and requirements/definitions for the usage of secondary raw materials (pull factor)
Sources of above mentioned information	Expertise and interviews with sorting plant operators

Table 8: Market catalogue table – PP

2.6.1.5 PS

Plastic type	PS
Polymertype	PS hollow bodies such as yoghurt and margarine pots
Purity	>94% by mass as per specification sheet No. 330 "Grüner Punkt"
Expected impurities	Other plastics (<3 % by mass as per "Grüner Punkt") Metallic impurities (<0.5 % by mass as per "Grüner Punkt") Other impurities (<3 % by mass as per "Grüner Punkt") - Paper and cardboard, beverage cartons, etc. - Aluminized plastics - Inerts (stones, ceramics, glass) - Organic impurities - etc.
Market price (EU/ton)	20 – 80 €/t (11/2019, Basis Austria)
Amount from DK potentially available	To be answered by COWI
Possible customers	Operators of PS recycling plants with processes as indicated in chapter 0 An overview of operators of PS recycling plants in D, NL, A and UK is provided in the charts in the Annex of this report.
Next step in value chain possible treatment	PS recycling plants with processes as indicated in chapter 0
Possible factors significantly reducing the value of the material	- Lower purity as indicated at row "Purity" - Critical impurities such as PVC, Silicone, etc. - Glass, sand and organic and fiber impurities
Challenges in the market	- High volatility of the prices - Intercontinental legal requirements (China ban, etc.) - Recycling targets (push factor) and requirements/definitions for the usage of secondary raw materials (pull factor)
Sources of above mentioned information	Expertise and interviews with sorting plant operators

TABLE 9: MARKET CATALOGUE TABLE – PS

2.6.1.6 PET bottles clear

Plastic type	PET
Polymertype	PET drinking bottles transparent
Purity	>98 % by mass as per specification sheet No. 325 "Grüner Punkt"
Expected impurities	Other PET bottles or packaging (<2 % by mass as per "Grüner Punkt") EPS items (<0.5 % by mass as per "Grüner Punkt") PVC items (<0.2 % by mass as per "Grüner Punkt") Metallic impurities (<0.5 % by mass as per "Grüner Punkt") Other impurities (<2 % by mass as per "Grüner Punkt") - Paper and cardboard, beverage cartons, etc. - Aluminized plastics - Inerts (stones, ceramics, glass) - Organic impurities - etc.
Market price (EU/ton)	400 – 500 €/t (11/2019, Basis Austria)
Amount from DK potentially available	To be answered by COWI
Possible customers	Operators of PET recycling plants with processes as indicated in chapter 0 An overview of operators of PET recycling plants in D, NL, A and UK is provided in the charts in the Annex of this report.
Next step in value chain possible treatment	PET recycling plants with processes as indicated in chapter 0
Possible factors significantly reducing the value of the material	- Lower purity as indicated at row "Purity" - Non bottle grade or respectively food-grade PET in the material - Polyester-based textiles - Critical impurities such as PVC, Silicone, etc. - Glass, sand and organic and fiber impurities
Challenges in the market	- High volatility of the prices

	- Intercontinental legal requirements (China ban, etc.) - Recycling targets (push factor) and requirements/definitions for the usage of secondary raw materials (pull factor)
Sources of above mentioned information	Expertise and interviews with sorting plant operators

Table 10: Market catalogue table – PET bottles clear

2.6.1.7 PET bottles blue

Plastic type	PET
Polymertype	PET drinking bottles blue
Purity	>98 % by mass analogue to specification sheet No. 325 "Grüner Punkt"
Expected impurities	Other PET bottles or packaging (<2 % by mass as per "Grüner Punkt") EPS items (<0.5 % by mass as per "Grüner Punkt") PVC items (<0.2 % by mass as per "Grüner Punkt") Metallic impurities (<0.5 % by mass as per "Grüner Punkt") Other impurities (<2 % by mass as per "Grüner Punkt") - Paper and cardboard, beverage cartons, etc. - Aluminized plastics - Inerts (stones, ceramics, glass) - Organic impurities - etc.
Market price (EU/ton)	280 – 350 €/t (11/2019, Basis Austria)
Amount from DK potentially available	To be answered by COWI
Possible customers	Operators of PET recycling plants with processes as indicated in chapter 0 An overview of operators of PET recycling plants in D, NL, A and UK is provided in the charts in the Annex of this report.
Next step in value chain possible treatment	PET recycling plants with processes as indicated in chapter 0
Possible factors significantly reducing the value of the material	- Lower purity as indicated at row "Purity" - Non bottle grade or respectively food-grade PET in the material - Polyester-based textiles - Critical impurities such as PVC, Silicone, etc. - Glass, sand and organic and fiber impurities

Challenges in the market	- High volatility of the prices - Intercontinental legal requirements (China ban, etc.) - Recycling targets (push factor) and requirements/definitions for the usage of secondary raw materials (pull factor)
Sources of above mentioned information	Expertise and interviews with sorting plant operators

Table 11: Market catalogue table – PET bottles blue

2.6.1.8 PET bottles green/brown

Plastic type	PET
Polymertype	PET drinking bottles green/brown
Purity	>98 % by mass analogue to specification sheet No. 325 "Grüner Punkt"
Expected impurities	Other PET bottles or packaging (<2 % by mass as per "Grüner Punkt") EPS items (<0.5 % by mass as per "Grüner Punkt") PVC items (<0.2 % by mass as per "Grüner Punkt") Metallic impurities (<0.5 % by mass as per "Grüner Punkt") Other impurities (<2 % by mass as per "Grüner Punkt") - Paper and cardboard, beverage cartons, etc. - Aluminized plastics - Inerts (stones, ceramics, glass) - Organic impurities - etc.
Market price (EU/ton)	150 – 250 €/t (11/2019, Basis Austria)
Amount from DK potentially available	To be answered by COWI
Possible customers	Operators of PET recycling plants with processes as indicated in chapter 0 An overview of operators of PET recycling plants in D, NL, A and UK is provided in the charts in the Annex of this report.
Next step in value chain possible treatment	PET recycling plants with processes as indicated in chapter 0
Possible factors significantly reducing the value of the material	- Lower purity as indicated at row "Purity" - Non bottle grade or respectively food-grade PET in the material - Polyester-based textiles - Critical impurities such as PVC, Silicone, etc. - Glass, sand and organic and fiber impurities

Challenges in the market	- High volatility of the prices - Intercontinental legal requirements (China ban, etc.) - Recycling targets (push factor) and requirements/definitions for the usage of secondary raw materials (pull factor)
Sources of above mentioned information	Expertise and interviews with sorting plant operators

TABLE 12: MARKET CATALOGUE TABLE – PET BOTTLES GREEN/BROWN

2.6.1.9 Mixed PET

Plastic type	PET
Polymertype	Mixed PET items such as bottles and other packaging
Purity	>95 % by mass as per specification sheet No. 499 "ARA"
Expected impurities	PVC, PA, PC items (<0.05 % by mass) Other plastics items Metallic impurities Other impurities - Paper and cardboard, beverage cartons, etc. - Aluminized plastics - Inerts (stones, ceramics, glass) - Organic impurities - etc.
Market price (EU/ton)	-50 up to -100 €/t (11/2019, Basis Austria)
Amount from DK potentially available	To be answered by COWI
Possible customers	Mixed PET fractions cannot be sent to PET recycling plants, except they are owning their own separation and purifying process prior their recycling line.
Next step in value chain possible treatment	After the purification process the material can be treated with a PET recycling process as indicated in chapter 0
Possible factors significantly reducing the value of the material	- Lower purity as indicated at row "Purity" - Critical impurities such as PVC, Silicone, etc. - Glass, sand and organic and fiber impurities
Challenges in the market	- High volatility of the prices - Intercontinental legal requirements (China ban, etc.) - Recycling targets (push factor) and requirements/definitions for the usage of secondary raw materials (pull factor)
Sources of above mentioned information	Expertise and interviews with sorting plant operators

Table 13: Market catalogue table – Mixed PET (90/10)

2.6.1.10 Mixed plastics

Plastic type	Mixed plastics
Polymertype	Mixed plastics consisting of foils, rigids of different polyolefins
Purity	>85 % by mass as per specification sheet No. 323 "Grüner Punkt"
Expected impurities	No polyolefins (PET, PS, etc.) (<7.5 % by mass as per "Grüner Punkt") Paper and cardboard (<5 % by mass as per "Grüner Punkt") PVC items (<0.5 % by mass as per "Grüner Punkt") Metallic impurities (<0.5 % by mass as per "Grüner Punkt") Other impurities (<3 % by mass as per "Grüner Punkt") - Paper and cardboard, beverage cartons, etc. - Aluminized plastics - Inerts (stones, ceramics, glass) - Organic impurities - etc. Particles <20 mm (<2 % by mass as per "Grüner Punkt")
Market price (EU/ton)	No revenue for this material Has to be considered with disposal costs
Amount from DK potentially available	To be answered by COWI
Possible customers	Mixed plastic fractions cannot be sent to recycling plants, except they are owning their own separation and purifying process prior their recycling line.
Next step in value chain possible treatment	After a purification process the material can be treated with different recycling processes as indicated in chapter 0
Possible factors significantly reducing the value of the material	- Lower purity as indicated at row "Purity" - Critical impurities such as PVC, Silicone, etc. - Glass, sand and organic and fiber impurities
Challenges in the market	- High volatility of the prices - Intercontinental legal requirements (China ban, etc.)

	- Recycling targets (push factor) and requirements/definitions for the usage of secondary raw materials (pull factor)
Sources of above mentioned information	Expertise and interviews with sorting plant operators

Table 14: Market catalogue table – Mixed plastics

2.7 EXISTING RECYCLING FACILITIES

The following chapters are including summaries of the survey regarding existing recycling facilities in the countries Netherlands, Germany, Austria and United Kingdom.

The matrix with the full information is attached as Annex to this report.

Attention:
There is partially no public data available about the origin of the input material (post-consumer plastics or industrial residues) for the recycling plants mentioned in this chapter. Subsequently there is no differentiation about treatment plants for post-consumer material and industrial residues (mono-charge materials).

2.7.1 Charts per country

2.7.1.1 The Netherlands

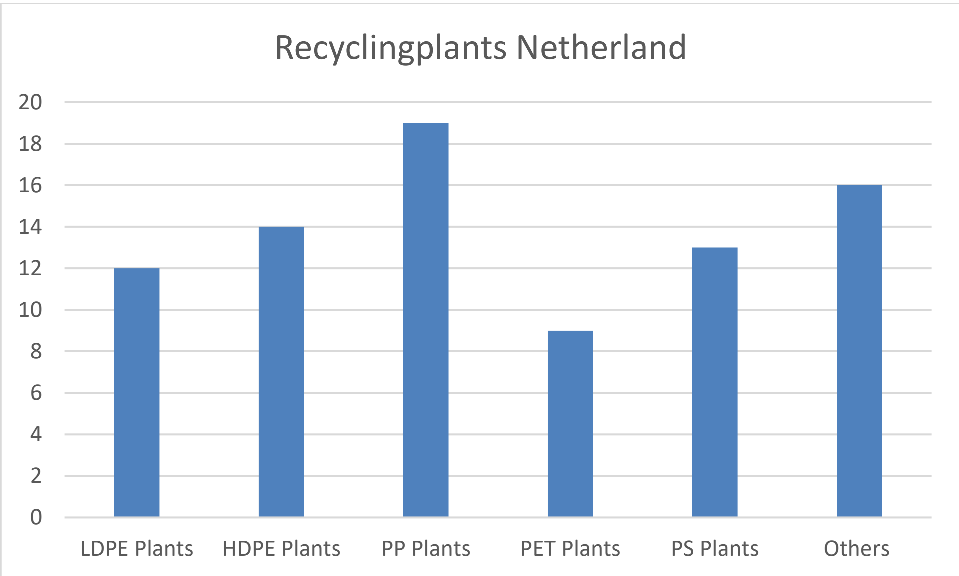

FIGURE 4: NUMBER OF RECYCLING PLANTS – COUNTRY CHART – THE NETHERLANDS

2.7.1.2 Germany

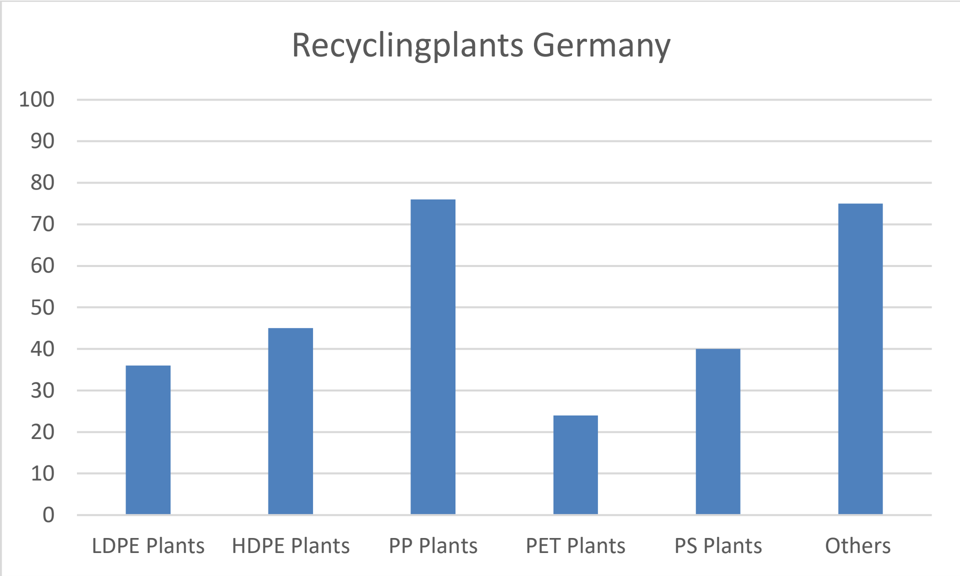

FIGURE 5: NUMBER OF RECYCLING PLANTS – COUNTRY CHART – GERMANY

2.7.1.3 Austria

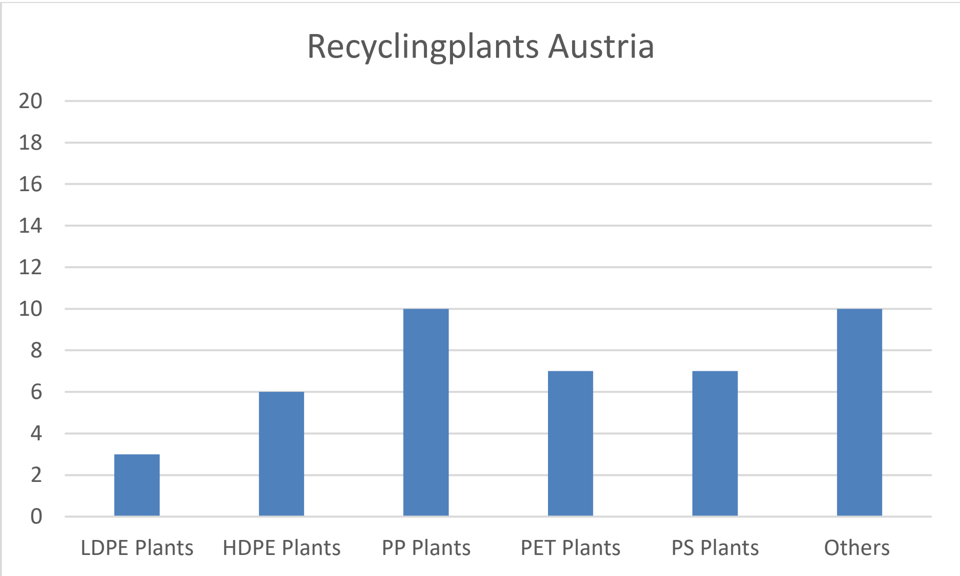

FIGURE 6: NUMBER OF RECYCLING PLANTS – COUNTRY CHART – AUSTRIA

2.7.1.4 United Kingdom

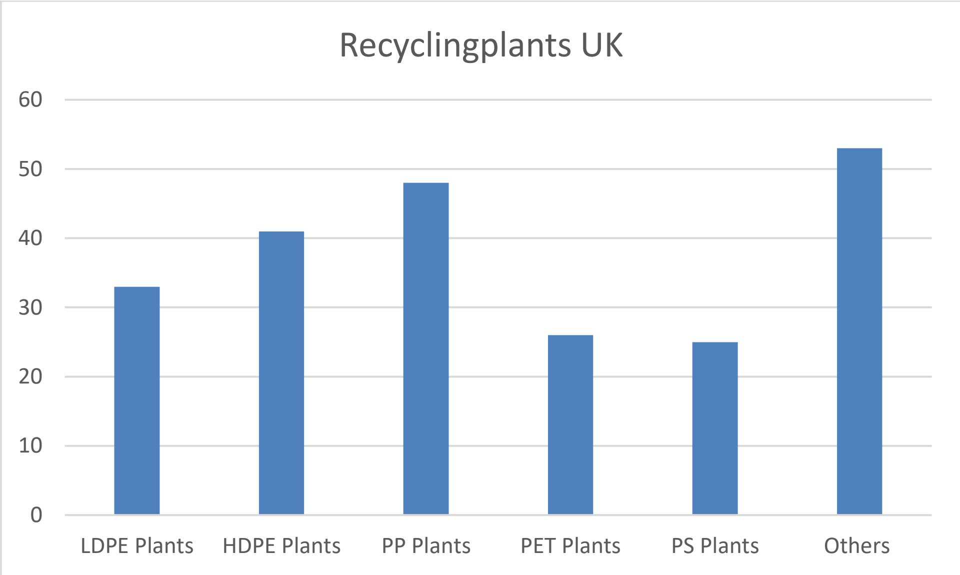

FIGURE 7: NUMBER OF RECYCLING PLANTS – COUNTRY CHART – UNITED KINGDOM

2.7.2 Charts per polymer type

2.7.2.1 Total number of plants

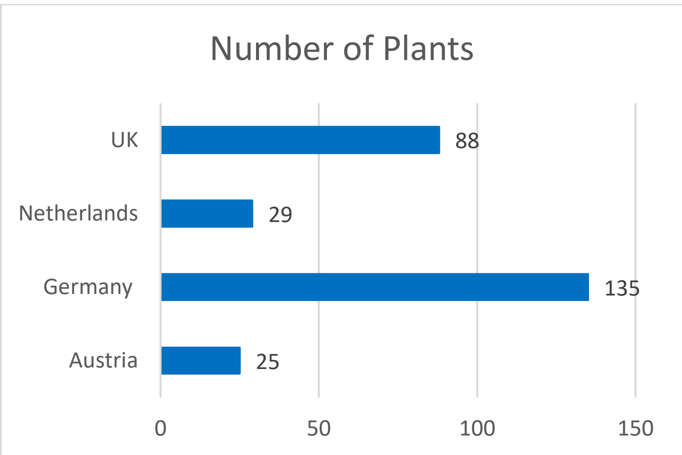

FIGURE 8: NUMBER OF RECYCLING PLANTS – TOTAL PER COUNTRY

2.7.2.2 Total of LDPE recycling plants

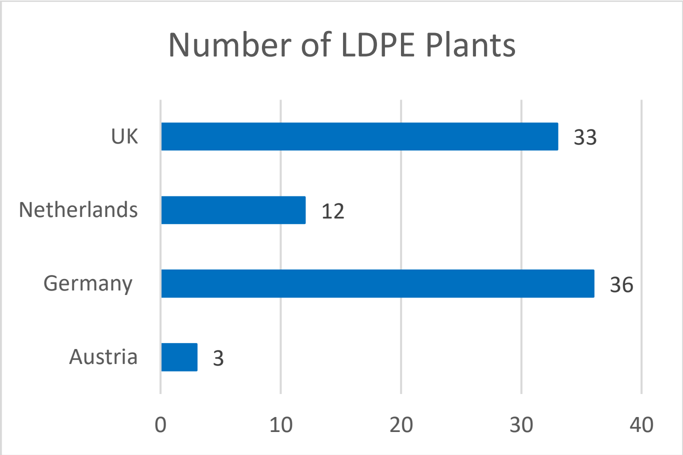

FIGURE 9: NUMBER OF RECYCLING PLANTS – LDPE RECYCLING PLANTS IN D, NL, A AND UK

2.7.2.3 Total of HDPE recycling plants

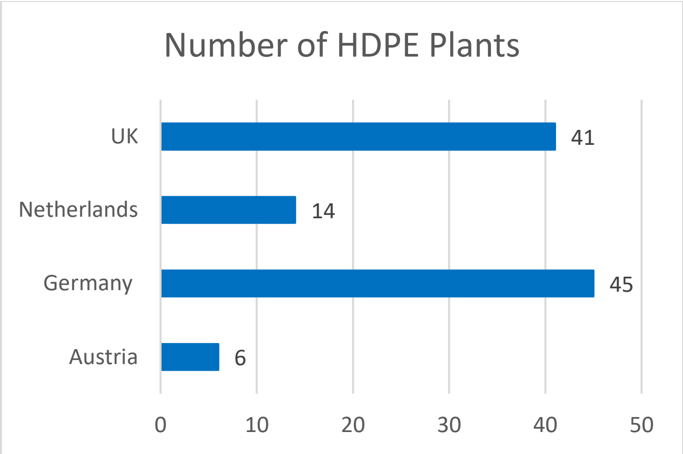

FIGURE 10: NUMBER OF RECYCLING PLANTS – HDPE RECYCLING PLANTS IN D, NL, A AND UK

2.7.2.4 Total of PP recycling plants

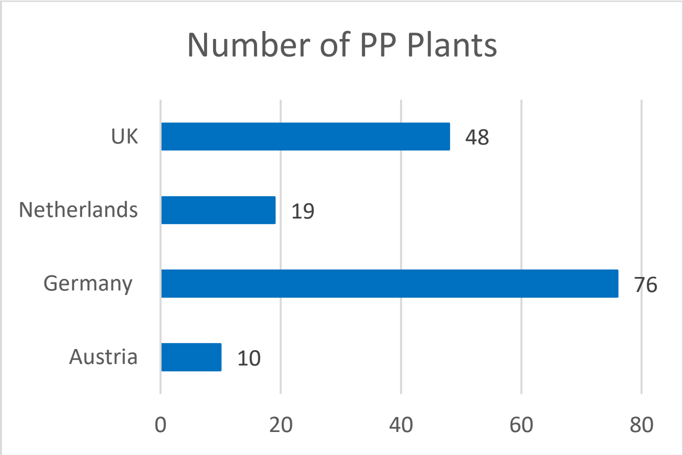

FIGURE 11: NUMBER OF RECYCLING PLANTS – PP RECYCLING PLANTS IN D, NL, A AND UK

2.7.2.5 Total of PET recycling plants

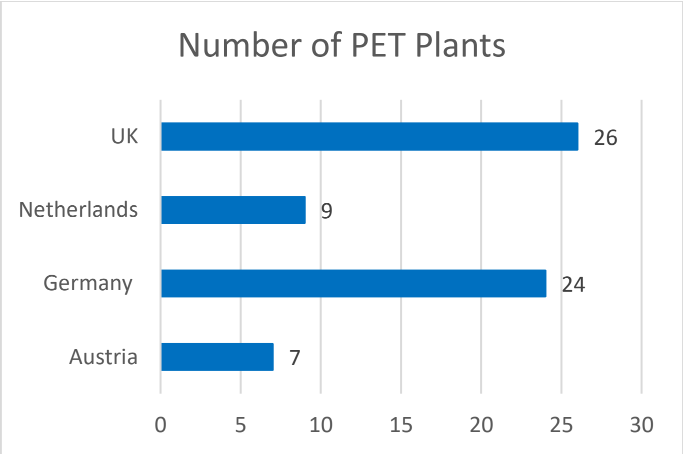

FIGURE 12: NUMBER OF RECYCLING PLANTS – PET RECYCLING PLANTS IN D, NL, A AND UK

2.7.2.6 Total of PS recycling plants

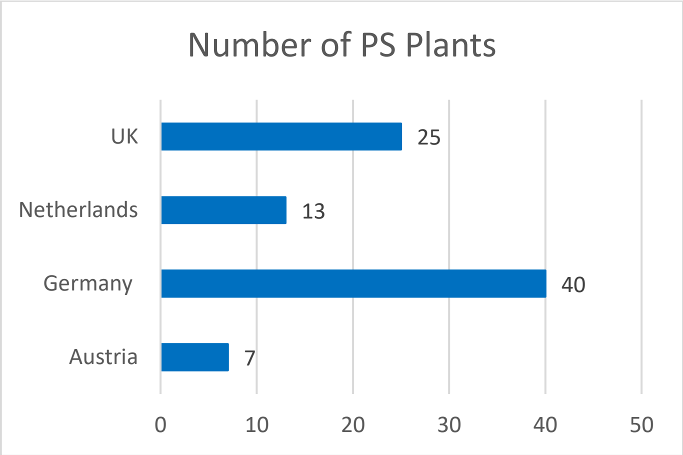

Figure 13: Number of recycling plants – PS recycling plants in D, NL, A and UK

2.7.2.7 Total of recycling plants for other polymers

The relatively high number of recycling plants for other polymers is on one hand resulting from treatment plants for e.g. PVC and ABS and on the other hand on the procedure, that recycling plant with no information about the treated polymer type have been categorized as treatment plant for other polymers.

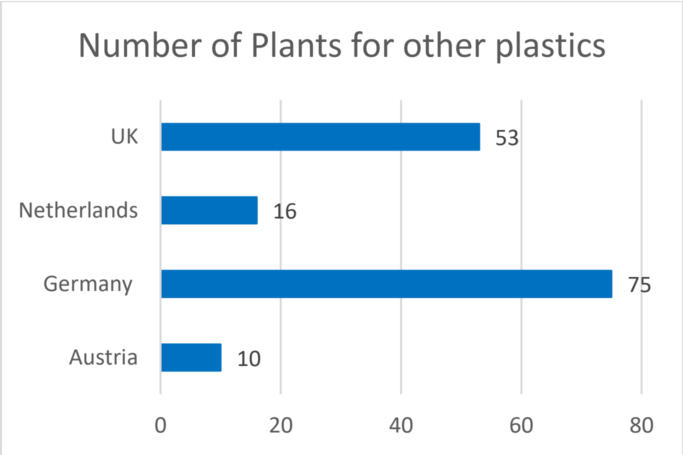

Figure 14: Number of recycling plants – Other plastics recycling plants in D, NL, A and UK

3 TECHNOLOGY CATALOGUE

3.1 SORTING PLANT

3.1.1 Key components in a modern sorting facility

3.1.1.1 Pre-conditioning

3.1.1.1.1 Bag-opener / Pre-shredder

As the input material can be delivered in different physical conditions (bales, loose) and from different sources, it is necessary to de-compact and "open" the incoming material. The main function of this "shredder" is to open the bag, to de-compact the material and to homogenize the flow.

If this bag-opening shredder cuts the pieces into too small particles, then it is counter-productive for the following sorting process.

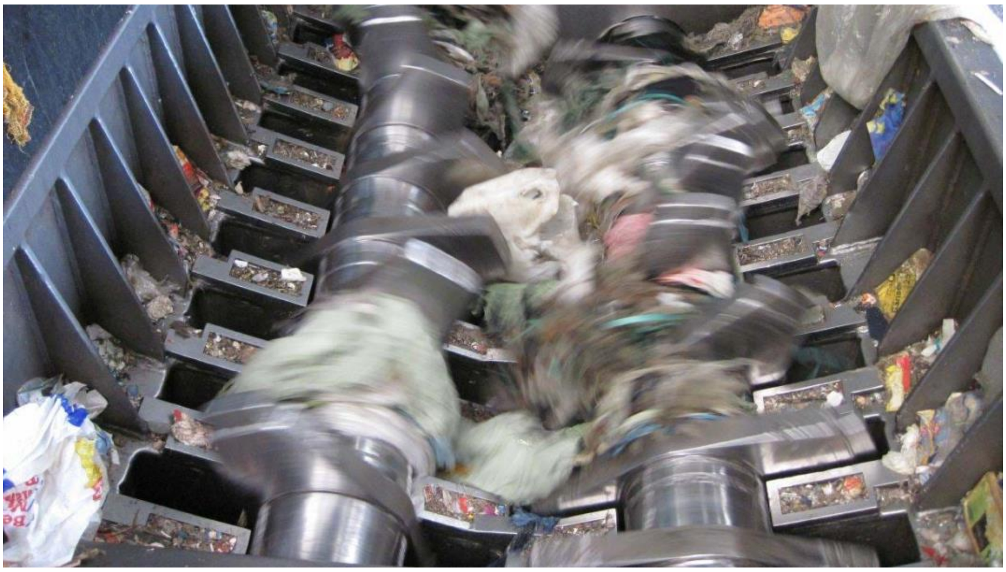

FIGURE 15: PHOTO BAG-OPENER / COMPANY METSO / PICTURE SOURCE: INTERNET

3.1.1.1.2 Foil separator

The function of a foil separator is to extract large sized plastic foils in an early stage of the treatment plant. This results in a better separation efficiency in following pre-conditioning steps such as screens and ballistic sorters.

Typically, these oversized fractions are manually sorted and the residues are handed over to the automated sorting systems. Another option is to shred the oversized particles for an automized sorting process. This option is maybe leading to lower recovery rates as a certain quantity of plastics will be cut to too small grain size and cannot be recovered with automatic sorting systems.

A conventional foils separator is equipped with a rotating drum with spikes to catch the foils. These spikes are pulled back into the drum with some types of foil separators. Air support or suction drums are also a frequently used system.

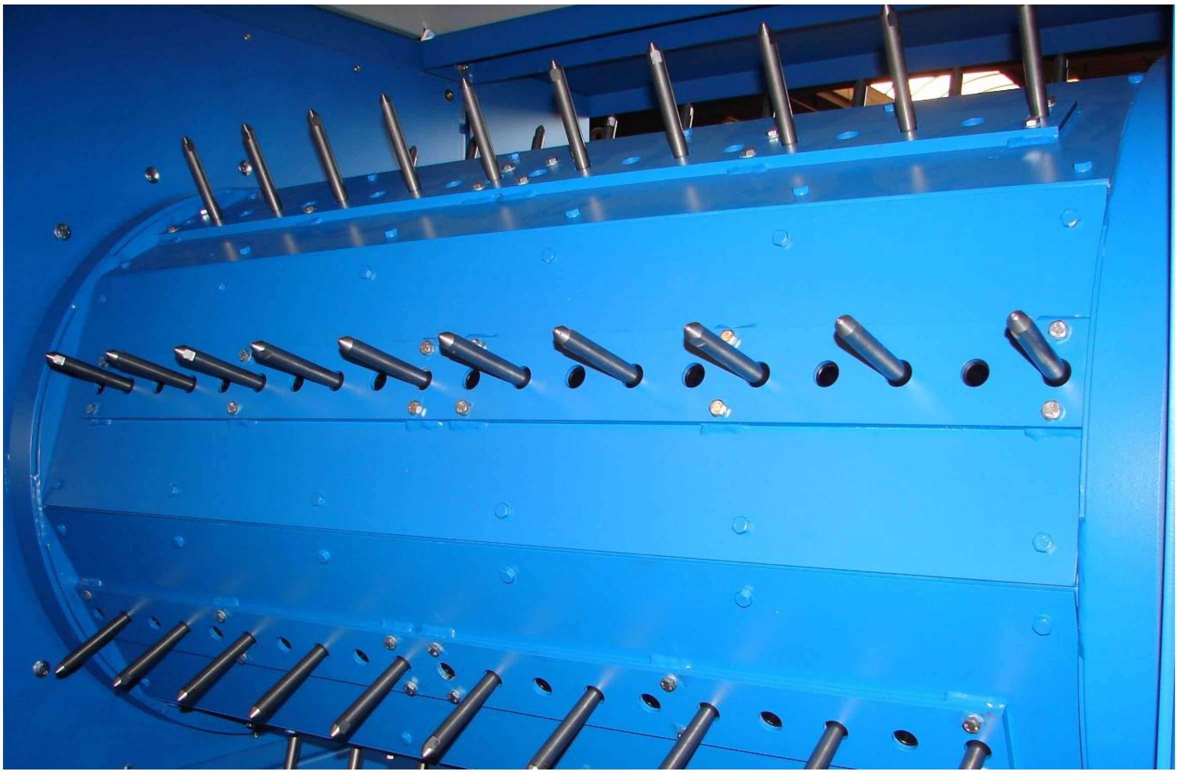

Figure 16: Photo Film Remover / Company Matthiessen Lagertechnik GmbH / Picture source: Internet

3.1.1.1.3 Screens

The screening can generally be done with rotating drum screens or vibrating flat screens.
The main function of these treatment step is to extract oversized particles (screen cut range from 240-300mm) from the material stream. These oversized particles are usually containing a high quantity of large foils and this stream is generally not suitable for automatic sorting processes without additional treatment.

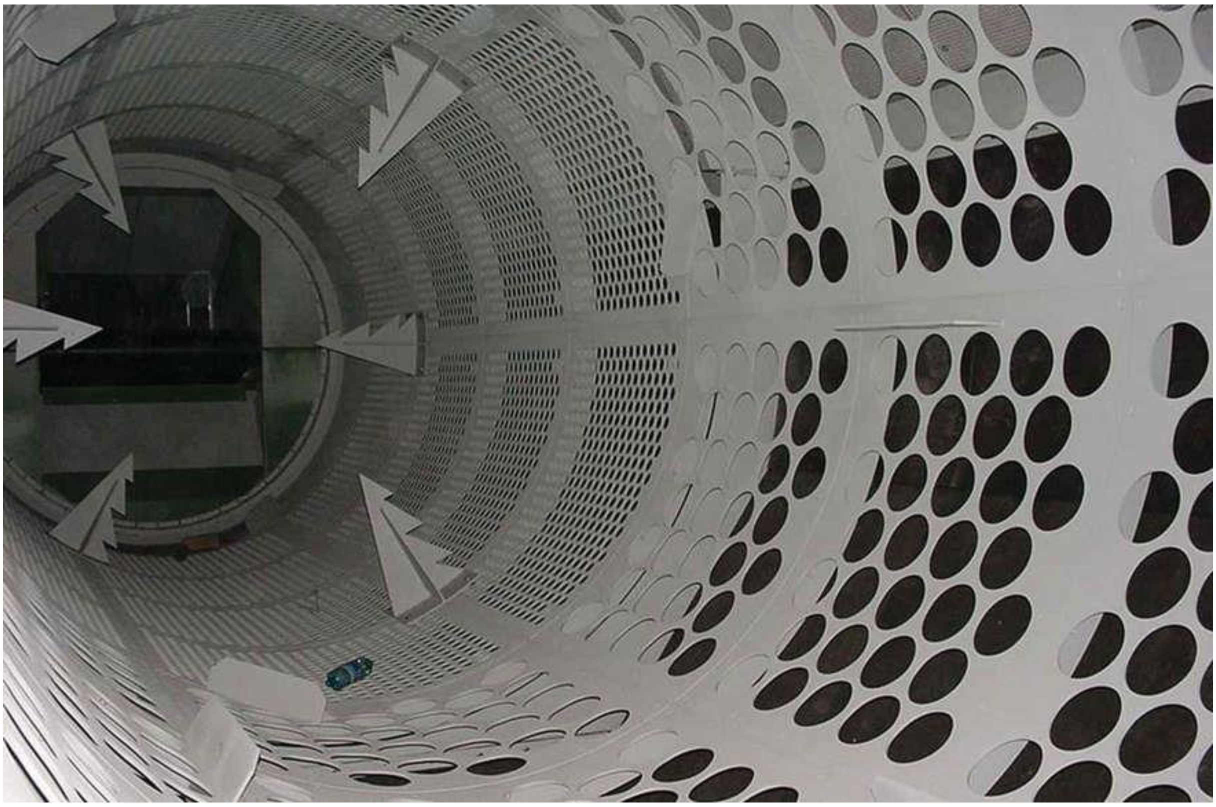

FIGURE 17: PHOTO DRUM SCREEN / COMPANY SUTCO / PICTURE SOURCE: INTERNET

3.1.1.1.4 Windsifters

There is a wide range of windsifters available on the market. The most common types of windsifters are drum windsifters, suction windsifters and Zik-Zak-Windsifters. The selection of the correct windsifters is done according to the application and the grain size spectrum of the infeed material.

The windsifters are able to extract light or ultra-light particles from a material stream.

FIGURE 18: PHOTO DRUM WINDSIFTER / COMPANY NIHOT / PICTURE SOURCE: INTERNET

Figure 19: Photo Cross-flow-Windsifter / Company Nihot / Picture source: Internet

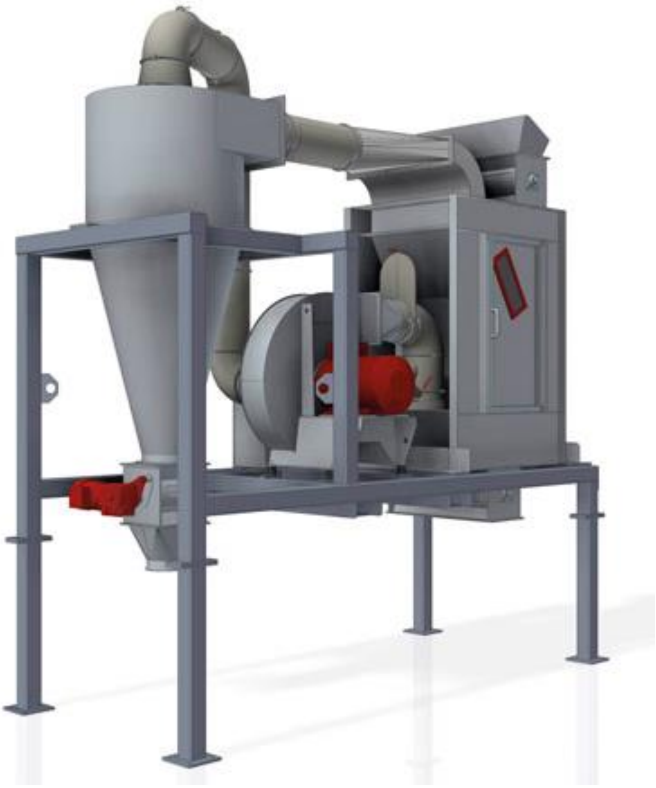

Figure 20: Photo Zik-Zak-Windsifter / Company trennso-Technik / Picture source: Internet

3.1.1.1.5 Ballistic sorters

<u>This process step separates the stream into 3 streams:</u>

- 2D-material (predominantly plastic foils, paper, etc.)
- 3D-material (predominantly bottles, cans, canisters, heavy objects, metals, etc.)
- Fine fraction

The 2D- and 3D- materials can be subsequently sent to different plastic extraction lines and the fines can be additionally treated with an additional screen and light/heavy separator (for improvement of the plastic recovery rate) or can be directly sent to the RDF-production process.

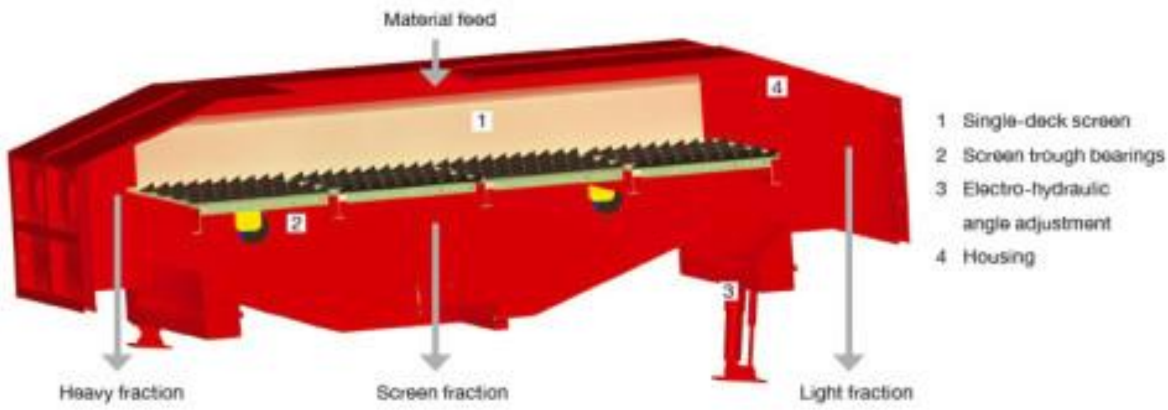

FIGURE 21: PICTURE BALLISTIC SORTER / COMPANY IMT / PICTURE SOURCE: INTERNET

3.1.1.2 Sorting/separation units

3.1.1.2.1 Iron separator

Iron separators can be built as overbelt magnets (in permanent- or electromagnetic execution) or as permanentmagnetic drum magnets. In the foreseen case it is proposed to use electromagnetic overband magnets.
An overbelt magnet is usually located in-line with the feeding conveyor at a transfer point between two conveyors and can extract ferromagnetic objects from different material streams.
The ferromagnetic belts are removed with the belt of the magnet and will be released into collection boxes or onto a discharging conveyor.

FIGURE 22: PICTURE OVERBAND MAGNET / COMPANY STEINERT / PICTURE SOURCE: INTERNET

3.1.1.2.2 Eddy current separator

An eddy current separator can be utilized to extract non-ferromagnetic objects with high electrical conductivity such as aluminum and copper from different material streams. It is important to know, that an eddy current separator cannot or hardly separate metals with a lower electrical conductivity or alloyed steels such as stainless steel.

A strong permanent magnet, that rapidly rotates in the front drum generates a pulse-like magnetic field, which induces eddy currents in the non-ferrous materials which in turn create in every piece a magnetic field of the opposite polarity to the permanent magnet system. The separation from the flow of material is brought about by the repulsive force in the area of the deflector roller on the output side.

Usually a vibrating feeder is used in combination with the separator to spread the flow of material on the full width of the separator. Modifications of the separating function can be achieved by adjustment of the rotor and conveyor speed and by adjustment of the splitter bar.

FIGURE 23: PICTURE EDDY CURRENT SEPARATOR / COMPANY STEINERT / PICTURE SOURCE: INTERNET

3.1.1.2.3 Automatic sorter based in NIR-Technology

NIR-sorting processes are used for mass extraction of polymers from 2D and 3D-plastic streams.

NIR-sorters are automatic sorting machines, which are analyzing the reflecting light from an object and are able to extract the detected goods by means of a compressed air impulse.

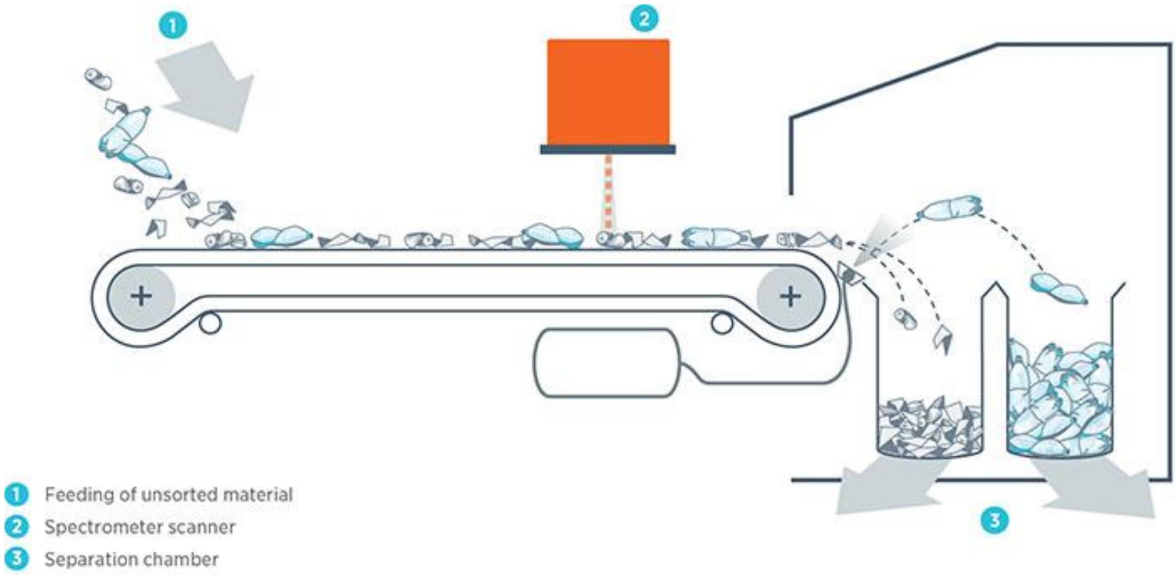

Figure 24: Picture NIR-Sorter / Company Tomra / Picture source: Internet

In fully automized plants with 2 step NIR-solutions, the first machine is performing the mass extraction of desired objects and the second machine is doing the quality sorting in order to reach a final product, which fulfills the requirements for a plastics recycling process.

Before the residual material will be sent to the residue handling it is possible to implement an additional NIR-sorter for the purpose of recovery of a mixed polyolefin-fraction for external recycling processes or as a scavenger machine to recover polymers, which will be once more sent to the sorting process.

3.1.1.2.4 Sorting robot

Sorting robots are one of the newest developments in the waste treatment sector. As described in chapter 3.1.2.2 the sorting robots are primarily at the extraction tasks for plastic hollow bodies and materials in C&D applications.

Many industrial robots are usually used for assembly line work or process steps with high precision that are repeated many times. For the application of robot systems in the waste management sector other requirements are given. Several systems are already successfully implemented on the market to meet these requirements through the correct combination of sensors, actuators and software.
The challenges of using robotic technologies to sort waste are mainly the heterogeneity and surface contamination of the waste streams, the inconsistent shapes or masses that are to be grabbed by the actuator, and the random location of the objects in the waste stream. Above all, the processes for material or object recognition with the associated algorithms and the software in the background are of great importance. If this software is combined with suitable hardware and an additional implementation of artificial intelligence is performed, robotic systems are able to take on multitasking actions in procedures. If necessary, new fractions can be "trained", making the technology very future-proof in terms of changing waste streams. The robots used in some cases replace or interact with human sorters and / or find application in areas (e.g. construction site wastes) that have not been sortable to date and / or allow automatic quality assurance and enhancements (e.g. plastics).

FIGURE 25: PICTURE SORTING ROBOT / COMPANY BHS / PICTURE SOURCE: INTERNET

3.1.1.2.5 Manual sorting

Manual sorting will be executed by sorting staff and the extracted goods will be discharged into sorting channels into boxes below the sorting stages. The boxes can be executed with bunker conveyors or as boxes, which are unloaded with the help of a front end loader or a fork lift.

FIGURE 26: PHOTO MANUAL SORTING STATION / COMPANY R&R BETH / PICTURE SOURCE: INTERNET

3.1.1.3 Conditioning units and residue handling systems

3.1.1.3.1 Baler and bale wrapper

A baler and bale wrapper are usually required to optimize the transport weight of the materials for external utilization and to minimize the internal storage areas.
Additionally, the baling and wrapping heavily reduces the possibility of a fire in a storage compartment and its speed of spreading.

Figure 27: Picture Baler / Company Bollegraaf / Picture source: Internet

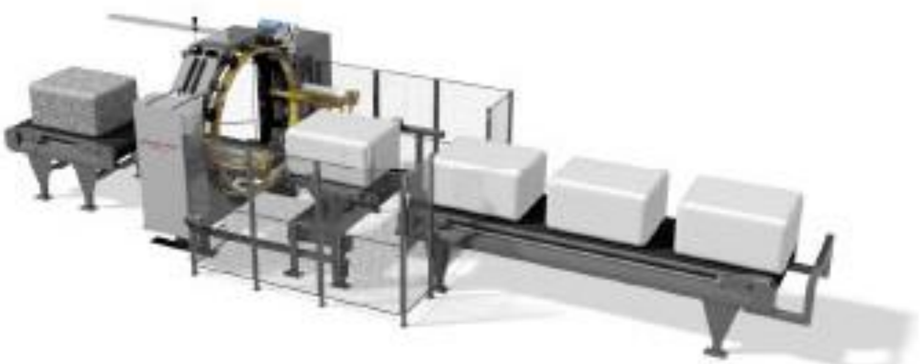

Figure 28: Picture Bale wrapper / Company CrossWrap / Picture source: Internet

3.1.1.3.2 RDF-treatment system

All the residues, which cannot be extracted as valuable or harmful materials, are usually baled and sent to external treatment or internally treated with an RDF-preparation and shredding step.

The preparation is considered as foreign part separator, which has the task to extract heavy objects (stones, remaining metals) from the material stream and to prevent the following RDF-shredder from damages due to such particles.

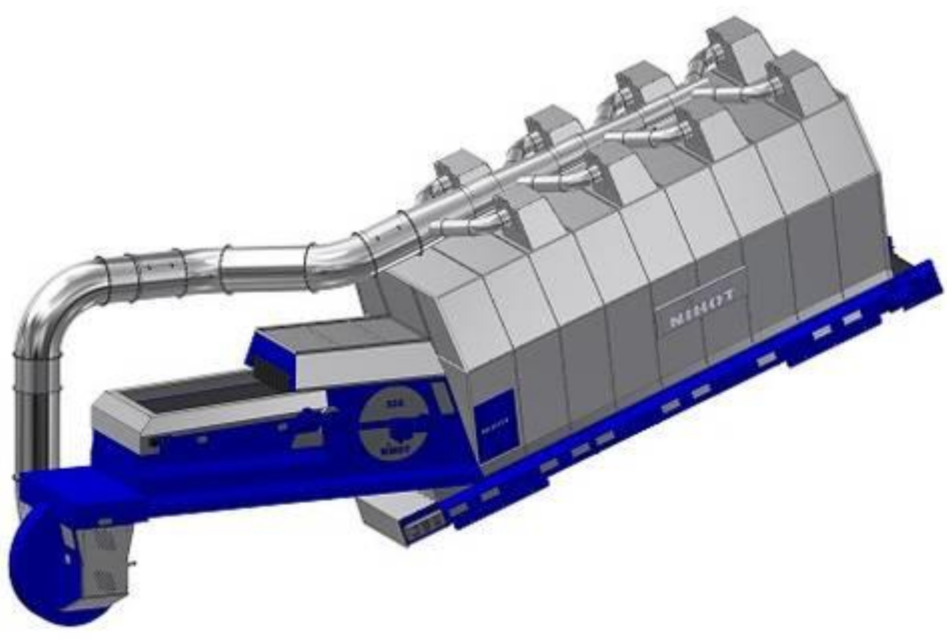

FIGURE 29: PICTURE FOREIGN PART SEPARATOR / COMPANY NIHOT / PICTURE SOURCE: INTERNET

The RDF-shredding is usually performed as single rotor granulator, which shreds the material to the desired particle size.
The shredded RDF can then be handed over to automatic RDF-loading boxes for intermediate storage.

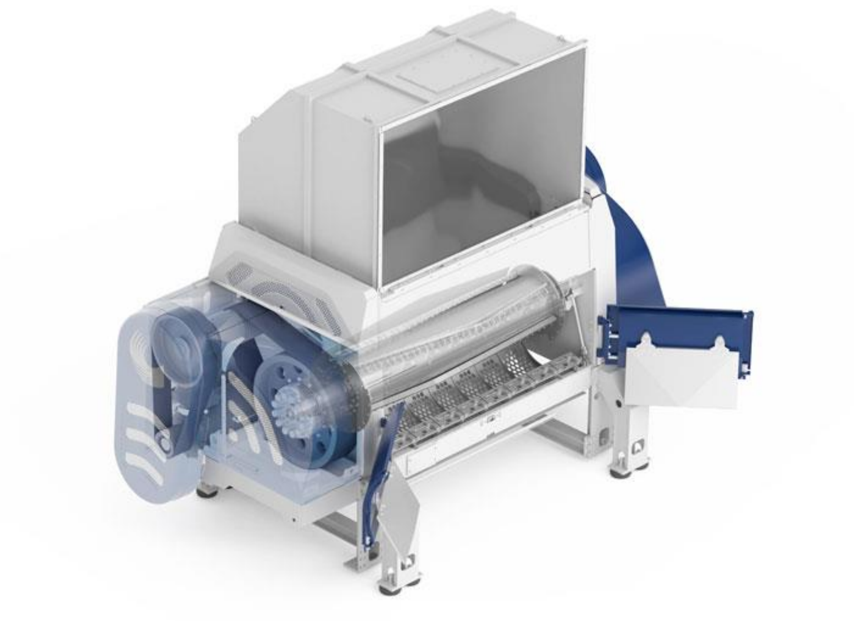

FIGURE 30: PICTURE SECONDARY SHREDDER / COMPANY LINDNER RECYCLINGTECH / PICTURE SOURCE: INTERNET

Iron separators, eddy current separators and PVC-sorters (NIR-sorters) are usually complete the RDF-treatment systems.

3.1.2 Status of automated sorting technologies

3.1.2.1 Overview of suppliers, technology and application

The chapters below are providing a general overview about available suppliers, technology and their application in this specific sector.

It is of very high interest in the waste management sector to develop systems to identify black particles by material type. Conventional material recognition systems such as NIR-sorting technology is not capable to identify the material of black particles. The development of such system is still in progress and not yet finished. By combination of sensor technologies, it is possible to identify black objects, but at the moment without information about the material type.

3.1.2.1.1 AMP Robotics

Company:	AMP Robotics
Product name:	AMP CORTEX™
Website:	https://www.amprobotics.com/
Type:	Robot
Application:	PET (type and colors), PP, PE etc. Plastic tubes, cups, films

3.1.2.1.2 Binder & Co

Company:	Binder & Co AG
Product name:	Clarity Plastic
Website:	https://www.binder-co.com/1000/CLARITY-plastic
Type:	Automatic sorter (VIS, NIR, EMS, sensor fusion)
Application:	Sorting by plastic type and color: PET, PE, PP

3.1.2.1.3 Bollegraaf

Company:	Bollegraaf
Product name:	BRS Robotic 2.0 / Bollegraaf Cogni (NIR, Robotic)
Website:	www.bollegraaf.com
Type:	Robot (up to 4 robotic actuators)
Application:	PET, HDPE, PS, PP

3.1.2.1.4 Bühler

Company:	Bühler
Product name:	SORTEX
Website:	https://www.buhlergroup.com/
Type:	Automatic sorter (Flake sorting)
Application:	PET-bottles, PVC, PP, PE, PS, PA, POM

3.1.2.1.5 BHS Bulk Handling Systems

Company:	BHS Bulk Handling Systems
Product name:	Max-AI® AQC (VIS, Robot)
Website:	www.bulkhandlingsystems.com
Type:	Robot
Application:	PET-bottles, Rigid plastics such as HDPE, PP, etc.

Company:	BHS Bulk Handling Systems
Product name:	Max-AI® AQC-C (VIS, Robot)
Website:	www.bulkhandlingsystems.com
Type:	Cobot
Application:	PET-bottles, Rigid plastics such as HDPE, PP, etc.

3.1.2.1.6 IMRO Maschinenbau GmbH

Company:	IMRO Maschinenbau GmbH
Product name:	DSS-N (NIR)
Website:	https://www.imro-maschinenbau.de/en/
Type:	Automatic sorter
Application:	PE, PP, PS, PVC, PET

3.1.2.1.7 Machinex

Company:	Machinex
Product name:	MACH Hyspec® (SWIR)
Website:	https://www.machinexrecycling.com/sorting-systems/plastic-recycling-optical-sorters/
Type:	Automatic sorter
Application:	PET, HDPE, PVC, LDPE, PP, PS

Company:	Machinex
Product name:	SamurAI™ (VIS)
Website:	https://www.machinexrecycling.com/sorting-systems/plastic-recycling-optical-sorters/
Type:	Robot (4200 picks/h)
Application:	PET-Bottles, rigid plastics such as HDPE, PP, etc.

3.1.2.1.8 MSS

Company:	MSS	
Product name:	CIRRUS™ Plastic-Max™ and Pure Plastic-Max™	
Website:	http://www.mssoptical.com/	
Type:	Automatic sorter	
Application:	PET, HDPE	

3.1.2.1.9 NRT

Company:	nrt
Product name:	ColorPlus™ (VIS)
Website:	https://www.nrtsorters.com/equipment/colorplus/
Type:	Automatic sorter
Application:	PET, HDPE, etc.

Company:	nrt
Product name:	SpydIR®-R (NIR)
Website:	https://www.nrtsorters.com/equipment/spydir-r/
Type:	Automatic sorter
Application:	PVC, PS, PETG, PLA, PC, PE, PP, PET

3.1.2.1.10 OP Teknik

Company:	OP Teknik
Product name:	SELMA
Website:	https://www.opteknik.se/produkter/sorteringsrobot-selma.html
Type:	Robot
Application:	Rigid plastics, containers, etc.

3.1.2.1.11 Pellenc ST

Company:	Pellenc ST
Product name:	Flake purifier (EMS, VIS, NIR)
Website:	www.pellencst.com
Type:	Automatic sorter (Flake sorter)
Application:	Sorting by material and color for e.g. PET, HDPE, PP and other plastics

Company:	Pellenc ST
Product name:	Mistral+ Film (VIS, NIR)

Website:	www.pellencst.com
Type:	Automatic sorter
Application:	LDPE, HDPE, PP, PET, PVC, PS

3.1.2.1.12 Redwave

Company:	Redwave
Product name:	Redwave NIR, NIR/C, NIR SSI/C (NIR, VIS, EMS, NIR HSI)
Website:	www.redwave.com
Type:	Automatic sorter
Application:	Sorting by material and color for e.g. LDPE, HDPE, PP, PET, PS, etc.

Company:	Redwave
Product name:	Redwave XRF-P (XRF)
Website:	www.redwave.com
Type:	Automatic sorter
Application:	Brominated plastics dark PVC

3.1.2.1.13 sesotec

Company:	sesotec
Product name:	Flake Purifier (VIS, NIR, EMS)
Website:	www.sesotec.de
Type:	Automatic sorter (Flake sorter)
Application:	PET-, HDPE- or mixed plastics

Company:	sesotec
Product name:	Varisort (VIS, NIR, EMS)
Website:	www.sesotec.de
Type:	Automatic sorter
Application:	Plastics

3.1.2.1.14 Steinert

Company:	Steinert
Product name:	UniSort PR (NIR)
Website:	https://steinertglobal.com/en/
Type:	Automatic sorter
Application:	Sorting by material and color for e.g. PET- bottles, PS (cups, bowls), PP, MPO, Pet-Tray, PET-Multilayer

Company:	Steinert
Product name:	UniSort Analyzer (NIR)
Website:	https://steinertglobal.com/en/
Type:	Automatic sorter
Application:	Quality monitoring of individual product streams

Company:	Steinert
Product name:	UniSort Black (NIR)
Website:	https://steinertglobal.com/en/
Type:	Automatic sorter
Application:	Identification of black objects

Company:	Steinert
Product name:	UniSort Blackeye (NIR)
Website:	https://steinertglobal.com/en/
Type:	Automatic sorter (Flake sorter)
Application:	Identification of black objects

Company:	Steinert
Product name:	UniSort Film (NIR)
Website:	https://steinertglobal.com/en/
Type:	Automatic sorter

Application:	Films made of e.g. PE and PP

Company:	Steinert
Product name:	UniSort Flake (NIR or VIS)
Website:	https://steinertglobal.com/en/
Type:	Automatic sorter
Application:	PET • Flake C: VIS (Sorting by color) • Flake P: NIR (Sorting by material) • Plastics: PET-bottles (Sorting by material and color)

3.1.2.1.15 Tomra

Company:	Tomra
Product name:	Autosort (NIR, VIS)
Website:	https://www.tomra.com/en-gb
Type:	Automatic sorter
Application:	PE, PP, PS, PVC, PET, EPS, ABS, PET/ PE (sorting by color)

Company:	Tomra
Product name:	Autosort Flake (VIS, EMS)
Website:	https://www.tomra.com/en-gb
Type:	Automatic sorter (Flake sorter)
Application:	PET, PVC and other impurities

3.1.2.1.16 unisensor Sensorsysteme GmbH

Company:	unisensor Sensorsysteme GmbH
Product name:	Powersort 200 (LIF)
Website:	https://www.unisensor.de/en.html
Type:	Automatic sorter (Flake sorter)

Application:	PET-Flakes, PVC, Nylon, Silicone, PET with TiO_2, PLA, PC

3.1.2.1.17 ZenRobotics

Company:	ZenRobotics
Product name:	Heavy Picker (Robotic, NIR, 3D, EMS, VIS)
Website:	https://zenrobotics.com/
Type:	Robot
Application:	PE, PET, PVC

Company:	ZenRobotics
Product name:	Fast Picker (Sensor Fusion)
Website:	https://zenrobotics.com/
Type:	Robot
Application:	HDPE, PP, PET, etc.

3.1.2.2 Overview of robot sorting systems

Robot sorting systems can be generally categorized in two types of machines according to their application:

- Robots for sorting e.g. plastic hollow bodies from post-consumer waste
- Robots for sorting heavy particles from e.g. construction & demolition waste

Depending on their application they are using different actuators to remove the desired objects

- Suction systems (suction nozzles) for light objects
- Mechanical grippers (clamps) for heavy objects

The market for sorting robots is booming at the moment and there is a lot of research and development ongoing.
As indicated above the current systems are focusing in rigid bodies and the systems for 2D-particles such as foils are still under development.

Manufacturer / system	Picks per hour and arm	Fields of application	Type of actuator
ZenRobotics Heavy Picker (FIN)	2.000	Construction and demolition waste	Mechanical gripper
OP TEKNIK AB - SELMA (SWE)	2.400	Wood, plaster, stone, concrete, bricks, metals, cardboard, plastics	Mechanical gripper
ZenRobotics Fast Picker (FIN)	4.000	Packaging and mixed municipal waste	Suction gripper
BulkHandlingSystems MAX-AI AQC (USA)	3.900	Packaging waste	Suction gripper
AMP Robotics Cortex (USA)	3.600	Packaging waste	Suction gripper
Bollegraaf Cogni (DK)	3.000	Packaging waste	Suction gripper
Machinex SamurAI (CAN)	4.000	Packaging waste	Suction gripper

TABLE 15: SUMMARY OF ROBOTIC SYSTEMS AND THEIR PERFORMANCE (SARC ET AL., 2019)

3.1.3 Concepts

The systems shown as basic variants represent low grade sorting technologies, which are still applied all around the world. These concepts are based on manual sorting and are economically feasible in countries with low wage levels.
In well developed countries and regions it is getting more and more restricted to manipulate and sort municipal waste with manual labor.

The systems shown as advanced systems are reflecting this requirement and trends by using automated sorting systems.

The critical materials for automated systems are still light weighed and large size materials such as large LDPE foils. This material cannot only be separated by its material properties e.g. with windsifter solutions as there are strict requirements for the purity and partially also color in the final sorted fraction. The automated systems are not yet capable to deal with such large size items and that is why the oversized particles are still very often sorted by hand or shredded into pieces to allow automated sorting.

The concepts in the chapters below are exemplary and can vary a lot with customer requirements, legal requirements, different machines and potential general suppliers!

Infrastructural, logistic and legal requirements such as weigh bridges, balers, exhaust air handling systems, etc. are not shown in the block diagrams below.

3.1.3.1 Concept – Basic 1

3.1.3.1.1 Description

The concept "Basic 1" is strongly depending on manual labor and these concepts are not built in the majority of Europe anymore.

3.1.3.1.2 Block diagram

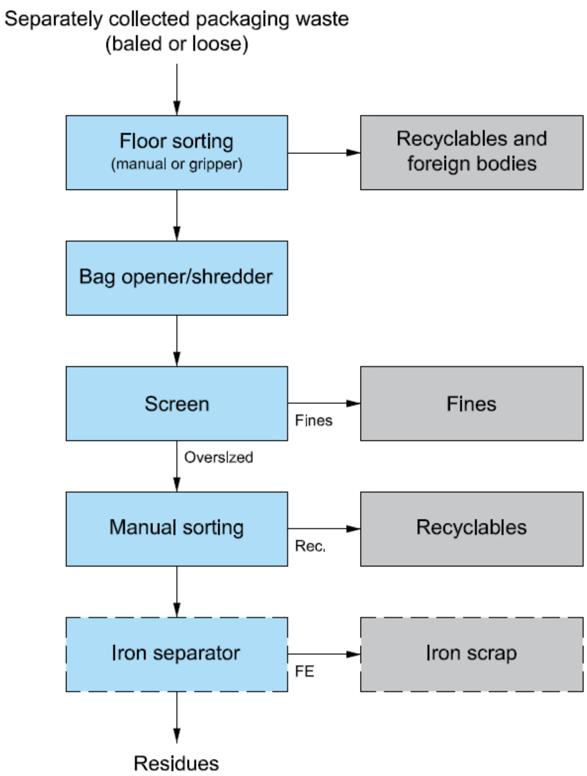

FIGURE 31: BLOCK DIAGRAM – SORTING CONCEPT BASIC 1

3.1.3.2 Concept – Basic 2

3.1.3.2.1 Description

The concept "Basic 2" is a development of "Basic 1" with the integration of a ballistic sorter after the drum screen. This allows an accumulation of 2D- (flat, light) and 3D-materials (hollow bodies, rigid) onto two separated sorting stages.

3.1.3.2.2 Block diagram

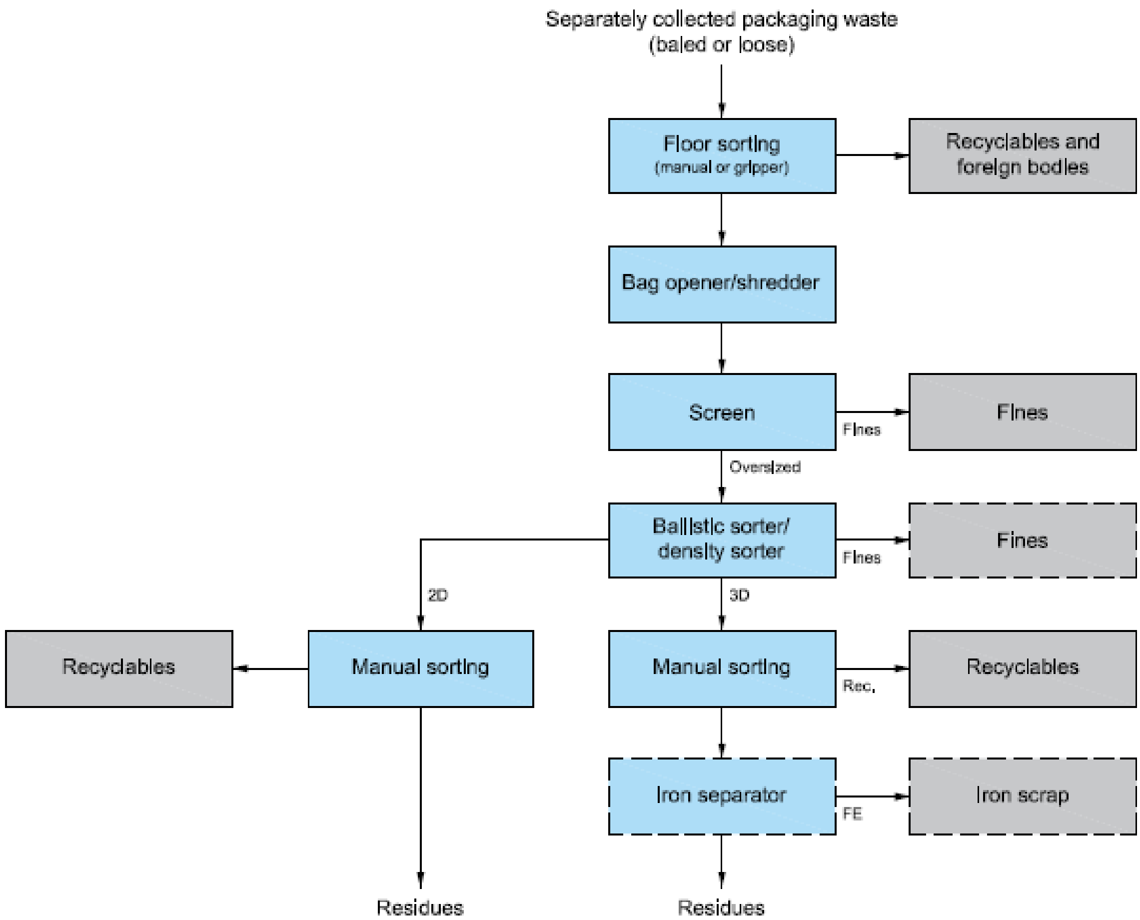

FIGURE 32: BLOCK DIAGRAM – SORTING CONCEPT BASIC 2

3.1.3.3 Concept – Advanced 1

3.1.3.3.1 Description

The concept "Advanced 1" is already reflecting a state of the art sorting solution for separately collected packaging waste.

The concept is generally consisting of a pre-conditioning stage consisting of bag opener/ shredder, foil separator (optionally), screen and ballistic separator or density separator (e.g. windsifter).
The pre-conditioning steps ensure proper material characteristics (separation of fines, type of material 2D or 3D, sizes, etc.) for the following automated sorting processes.

In order to produce the required output material qualities, the sorting lines are often equipped with 2 step sorting processes for the individual materials. In that processes the first step is responsible for mass extraction (to ensure a high recovery rate) and the second step (manual, automated or automated and following manual quality check) is taking care about the quality assurance.

This combination of systems has to be multiplied with each material type to be extracted!

Synergies (split machines, etc.) can be foreseen, if the capacity (volume of the material) is allowing such measures.

3.1.3.3.2 Block diagram

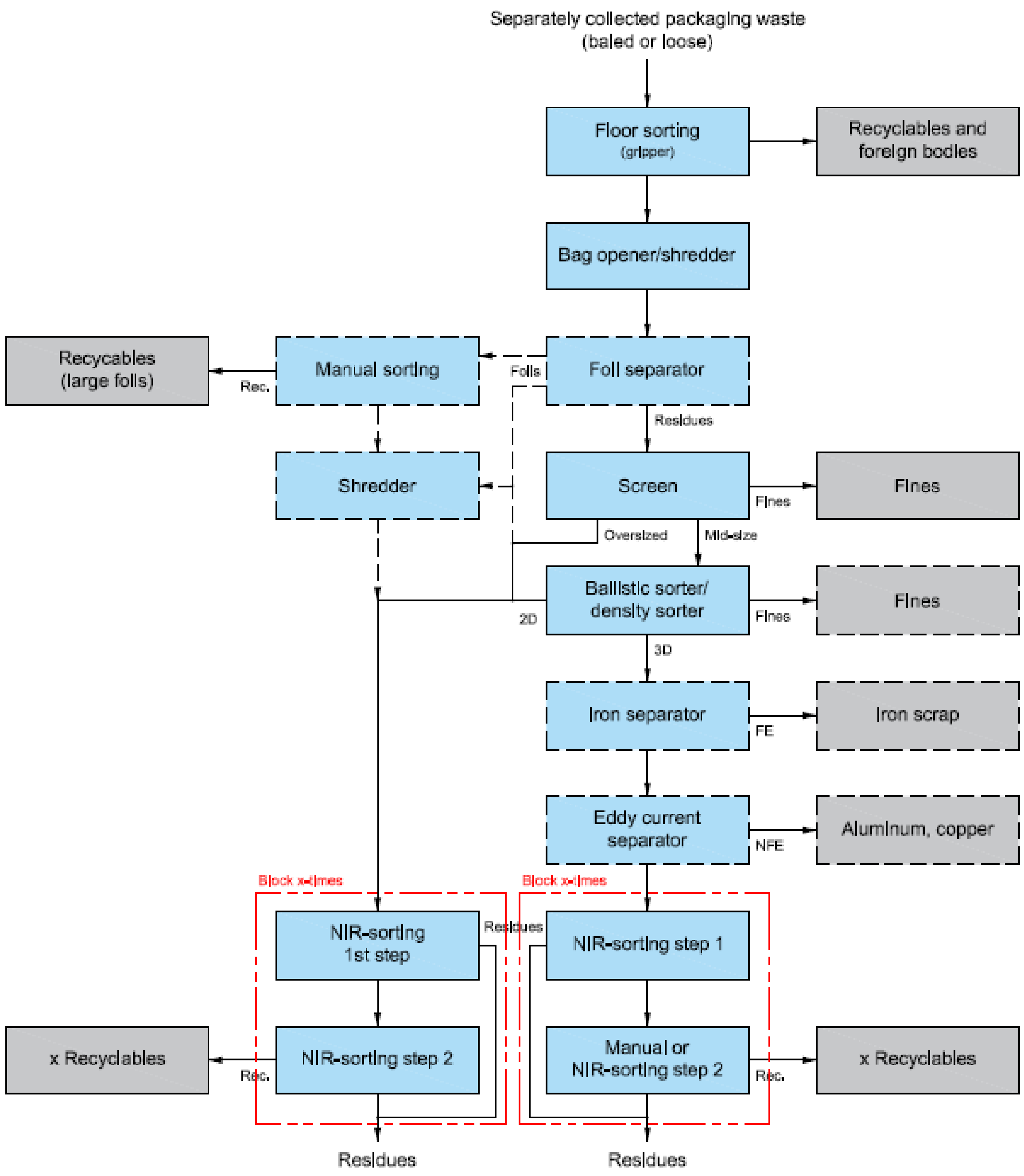

FIGURE 33: BLOCK DIAGRAM – SORTING CONCEPT ADVANCED 1

3.1.3.4 Concept – Advanced 2

3.1.3.4.1 Description

The concept "Advanced 2" is very similar to the concept "Advanced 2" with the only difference, that manual sorting tasks are taken over by sorting robots.
The choice between NIR-based automated sorter or robot has to be taken according to the hit/pick-rates necessary to extract the desired material from the infeed stream of this process step.

3.1.3.4.2 Block diagram

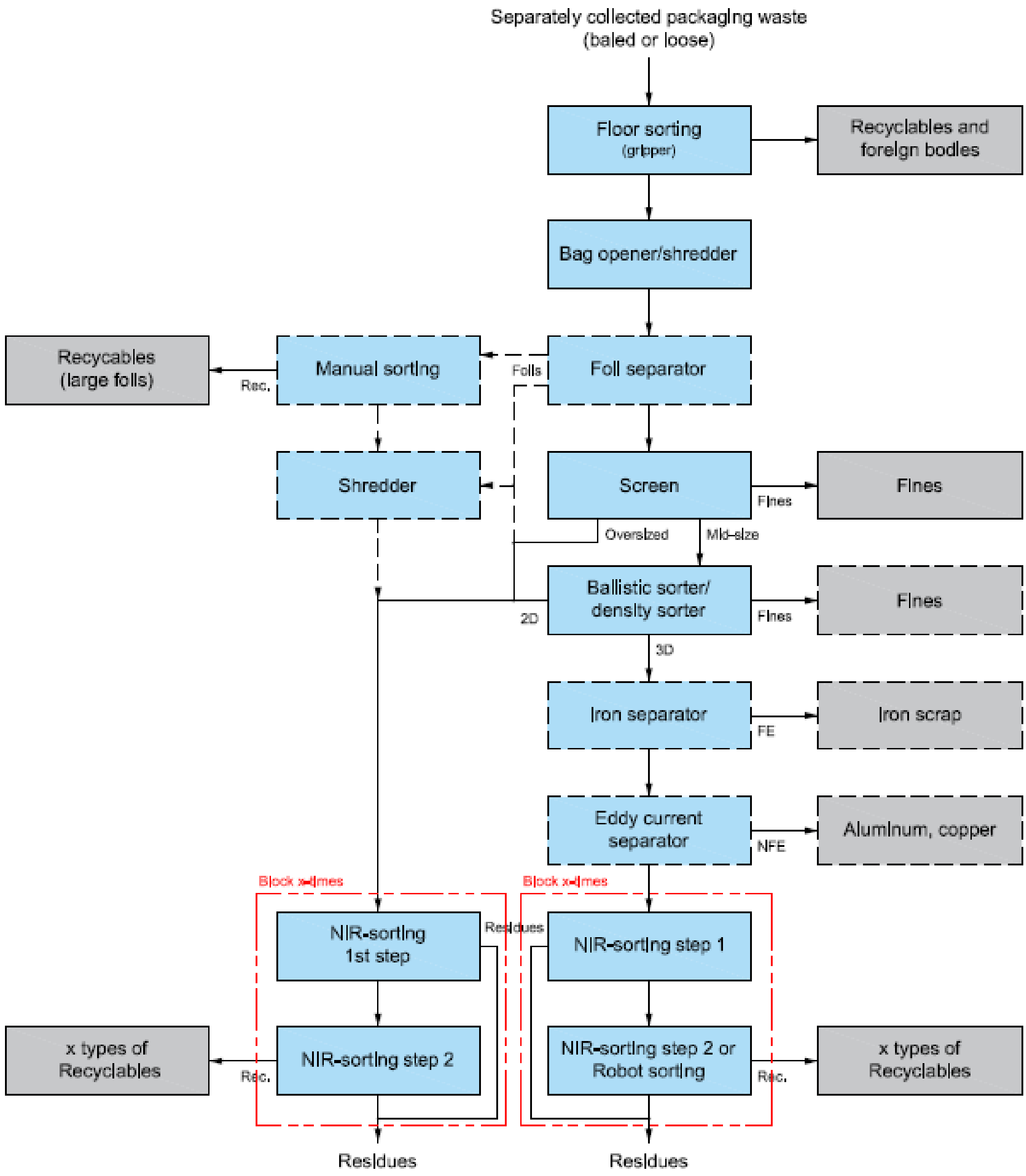

FIGURE 34: BLOCK DIAGRAM – SORTING CONCEPT ADVANCED 2

3.2 RECYCLING PLANT

3.2.1 Conventional recycling plants

3.2.1.1 Key components of a recycling plant

3.2.1.1.1 Pre-shredding

It is necessary to implement a pre-shredding unit for following tasks:

- Opening of bales
- De-compaction of the input material
- Homogenization of the input flow
- Size reduction prior the first washing step

The shredding process can be realized as dry or wet shredding process, but the standard solution is the dry pre-shredding.

The grain size of the material will be reduced from approx. 300mm (grain size in sorting process) to approx. 100mm.

3.2.1.1.2 Iron separation

An iron separator is recommended in order to extract ferromagnetic particles (e.g. bales wires) prior the washing process.
The iron separator can be built as conventional overbelt magnet at a transfer point between two conveyors.

3.2.1.1.3 Pre-washing

There are different options for the pre-washing section depending on the chosen supplier:

- Swim sink tank
- Pre-wash drum

The function of the pre-wash section is to

- separate heavy particles from the material stream (soil, stones, metals, plastics with a density >1kg/m³ as e.g. PVC)
- wash off contaminations from the surface (bad efficiency in this process step)

The function of the pre-washing system is usually based on the swim-sink-principle, i.e. on the separation according to the difference of the specific weight of compounds of the overall material stream. Light parts will float on the water surface and heavy parts will sink to the bottom of the separator.
These swim-sink units are usually combined with drums on the water surface, which are turning the material and are pushing the particles also below the water surface. These drums are also relevant to ensure the retention time of the material inside the separator. The last drum of the separator is also responsible to discharge the pre-cleaned light fraction into the subsequent line component.
The heavy particles are discharged by help of tight trough chain conveyors into e.g. collection boxes. The material is also mechanically de-watered during the material transport.

FIGURE 35: PHOTO PRE-WASH (SWIM-SINK) / COMPANY HERBOLD MECKESHEIM / PICTURE SOURCE: INTERNET

FIGURE 36: PHOTO PRE-WASH-DRUM / COMPANY NEUE HERBOLD / PICTURE SOURCE: INTERNET

3.2.1.1.4 Grinding

The common system for the grinding section is the wet grinding technology. Material will be introduced together with water and will be shredded to a particle size of ~20 mm.

Wet grinders are simultaneously washing and shredding the infeed material. Large quantities of water are fed to the rotor chamber during the shredding process.
Since the granulate is discharged from the grinder together with the water it is necessary to install a screen or de-watering screw underneath the outlet of the shredder.

The grinder is also very efficient in fibering paper components (such as e.g. Tetrapack). It assists in handling high percentages of paper in the inbound fraction (e.g. resulting from mixed plastics from household waste).

The shredding chamber is usually cladded with a highly wear-resistant material (Hardox). This cladding, along with the rotor knifes, stator blades, etc. is completely replaceable.

Figure 37: Photo Wet Granulator / Company Sorema / Picture source: Internet

3.2.1.1.5 Intensive washing

There are also different options for the intensive washing section depending on the chosen supplier:

- Swim sink tank
- Hydrocyclone
- Turbo washers

Swim-sink tanks use the different specific weights of the various kinds of plastics to separate them. Typical applications are the separation of PET or PVC (both sink) from polyolefins, such as PE or PP (both of them swim). The light fraction is being transported along the surface of the water by means of paddle drums to a discharge conveyor; the heavy fraction is being deducted depending on its amount either by a pair of pneumatic valves at the bottom of the container or a redler.

FIGURE 38: PHOTO SWIM-SINK-TANK / COMPANY B+B / PICTURE SOURCE: INTERNET

Hydrocyclones are used for similar separation tasks as the swim-sink tanks.
The hydrocyclone is working with the pressure force of the feeding pump and reaches higher separation effects (approx. 20 times earth gravity compared to a swim sink tank which uses only the earth gravity). But that they can achieve a better separating efficiency than tanks.

The light material (lighter than water such as e.g. PE / PP) is leaving the hydrocyclone on the top together with the main stream of the recirculated water. Heavy particles (heavier than water) such as PET, stones, grit, etc. is sinking to the bottom of the hydrocyclone and is discharged with the help of a cell wheel.

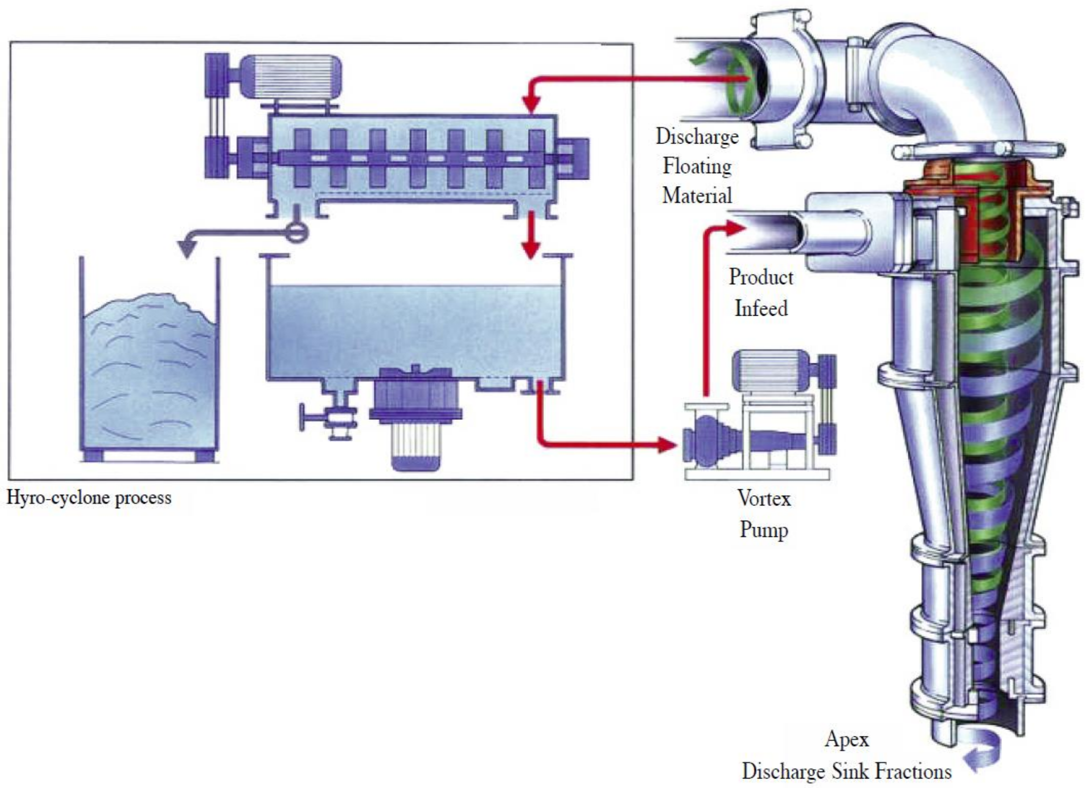

FIGURE 39: PICTURE HYDROCYCLONE / COMPANY HERBOLD MECKESHEIM / PICTURE SOURCE: INTERNET

The above-mentioned steps are very often in combination with friction washers in order to separate the water circuits.

Friction washers are typically used after washing or separation steps and after washing grinders in order to separate the (dirt-, paper-fiber- and/or detergent-containing waste) water from the plastic particles. The friction washers are usually built from a fast running paddle screw, which is surrounded by a screen housing.

The friction inside the machine e.g. de-fibers the paper, thus enabling its deduction from the floating plastics via the water recycling system of the line.

FIGURE 40: PHOTO FRICTION WASHER / COMPANY HERBOLD MECKESHEIM / PICTURE SOURCE: INTERNET

3.2.1.1.6 Hot wash (optional)

The hot wash section is an option to boost the material quality in e.g. contaminations and smell. Usually these are batch-operated systems (similar to a conventional laundry machine). Material is entering and hot water (~70-80 °C) with a cleaning agent (e.g. caustic soda / concentration 0.5 – 1.5%) is introduced. The hot wash unit is usually also equipped with a stirrer to activate the material. The material is cleaned with the help of the hot water, the cleaning agent and the friction. The contaminations are leaving together with the hot water.

FIGURE 41: PHOTO HOT-WASH / COMPANY B+B / PICTURE SOURCE: INTERNET

3.2.1.1.7 Mechanical drying and thermal drying

It is necessary to reduce the water content in the product prior the extrusion to at least <5 weight%. For the 2D-material the drying has to be realized as combination of a mechanical and thermal drying. The mechanical drying it the first step in the drying section and is usually consisting of a number of serial centrifuges. After certain steps of mechanical drying it is not possible (feasible) to enter another mechanical dryer.

After the mechanical drying the material enters a thermal dryer. The thermal drying can be realized with mid temperature and short retention time or low temperature and longer retention time. The thermal dryers can be heated with electricity, gas or an alternative source of energy.

The use of mechanical drying systems is sufficient at the operation with 3D-plastics such as HDPE and PP.

FIGURE 42: PHOTO MECHANICAL DRYER (CENTRIFUGE) / COMPANY B+B / PICTURE SOURCE: INTERNET

FIGURE 43: PHOTO THERMAL DRYING / COMPANY B+B / PICTURE SOURCE: INTERNET

Another option for 2D-plastics is a dewatering press (filter- or screw-press), which separates liquids from solids.

It is a simple, slow moving device that accomplishes dewatering by continuous gravitational drainage. Screw presses are often used for materials are difficult to press, for example those that tend to pack together. The screw press squeezes the material against a screen, filter or deflector plate and the liquid is discharged through the screen for collection.

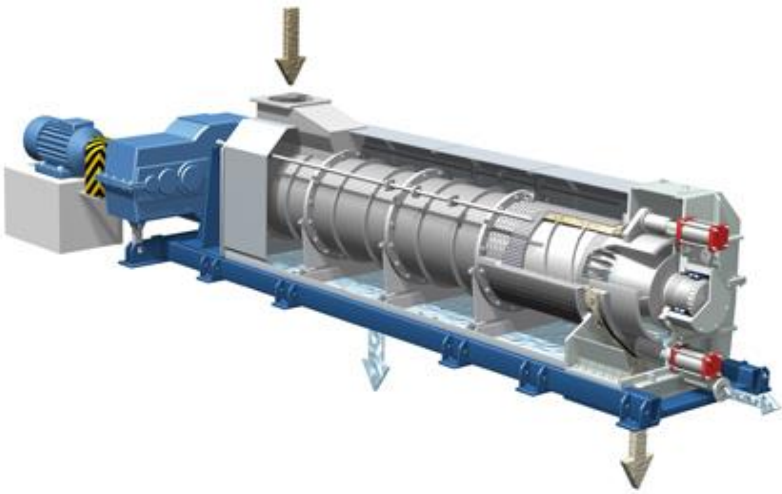

FIGURE 44: PHOTO SCREW PRESS / COMPANY ANDRITZ / PICTURE SOURCE: INTERNET

3.2.1.1.8 Extrusion

Single screw extrusion process is the state of the art for extrusion of secondary raw materials!

The extrusion process consists usually of following components:

- Cutter at inlet section
- Extrusion including
  - Extruder screw
  - Melt filter
  - De-gassing
  - Die-face (Pelletizer)

The plastics are usually gravity fed from a top mounted hopper (usually equipped with a cutter/agglomerator) into the infeed zone of the extruder. Additives such as colorants and UV inhibitors (in either liquid or pellet form) are often used and can be mixed into the flakes inside the hopper.

The material enters through the infeed zone and comes into contact with the screw. The rotating screw forces the plastic flakes forward into the screw barrel, which is heated to the desired melt temperature of the molten plastic. In most processes, a heating profile is set for the barrel in which three or more independent controlled heater zones gradually increase the temperature of the barrel from the rear (where the plastic enters) to the front. This allows the plastic beads to melt gradually as they are pushed through the barrel and lowers the risk of overheating, which may cause degradation in the polymer.

Extra heat is contributed by the intense pressure and friction taking place inside the barrel. In fact, if an extrusion line is running continuously, the heaters can be shut off and the melt temperature maintained by pressure and friction alone inside the barrel. In most extruders, cooling units are present to keep the temperature below a set value if too much heat is generated.

The extruders are also equipped with de-gassing (1- or 2 step) units, which are extracting undesired gases, humidity, etc. with the help of a vacuum pump system.

At the front of the barrel, the molten plastic leaves the screw and travels through a screen pack (or laser filter units) to remove any contaminants in the melt. The screen pack assembly also serves to create back pressure in the barrel. Back pressure is required for uniform melting and proper mixing of the polymer.

After passing through the screen the plastic enters the die. With the help of a cutter in front of the die, the plastic is cut into granulate.

The product must now be cooled and this is usually achieved by discharging the granulate into a water bath. After the water bath the granulates are usually entering a drying centrifuge before they are packed into big-bags for transport purposes.

Figure 45: Picture Extruder / Company Erema / Picture source: Internet

After the extruder there is additional equipment such as coolers, chillers, pneumatic transport systems, silos and big-bag filling stations.

Double screw extrusion is mainly used for compounding of different materials and is not the right technology for the basic extrusion of secondary raw materials, with the approach to produce a re-granulate, which shall be sold on the market.

3.2.1.1.9 Water treatment

The water treatment is of utmost importance for the operation of the recycling plant, as the water is the carrier of impurities.

There are usually different water circles in the recycling plant, whereby the clean water enters in counterflow direction at the end of the washing line, will be usually mechanically treated, partially recirculated and will enter the previous water circuits.

The efforts for the water treatment are influencing the investment costs for a recycling plant significantly and can vary a lot in regards to the local sewer or effluent requirements.

The process can range from mechanical up to biological treatment processes for the process water.

Depending on the process there are different additives and agents used in the general treatment process or in the water treatment such as caustic soda, anti-foam agents and flocculants.

3.2.1.2 Concepts

The following block diagrams are showing exemplary solutions to handle LDPE, HDPE, PP, PS and PET fractions in washing and extrusion lines.
The line configuration is very often depending on the "standard solution" of the individual supplier of such lines. Each supplier has his own portfolio of machines and varies the arrangement of the steps according to his portfolio.
There are systems available on the market to boost the quality of the output product such as hot-wash-units, de-odorization ("re-fresher"), laser filters, etc.

Conventional washing lines are built in a very similar way:

1. Size reduction and conditioning
This part of the plant ensures a homogeneous feeding, a first size reduction and separation of ferrous particles.

2. Pre-wash
The majority of heavy particles, foreign plastic fractions (sinking or floating depending on the application), sand, glass are extracted in the pre wash section. This step also safeguards the following granulation step from serious damages.

3. Granulation
The plastics fraction will be shredded to approx. 5-10 mm particle size and are simultaneously washed by friction.

4. Intensive wash
The intensive washing step can include several washing processes (hot, cold) with different systems (sink-float, friction washing) etc. and shall finally ensure the necessary cleanness of the output material

5. Drying

The output material has to be mechanically and thermally (in case of foils) dried to fulfill the input moisture content for the extrusion process. The heat for the drying can be generated e.g. with electricity, natural gas or with heat from alternative processes (in case of synergies with other processes on the site). The drying process is often also combined with a separator unit to extract e.g. remaining heavy particles or light particles (depending on the application) from the material stream. In order to have a stable operation of the washing and extrusion systems it is recommended to build a buffer capacity between the washing line and the extrusion.

6. Extrusion

The extrusion process is depending on the input material. In case of PET the extrusion process is much more complicated and expensive compared to Polyolefins such as LDPE, HPDE and PP.
The extrusion process is a combination of several process steps such as cutting, extrusion, de-gassing, melt filtration and pelletizing and is combined with following units such as de-odorization, pneumatic transport system, storage (e.g. silos) and/or big-bag-loading stations.

CAPEX and OPEX costs for such plants are depending on a lot of following, site specific conditions and are therefore (if at all possible) indicated only in ranges.
<u>Conditions influencing the CAPEX and OPEX for recycling plants:</u>

- Material specifications (impurities, thickness of materials, etc.)
- Input material quantity and therefore capacity of the line (Attention: Lines with low capacities can hardly be operated economically)
- Fresh water quality and quantity and requirements on waste water quantity and quality
- Site infrastructure
- Availability of alternative heat sources
- Personnel costs
- etc.

The CAPEX and OPEX costs for recycling plants have to be evaluated from case to case individually.

The water treatment process is of utmost importance for each of the below mentioned recycling processes.

3.2.1.2.1 Recycling plant for LDPE

3.2.1.2.1.1. Blockdiagram

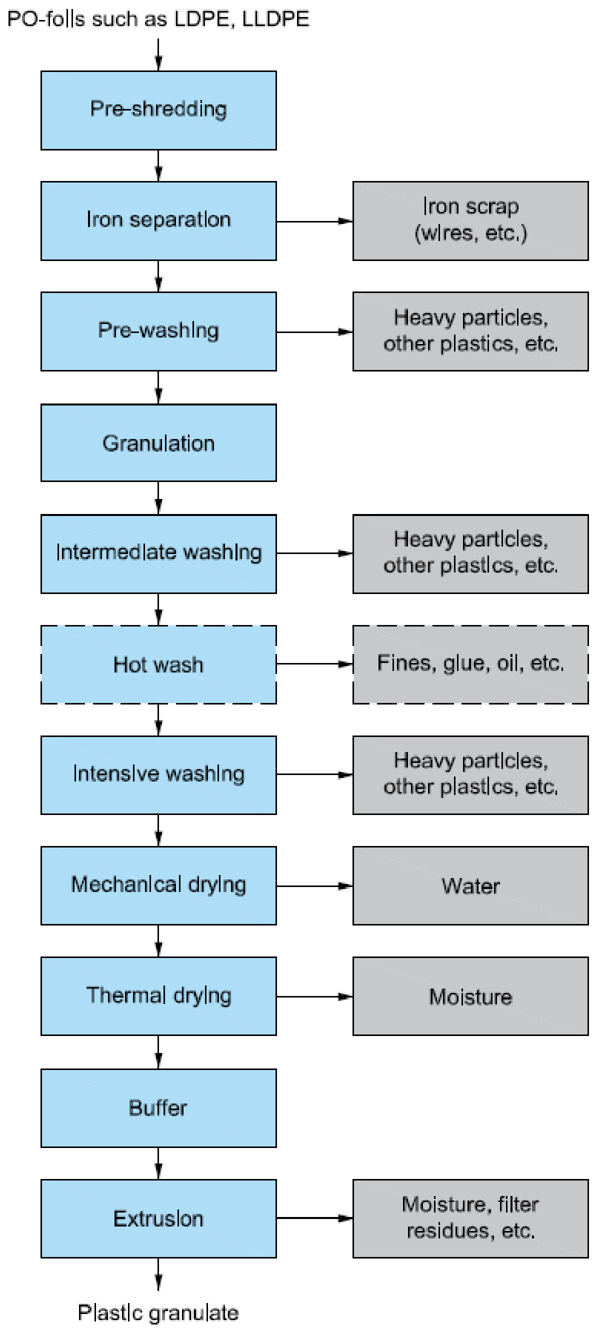

FIGURE 46: BLOCK DIAGRAM – RECYCLING PLANT FOR LDPE

3.2.1.2.1.2. Technology catalogue LDPE

Technology	Washing and extrusion processes for LDPE films
Description of the technology	The above block diagram is showing a possible configuration scenario based on conventional proven systems.
Development status	Proven technology
Input material for the facility	- Pre-sorted LDPE streams as described in chapter 2.6.1.1 and 0 - Monofractions from production processes - LLDPE-foils (Attention: Low thickness, reduces line capacity!) - Agricultural foils (Attention: Partially low thickness, reduces line capacity!)
Variable OPEX (EUR/ton)	As described above it is not possible to provide variable costs without definition of a detailed project. Generally the OPEX costs are in the range of several hundred € per ton. The OPEX costs are influenced by following main parameters, which can be characterized in ranges as following: Connected power (consumption approx. 60-70%): - Washing line: ~1,000 – 1,200 kW per line - Hot wash: ~200 kW per line (excl. heat source, typically steam) - Thermal drying: ~300 kW per line - Extrusion: ~500 kW per extruder Other data: - Wear and tear parts 2 - 5 % of invest for machines/a - Fresh water 2 - 5 m³/t input - Steam requirement 250 kcal/kg output - Steam parameters: min. 4 bar at 133 °C

Total CAPEX (mill. EUR)	An investment in the range of 3.0 – 5.0 M€ has to be considered for one washing line with an input capacity of 1.2 – 1.5 t/h. The costs for one extruder (~1 t/h) with the recyclate handling and storage is in the range of 1.0 – 1.5 M€. The prices indicated above include the standard configuration with basic mechanical water treatment. The prices are not including infrastructure, civil works, property, further water treatment systems, etc.! <u>The space demands for the buildings for the washing and extrusion process are approx. as following:</u> - Manipulation area: ~500 m² - Washing line area: ~1,200 m² - Extrusion area: ~300 m²
Annual fixed OPEX (mill. EUR/year)	Has to be calculated from case to case individually.
Output	Preferably LDPE-recyclate allowing film blow application
Process efficiency (% of input recycled - output/input)	This factor is usually between 75 and 80%. <u>This factor is strongly depending on following factors:</u> - Quantity of impurities - Moisture of input material
Energy consumption / ton input	The energy consumption is usually in the range of 800 - 1,000 kWh/ton. This data is based on the described standard configuration with basic mechanical water treatment.
Employed staff	Beside of overhead stuff (plant manager, weigh bridge, accountant, laboratory, etc.) it is necessary to consider for the operation per line per shift approx.:

	- 1 person feeding the line - 1-2 people taking care about the line in terms of preventive maintenance and operations - 1 person taking care about the extrusion process and material handling after the extrusion process Synergies can be considered in case of more than one recycling line.
Companies	See Annex of the report for companies in that field of business in the countries D, NL, A and UK.
Rejects	There are several reject fractions arising from the operation of such a line - Metals (external recycling) - Sinking fraction (mixture of inerts, other polymers, etc. external disposal) - Sludges and other wastes from the water treatment process (external disposal) - Extrusion residues such as e.g. filter residues (external disposal or RDF treatment) - etc.
Specific challenges	- Quality of input material - Water treatment
Sources of information	Expertise and interviews with recycling plant suppliers

Table 16: Technology catalogue – Recycling Plant for LDPE

3.2.1.2.2 Recycling plant for HDPE/PP

The treatment plant for HDPE and PP can have the same configuration and could even be operated in campaigns.

3.2.1.2.2.1. Blockdiagram

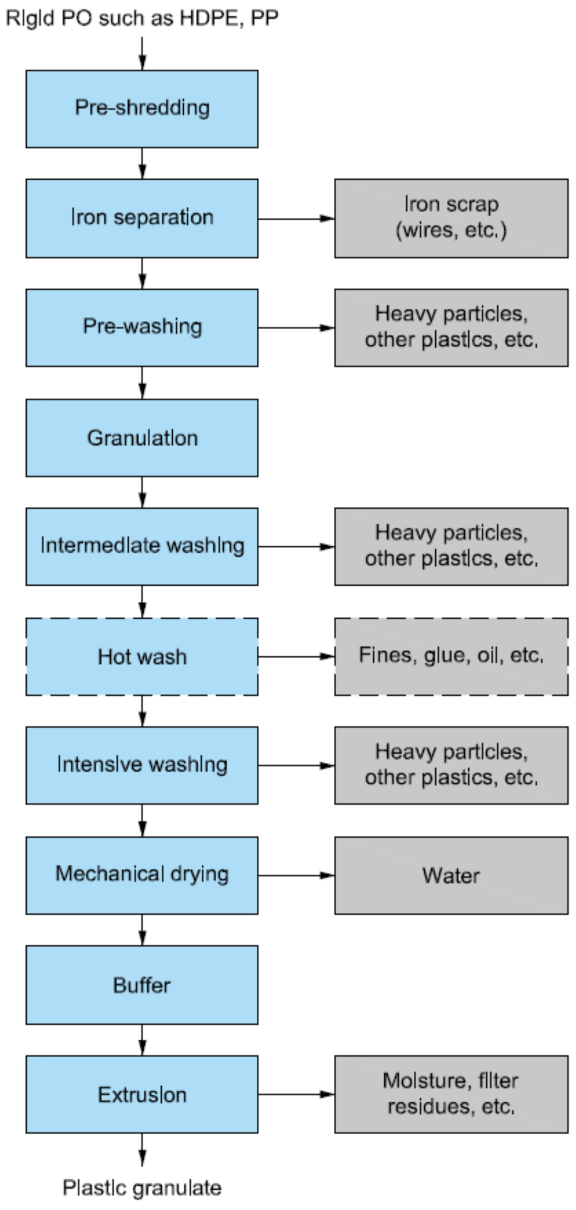

FIGURE 47: BLOCK DIAGRAM – RECYCLING PLANT FOR HDPE AND PP

3.2.1.2.2.2. Technology catalogue HDPE/PP

Technology	Washing and extrusion processes for rigid HDPE or PP The line can be operated in campaigns
Description of the technology	The above block diagram is showing a possible configuration scenario based on conventional proven systems.
Development status	Proven technology
Input material for the facility	- Pre-sorted HDPE as described in chapter 2.6.1.3 or - Pre-sorted PP as described in chapter 2.6.1.4 - Monofractions from production processes
Variable OPEX (EUR/ton)	As described above it is not possible to provide variable costs without definition of a detailed project. Generally the OPEX costs are in the range of several hundred € per ton. <u>The OPEX costs are influenced by following main parameters, which can be characterized in ranges as following:</u> Connected power (consumption approx. 60-70%): - Washing line: ~600 – 900 kW per line - Hot wash: ~200 kW per line (excl. heat source) - Extrusion: ~500 kW per extruder Other data: - Wear and tear parts 2 - 5 % of invest for machines/a - Fresh water 2 - 5 m^3/t input - Steam requirement 250 kcal/kg output - Steam parameters: min. 4 bar at 133 °C
Total CAPEX (mill. EUR)	An investment in the range of 4.0 – 6.0 M€ has to be considered for one washing line with an input capacity of 2.0 – 2.5 t/h. The costs for one extruder (~1.2 – 1.5 t/h) with the recyclate handling and storage is in the range of 1.0 – 1.5 M€.

	The prices indicated above include the standard configuration with basic mechanical water treatment. The prices are not including infrastructure, civil works, property, further water treatment systems, etc.! <u>The space demands for the buildings for the washing and extrusion process are approx. as following:</u> - Manipulation area: ~500 m² - Washing line area: ~1,200 m² - Extrusion area: ~300 m²
Annual fixed OPEX (mill. EUR/year)	Has to be calculated from case to case individually.
Output	Preferably HDPE- or PP-recyclate allowing the best possible molding applications
Process efficiency (% of input recycled - output/input)	This factor is usually between 80 and 90%. This factor is strongly depending on the quantity of impurities in the input material!
Energy consumption / ton	The energy consumption is usually in the range of 500 - 700 kWh/ton. This data is based on the described standard configuration with basic mechanical water treatment.
Employed staff	Beside of overhead stuff (plant manager, weigh bridge, accountant, laboratory, etc.) it is necessary to consider for the operation per line per shift approx. - 1 person feeding the line - 1-2 people taking care about the line in terms of preventive maintenance and operations - 1 person taking care about the extrusion process and material handling after the extrusion process

	Synergies can be considered in case of more than one recycling line.
Companies	See Annex of the report for companies in that field of business in the countries D, NL, A and UK.
Rejects	There are several reject fractions arising from the operation of such a line - Metals (external recycling) - Sinking fraction (mixture of inerts, other polymers, etc. external disposal) - Sludges and other wastes from the water treatment process (external disposal) - Extrusion residues such as e.g. filter residues (external disposal or RDF treatment) - etc.
Specific challenges	- Quality of input material - Water treatment
Sources of information	Expertise and interviews with recycling plant suppliers

Table 17: Technology catalogue – Recycling Plant for HDPE and PP

3.2.1.2.3 Recycling plant for PS/PET bottles

The treatment plant for PS and PET bottles are having a similar configuration and could even be operated in campaigns.
The treatment of PS has although lower demands for the washing and extrusion process and subsequently lower investment and operating costs.

In terms of PET treatment it is very essential to receive or sort the PET bottles with very high quality in terms of purity and color!!!

3.2.1.2.3.1. Blockdiagram

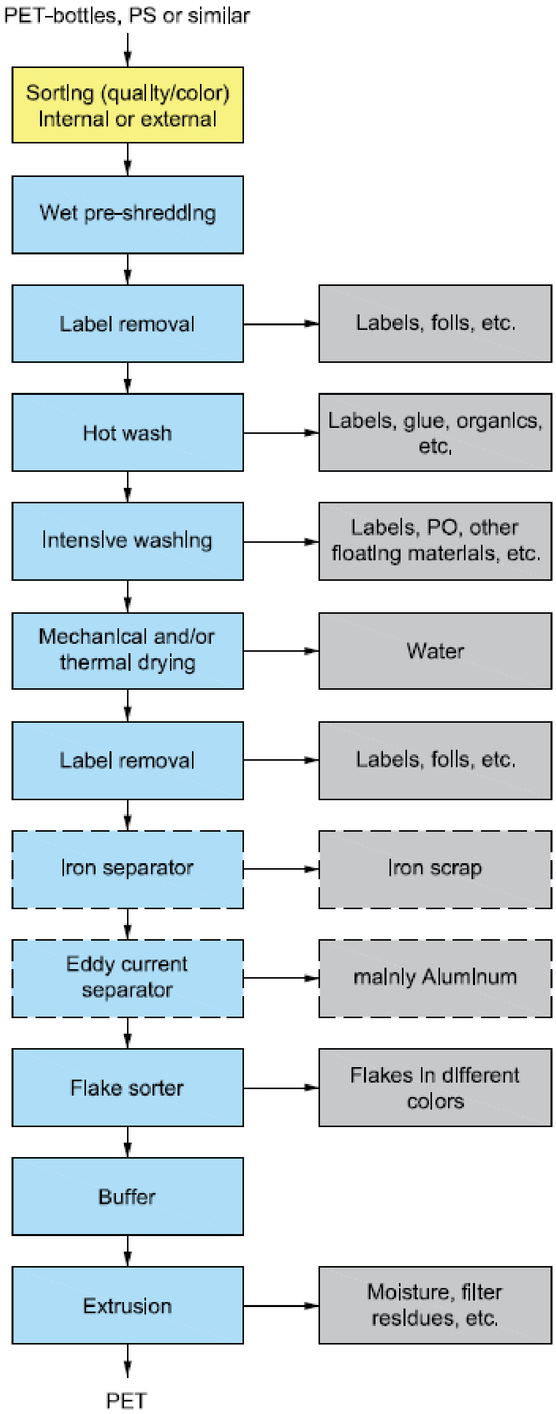

FIGURE 48: BLOCK DIAGRAM – RECYCLING PLANT FOR PET AND PS

3.2.1.2.3.2. Technology catalogue PS

Technology	Washing and extrusion processes for rigid PS
Description of the technology	The above block diagram is showing a possible configuration scenario based on conventional proven systems.
Development status	Proven technology
Input material for the facility	- Pre-sorted PS as described in chapter 2.6.1.5 - Monofractions from production processes
Variable OPEX (EUR/ton)	As described above it is not possible to provide variable costs without definition of a detailed project. Generally the OPEX costs are in the range of several hundred € per ton. <u>The OPEX costs are influenced by following main parameters, which can be characterized in ranges as following:</u> Connected power (consumption approx. 60-70%): - Washing line: ~800 – 1,200 kW per line - Extrusion: ~500 kW per extruder Other data: - Wear and tear parts 2 - 5 % of invest for machines/a - Fresh water 2 - 5 m^3/t input - Steam requirement 250 kcal/kg output - Steam parameters: min. 4 bar at 133 °C
Total CAPEX (mill. EUR)	An investment in the range of 4.0 – 6.0 M€ has to be considered for one washing line with an input capacity of 2,0 – 2,5 t/h. The costs for one extruder (~1,2 t/h) with the recyclate handling and storage is in the range of 2.5 – 3.0 M€. Two extruders have to be considered for one washing line with the above mentioned capacity!

	The prices indicated above include the standard configuration with basic mechanical water treatment. The prices are not including infrastructure, civil works, property, further water treatment systems, etc.! <u>The space demands for the buildings for the washing and extrusion process are approx. as following:</u> - Manipulation area: ~500 m² - Washing line area: ~1,300 m² - Extrusion area: ~300 m²
Annual fixed OPEX (mill. EUR/year)	Has to be calculated from case to case individually.
Output	Preferably PS-recyclate allowing best possible molding application
Process efficiency (% of input recycled - output/input)	This factor is usually between 90 and 95%. This factor is strongly depending on the quantity of impurities in the input material!
Energy consumption / ton	The energy consumption is usually in the range of 500 – 750 kWh/ton. This data is based on the described standard configuration with basic mechanical water treatment.
Employed staff	Beside of overhead stuff (plant manager, weigh bridge, accountant, laboratory, etc.) it is necessary to consider for the operation per line per shift approx. - 1 person feeding the line - 1-2 people taking care about the line in terms of preventive maintenance and operations - 1 person taking care about the extrusion process and material handling after the extrusion process Synergies can be considered in case of more than one recycling line.

Companies	See Annex of the report for companies in that field of business in the countries D, NL, A and UK.
Rejects	There are several reject fractions arising from the operation of such a line - Metals (external recycling) - Sinking fraction (mixture of inerts, other polymers, etc. external disposal) - Sludges and other wastes from the water treatment process (external disposal) - Extrusion residues such as e.g. filter residues (external disposal or RDF treatment) - etc.
Specific challenges	- Quality of input material - Water treatment
Sources of information	Expertise and interviews with recycling plant suppliers

Table 18: Technology catalogue – Recycling Plant for PET and PS

3.2.1.2.3.3. Technology catalogue PET

Technology	Washing and extrusion processes for PET bottles
Description of the technology	The above block diagram is showing a possible configuration scenario based on conventional proven systems.
Development status	Proven technology
Input material for the facility	- Pre-sorted PET-bottles as described in chapter 2.6.1.6 , 2.6.1.7 and 2.6.1.8 - Monofractions from production processes
Variable OPEX (EUR/ton)	As described above it is not possible to provide variable costs without definition of a detailed project. Generally the OPEX costs are in the range of several hundred € per ton. <u>The OPEX costs are influenced by following main parameters, which can be characterized in ranges as following:</u>

	Connected power (consumption approx. 60-70%): - Washing line: ~900 – 1,300 kW per line - Extrusion: ~500 kW per extruder Other data: - Wear and tear parts 2 - 5 % of invest for machines/a - Fresh water 2 - 5 m³/t input - Steam requirement 450 kcal/kg output - Steam parameters: min. 4 bar at 133 °C
Total CAPEX (mill. EUR)	An investment in the range of 5.0 – 7.0 M€ has to be considered for one washing line with an input capacity of approx. 3,0 t/h. The costs for one extruder (~1,2 t/h) with the recyclate handling and storage is in the range of 2.5 – 3.0 M€. Two extruders have to be considered for one washing line with the above mentioned capacity! The prices indicated above include the standard configuration with basic mechanical water treatment. The prices are not including infrastructure, civil works, property, further water treatment systems, etc.! <u>The space demands for the buildings for the washing and extrusion process are approx. as following:</u> - Manipulation area: ~500 m² - Washing line area: ~1,300 m² - Extrusion area: ~300 m²
Annual fixed OPEX (mill. EUR/year)	Has to be calculated from case to case individually.
Output	Preferably PET-recyclate allowing bottle-to-bottle application
Process efficiency (% of input recycled - output/input)	This factor is usually between 80 and 90%.

	This factor is strongly depending on the quantity of impurities in the input material!
Energy consumption / ton	The energy consumption is usually in the range of 600 – 900 kWh/ton. This data is based on the described standard configuration with basic mechanical water treatment.
Employed staff	Beside of overhead stuff (plant manager, weigh bridge, accountant, laboratory, etc.) it is necessary to consider for the operation per line per shift approx. - 1 person feeding the line - 1-2 people taking care about the line in terms of preventive maintenance and operations - 1 person taking care about the extrusion process and material handling after the extrusion process Synergies can be considered in case of more than one recycling line.
Companies	See Annex of the report for companies in that field of business in the countries D, NL, A and UK.
Rejects	There are several reject fractions arising from the operation of such a line - Metals (external recycling) - Sinking fraction (mixture of inerts, other polymers, etc. external disposal) - Sludges and other wastes from the water treatment process (external disposal) - Extrusion residues such as e.g. filter residues (external disposal or RDF treatment) - etc.
Specific challenges	- Quality of input material - Water treatment
Sources of information	Expertise and interviews with recycling plant suppliers

Table 19: Technology catalogue – Recycling Plant for PET and PS

3.2.2 Chemical recycling

3.2.2.1 Introduction

The term pyrolysis refers to thermochemical decomposition of organic materials caused by external heat supply in the absence of either oxygen, other oxidizing agents or other reactants, whereas in practice introduction of small amounts of oxygen or air with input materials cannot be avoided.

Depending on process temperature, the following distinction is drawn (Quicker et al., 2014; Quicker, 2015):

- Low temperature pyrolysis (LTP) T < 500°C,
- Medium temperature pyrolysis (MTP) 500°C < T < 800°C,
- High temperature pyrolysis (HTP) T > 800°C

Another criterion to differentiate pyrolysis processes can be (gas-)residence time. When input materials go through a rapid heating phase, the process is called flash pyrolysis. This way a high yield of liquid products can be achieved especially at low temperatures. Higher process temperatures lead to more gaseous components in the product range.

For thermal treatment of waste, intermediate and slow rate pyrolysis methods in the medium and high temperature range are relevant. Products expelled under these conditions are mainly gaseous. Yet with sufficiently long residence time, aromatization and polymerization may lead to (re-)composition of liquid or solid reaction products. The gas mainly consists of CO2, CO, hydrogen, methane, ethane and ethene. Product properties are determined by waste composition. For example, different dominating plastic fractions in the input material cause a significantly altered composition of product gas. Another important factor influencing the product range of pyrolysis is the water content of input waste, because higher humidity leads to increasing relevance of the heterogeneous and homogeneous water-gas reaction

Liquefaction of waste or biomass aims to generate a fuel product in a direct process. The output is to be a product that is either conforming to fuel standards or an intermediate product comparable to crude oil or gas oil.

The possibility to liquefy waste fractions depends on their chemical composition. The target product consists of hydrocarbon chains, or simpler: (-CH2-)n. Input materials with a comparable structure are polyolefins. Other plastic fractions and biomass contain an increased share of heteroatoms (oxygen, nitrogen, sulphur, chloride) which either prevent direct formation of pure CH2-chains or significantly reduce the content of these chains in the product.

Polyolefins can be directly split thermally into short-chain paraffin waxes and olefins. High temperatures (> 600°C) and short residence time lead to a higher content of short chain hydrocarbons, whereas low temperatures (< 400°C) and longer residence time cause longer chains. Unless saturated with hydrogen, olefins tend to polymerize and therefore show low ageing stability. When product oils shall be used as fuels, they must meet the specifications of respective standards. For diesel fuels, this is DIN EN 590, for petrol it is DIN EN 228.

Process approaches for liquefaction can be distinguished as follows:

- High pressure hydrogenation,
- Depolymerization,
- Solvolysis:
    - Organic solvent,
    - Water as solvent (hydrolysis),
- Combined processes.

All treatment principles operate with a liquid phase. This is to enhance miscibility and allow rapid heating of input materials. Depolymerization is basically a thermal decomposition of the input material. A start-up oil added in the start-up phase should not be converted within in the process. The process is operated at 250 to 420°C slightly below atmospheric pressure. Liquefaction processes which are currently offered on the market operate based on the principle of depolymerization. Several pilot plants have produced product oils in campaign operation. Yet the quality of these oils is insufficient for direct marketing as fuel. To achieve the necessary product properties, post-treatment, for example hydrogenation, is necessary. Industrial size plants for the production of fuel oil or diesel in permanent operation do not exist so far. Statements concerning economic figures are therefore solely based on planning data. Suitable input materials can be polyolefins (e.g. PE, PP, PS) respectively waste fractions with a high share of these plastic materials or compounds containing oil (e.g. waste oils).

3.2.2.2 Selected international information and exemplary projects

3.2.2.2.1 Chemical Recycling Europe (Association at European level)

Chemical Recycling Europe (ChemRecEurope) was established in 2019 to promote and implement the innovative solutions that the chemical recycling of plastic waste offers to benefit our economy and society. Chemical Recycling Europe (ChemRecEurope) is committed to coordinate and represent the interest of the chemical recycling community in Europe, and is open for all companies active in the whole value chain of chemical recycling of polymers.

Definition of "Chemical Recycling" is described as follow:
"Chemical Recycling of polymer waste is defined as any reprocessing technology that directly affects either the formulation of the polymeric material or the polymer itself and converts them into useful products like monomers, basic-chemicals, alternative fuels and other value-added materials."

Information under: https://www.chemicalrecyclingeurope.eu/

3.2.2.2.2 Boston consulting group (BCG) has published (2019) a study: "A circular solution to plastic waste

BCG recently completed several comprehensive analyses of global waste markets, collection systems, and recycling regulations, including the business cases for mechanical recycling and conversion technologies. The main conclusion is that while the economics and business challenges vary, conversion technologies such as pyrolysis are economically viable in all the market types described in the study. In some, pyrolysis can have an immediate and substantial impact—it has the potential to treat up to two-thirds of the plastic waste generated in Jakarta, for example. In others, the business case is feasible only if governments act to make inexpensive and environmentally detrimental means of disposal—principally landfills—less financially attractive.

There are seven different major types of plastic, each with its own chemical composition (see figure below):

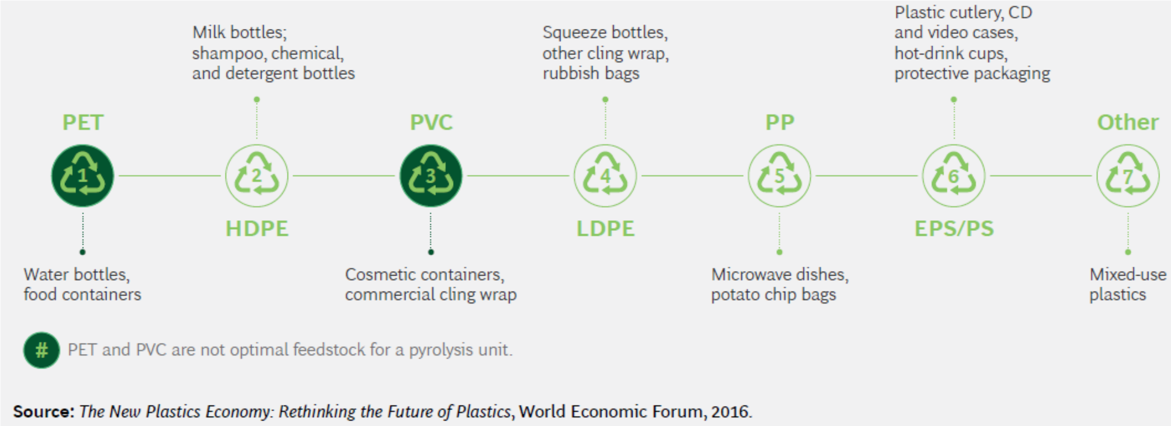

Figure 49: Plastic Types and their uses and makeups (BCG, 2019)

A hierarchy of plastic waste management describes the options for disposing of all this plastic (see figure below). Outside of actually reducing the amount of waste generated, reuse is the best method we have. Leakage of plastic waste into the environment is the least desirable, and disposal in landfills is only marginally better. Various groups and organizations are actively pursuing initiatives to push waste management practices toward the top of the pyramid. An intermediate target is to find ways to reduce the use of landfills and incineration and move toward more recycling and reuse (as well as reduction).

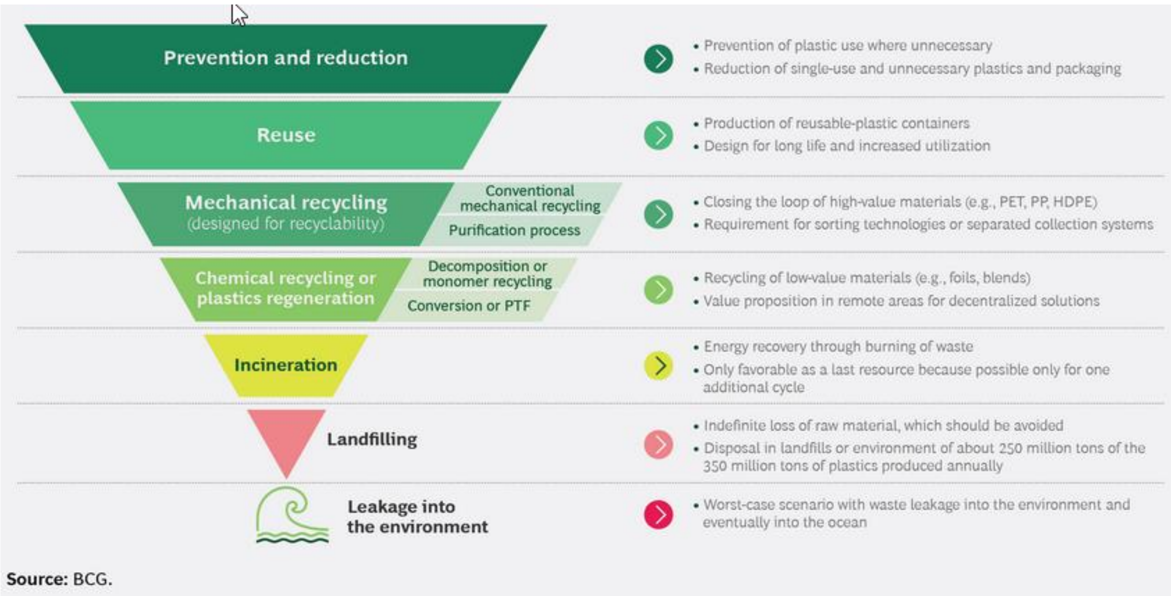

FIGURE 50: THE PYRAMID OF PLASTIC WASTE MANAGEMENT ACC. TO THE BCG (2019)

Like any chemical process, pyrolysis has its challenges. The biggest are scale and operational complexity. Pyrolysis reactors require regular maintenance, and the downtime is costly. A plant typically comprises multiple reactors, with additional units added in parallel to increase capacity. Some players are exploring continuous-process reactors of smaller size to gain scale. Pyrolysis also requires a sustained and consistent amount of good-quality feedstock to function effectively; this is one of the major challenges of the process because the plastics must be sorted and cleaned in advance to avoid contamination (although the cleaning and processing standards are less stringent than those required for mechanical recycling). These and other issues raise a key question with respect to whether pyrolysis can contribute in a meaningful way to plastic waste solutions: Is it economically viable? Four factors directly determine the economic viability of pyrolysis, and they can vary considerably by region and market. They include the addressable volume of plastic waste, feedstock acquisition and treatment costs, the capacity and operating expenses of pyrolysis plants, and potential revenues from the sale of pyrolysis gas and liquids. In addition, several structural and environmental trends shape the impact of these factors and the feasibility of pyrolysis in a market (see figure below).

FIGURE 51: THE FACTORS AFFECTING THE ECONOMIC VIABILITY OF MARKETS ACC. TO THE BCG (2019)

Further information under: https://www.bcg.com/de-at/publications/2019/plastic-waste-circular-solution.aspx

3.2.2.2.3 The „ReOil® " Process – OMV (OMV, Austria: Factsheet ReOil, September 2018

Since 2011 OMV downstream has been researching ways to harness the highly interesting resource potential of used plastics. After an intensive but unfortunately disappointing screening of available process technologies, the ReOil® process has been developed. The ReOil® process is based on thermal cracking, a proven refining technology, whereby long-chain hydrocarbons are cracked into shorter-chain light hydrocarbons. This unique process utilizes a solvent to decrease the viscosity of the plastics feed and to improve the heat transfer and is currently patented by OMV in Europe, USA, Russia, Australia, Japan, India and China and many other countries. After a year-long planning phase, the first lab-scale production plant with around 5 kg/h went into operation at the technical center of the Schwechat Refinery.

As a next step in developing the process OMV invested around EUR 10 mn in the construction of a pilot plant at the Schwechat Refinery, supported by the Austrian Research Promotion Agency (FFG) within the framework of the Competence Headquarter Program. This pilot plant, which will process

100 kg/h of waste plastics, will perform all of the experiments required to enable the implementation of a commercial-size installation (see figure below).

FIGURE 52: PHOTO REOIL PILOT PLANT; PHOTO: © OMV

Further information under: https://www.omv.com/en/blog/reoil-getting-crude-oil-back-out-of-plastic

3.2.2.2.4 The „ChemCycling" Process – BASF (BASF, Germany)

ChemCycling is the name of BASF's chemical recycling project: Through thermochemical processes, plastic waste is broken down to oil or gaseous products as raw materials for the chemical industry. These raw materials can replace fossil feedstock in the Verbund and be used to produce new products, especially plastics. Plastics can be utilized to produce syngas or oils. The resulting recycled raw materials can be used as inputs in BASF's production, thereby partially replacing fossil resources. BASF is already developing pilot products, including mozzarella packaging, refrigerator components and insulation panels, with 10 customers from various industries. Multilayer packaging consists of up to 11 individual, ultra-thin layers, making it considerably lighter and thinner than comparable

packaging. This pilot project was made possible thanks to the collaboration between the four partners BASF, Borealis, Südpack and Zott. BASF supplies chemically recycled polyamide, while Borealis provides sustainably produced polyethylene. Südpack, one of Europe's leading producers of film packaging for food products, uses these materials to produce multilayer film for a specially sealed Mozzarella packaging for Zott Gourmet Dairy. Zott enjoys numerous benefits thanks to this multilayer film.
However, thermochemical recycling needs acceptance as recycling from market and regulators. There are many open questions with regards to technology, economy and regulation.

Further information under: https://www.basf.com/global/en/who-we-are/sustainability/we-drive-sustainable-solutions/circular-economy/chemcycling.html

3.2.2.2.5 Neste "Replacing crude oil with waste plastics" (Neste, Finland, 2019)

Neste explores the use of waste plastic as a raw material for fuels, chemicals and new plastics. Neste has started a development project targeting to use liquefied waste plastic as a raw material for its fossil refinery. The aim is to proceed to an industrial scale trial during 2019. By 2030, Neste targets to process more than one million tons of plastic waste annually.
On 16 October 2018, a working group set up by the Ministry of the Environment in Finland announced its proposal for a Plastics Roadmap for Finland. This proposal is a list of actions that would help Finland reduce the scale and severity of the harm caused by plastic waste and littering, and accelerate plastics recovery and recycling.
In 2018, following information was published at Homepage: Neste, the world's leading producer of renewable diesel, UK-based chemical recycling company ReNew ELP ("End-of-Life-Plastics"), and Australian technology developer Licella are joining forces in a development project to explore the potential of using mixed waste plastic as a raw material for fuels, chemicals, and new plastics.

Further information under: https://www.neste.com/companies/products/fossil-fuels/replacing-crude-oil-waste-plastics

3.2.2.2.6 Indaver "Chemical recycling of end-of-life-plastics – Plastics2chemicals" (Indaver, Ireland, 2019)

Waste management company Indaver has received the environmental permit (status: 15.10.2019) to build a new demo plant for recycling 15,000 tons of end-of-life plastics each year. This is an important step towards creating a facility that will recycle around 50 tons of plastics into valuable raw materials for the industry every day. Indaver is planning to install the facility on its site on the right bank of the port in Antwerp and intends to start treating the first waste streams in the summer of 2021. With its Plastics2chemicals project Indaver has developed an innovative depolymerization technique to convert plastic waste into base chemicals. During the treatment process, the plastics are broken down into smaller carbon chains or monomers. The polyolefins (PE and PP) will produce base products such as naphtha and wax. The polystyrenes will be broken down into monomers that are re-usable as raw materials. P2C thus provides new raw materials with the same virgin qualities as primary raw materials. The recycled products will fit the requirements for direct industrial use in petrochemical processes. The new polymers are also fit for food applications. Since 2017, Indaver has expanded and tested the new process successfully in a laboratory environment in collaboration with Ghent University and the University of Antwerp. With the installation of the new demo plant facility in Antwerp the process is being scaled up from 2kg/hour to 2 tons/hour.
Goal of the company Indaver is to recycle 1 million tons of plastic waste, with focus on polyolefins post-consumer (packaging) waste. Therefore, Indaver aims to build 10 factories across Europe, 100,000 t/y capacity and ca. 80 Mio. Euro capex each. (Indaver; Erik Moerman, Business Development Manager, Presentation at Identiplast 2017 Vienna on 23.02.2017).

Further information under: https://www.indaver.com/ie-en/media-and-downloads/news-detail/press-release-indaver-receives-permit-to-build-a-new-plant-for-the-chemical-recycling-of-end-of-lif/

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5 ANNEX

1. Evaluation table indicating the recycling companies in D, NL, A and UK ("2019-11-29 - Plastic Recycling Plants - D, NL, A, UK.xslx"
2. Grüner Punkt Specifications
   - Grüner Punkt specification - 310_Plastics_Films.pdf
   - Grüner Punkt specification - 310-1_Plastics_Films.pdf
   - Grüner Punkt specification - 322_Plastic_Hollow_Bodies.pdf
   - Grüner Punkt specification - 323_Mixed PO
   - Grüner Punkt specification - 324 Polypropylene_PP.pdf
   - Grüner Punkt specification - 324-1_Polypropylene_plus.pdf
   - Grüner Punkt specification - 325_Pet_Bottles_Transparent.pdf
   - Grüner Punkt specification - 328-1_Mixed_PET_90_10.pdf
   - Grüner Punkt specification - 328-2_Mixed_PET_70_30.pdf
   - Grüner Punkt specification - 329_Polyethylene.pdf
   - Grüner Punkt specification - 330_cups.pdf
   - Grüner Punkt specification - 331_Polystyrene.pdf
   - ARA specification Mixed PET
   - ARA specification PS

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