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Rethinking Plastics
Circular Economy Solutions to Marine Litter




MANUAL FOR SUSTAINABLE PLASTIC RECYCLING

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Preface

Governments, businesses, academia, and civil society increasingly recognize that a switch towards a circular economy approach to plastic waste is necessary to tackle the plastic waste problem, especially marine littering.

In various activities geared towards sustainable plastic recycling such as technical support related to the reduction of plastic packaging and single-use products, the design of plastic products and packaging for reuse and recycling, as well as alternatives to plastics, standards for recycled plastics, and reduce microplastics in products, ***Sustainable plastic recycling*** plays a very important role.

Manual for sustainable plastic recycling was identified as an essential guide to provide more in-depth understanding related to the plastic recycling sector as well as contribute to the implementation of Vietnam's National Action Plan on Sustainable Production and Consumption in the period of 2021-2030 (Decision 889/QD-TTg dated June 24, 2020).

Manual for sustainable plastic recycling was made within the framework of the Project "Rethinking Plastics – Circular Economy Solutions to Marine Litter". The project is funded by the European Union and the German Federal Ministry for Economic Cooperation and Development (BMZ). It is implemented by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) and Expertise France.

Manual for sustainable plastic recycling is written in five chapters, each addressing different issues but forming a coherent and logical document.

- *Chapter 1 focuses briefly on the concepts, classifications, and sources of waste plastics.*
- *Chapter 2 presents an overview of plastic waste recycling. This chapter cites reliable data sources on the current recycling situation in Vietnam, industry capacity calculation, recycled plastic content to meet recycling targets. This is important for recyclers to determine the direction of investment in the field of plastic recycling. In addition, issues such as requirements for classified plastic scrap, for recycled materials, biodegradable plastics, bio-based plastics, etc. have been presented in quite detail. Especially the economic, technical and environmental barriers in plastic recycling are also synthesized and analyzed. This helps recyclers gain more industry information.*
- *Chapter 3 is the main chapter in the Manual with specialized knowledge about technology and equipment in the plastic recycling industry presented and illustrated in quite detail. This chapter is presented in two separate sections: Sorting and Recycling. This can be new and specialized knowledge to help recyclers and managers update the current plastic recycling industry information in the world and its applicability in Vietnam*
- *Chapter 4 focuses on legal compliance guidelines and environmental protection measures in plastic waste recycling. This is a chapter that comes from the needs of recyclers. The legal provisions on environmental protection along with the description of the sources of waste, the measures to treat the sources of environmental pollution and recommendations for good working practice for plastic recycling are also presented in this chapter.*
- *Chapter 5 presents national policies and international integration. The national policy part of the chapter focuses on presenting Vietnam's EPR regulations. International integration part focuses on presenting recycled plastic standards and standardizing them according to international practices.*

Manual for sustainable plastic recycling is updated with advanced technologies and sustainable trends in the world's plastic recycling industry in order to raise awareness about a plastic recycling industry for managers as well as plastic recyclers.

This is the first time a manual on plastic recycling has been released in Vietnam. With limited domestic references, the research team has made efforts to search and synthesize many various foreign specialized manuals for plastic recycling, combined with the active support of international experts to update new knowledge and practices applied in the field of plastic recycling. In addition, in the process of finalizing this manual, the research team carried out consultations with stakeholders and recyclers to make appropriate adjustments.

Hopefully this manual will contribute useful information and knowledge to the plastic recycling industry and will continue to be updated and adjusted in the next versions.

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LIST OF ABBREVIATIONS

BFRs	Brominated flame retardants
CAPEX	Capital Expenditure
CFR	Collected for Recycling
DIN	German institute for standardization
EIA	Environmental Impact Assessment
EN	European Standard
EPR	Extended Producer Responsibility
EU	European Union
FR	Flame retardant
HDPE	High Density Polyethylene
ISO	International Organization for Standardization
LDPE	Low Density Polyethylene
LIF	Laser-induced fluorescence
LIBS	Laser-induced breakdown spectroscopy
NIOSH	National Institute for Occupational Safety and Heal
NIR	Near-infrared
OECD	Organisation for Economic Co-operation and Development
PBDEs	PolyBrominated Diphenyl Ethers
PE	Polyethylene
PET	Polyethyleneterephthalate
POP-PBDE	Persistent Organic Pollutants - PentaBromoDiphenyl Ethers
PP	Polypropylene
PS	Polystyrene
PC	Polycarbonates
PVC	Polyvinylchloride
RDF	Refuse-derived fuel
XRF	X-Ray Fluorescence
XRT	X-Ray Transmission
SDG	Sustainable development goal
TPY	Ton per year
UV	Ultraviolet
VIS	Visible spectroscopy
WEEE	Waste Electrical and Electronic Equipment

CHAPTER 1

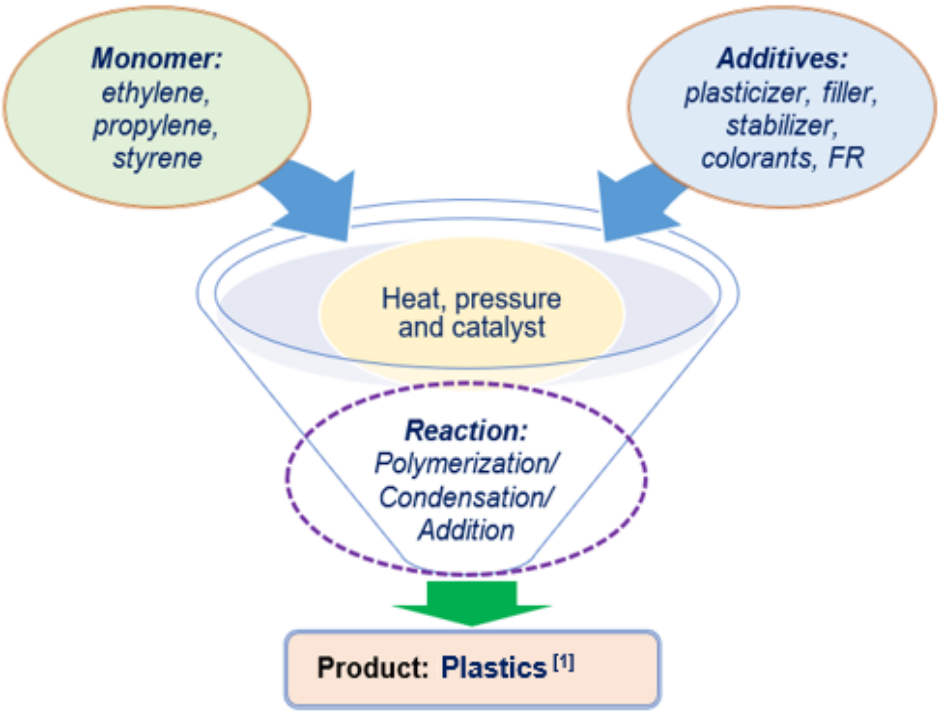
PLASTICS AND PLASTIC WASTES

1.1. CONCEPT AND CLASSIFICATION OF PLASTICS

1.1.1. Concept of plastic

According to the ISO 472: 2013 *"Plastic is a material which contains as an essential ingredient a high polymer and which, at some stage in its processing into finished products, can be shaped by flow".*

Plastic is usually a synthetic material, which is a polymer or a combination of high-molecular-weight polymers. Monomers are linked into chains by polymerization, compounded with additives such as fillers, plasticizers, stabilizers, lubricants, pigments.



1.1.2. Classification of plastics

The plastics can be classified on the basis of three criteria:

(1) Behaviour to heat:

- The way a certain type of plastic physically reacts to heat, i.e. melts or becomes irreversibly rigid, and based on whether it can be further remoulded into a desired shape, it is classified into thermo-plastic or thermoset.

  a) Thermoplastics are polymers which soften when heated and solidify upon cooling, allowing them to be remolded and recycled. Examples are polyethylene (PE), polypropylene (PP), and polystyrene (PS). Most common consumer plastics are thermoplastics.

b) Thermosets are plastics that are set into a mould once, normally with a chemical reaction taking place, and cannot be re-softened or moulded again. Examples of thermosets include urea formaldehyde resins, phenol formaldehyde resins, and melamine formaldehyde resins. Thermosets are often used for high-heat applications such as electronic equipment and appliances.

- Out of the total plastic waste generated, around more than 90 per cent comprises of thermoplastic content (such as PET, LDPE, HDPE, PVC, etc.) which is recyclable. The remaining belongs to a family of thermoset and other categories of plastics (such as sheet moulding compound—SMC, fibre reinforced plastic—FRP, etc.) which are non-recyclable.

(2) Chemical structure

- The types of monomers in a certain polymer (plastic) can be used to categorize a polymer as homo-polymer (same monomer running across the polymeric chain) or hetero-polymer (more than one monomer running across the polymeric chain).
- Theoretically and practically, if a plastic is made up of a single type of monomer, it would be much easier to process and recycle (assuming that it is not contaminated). Presence of more than one type of monomer in a plastic make the process of recycling difficult.

(3) Resin Identification Codes (RIC)

Most widely used plastic (for thermoplastics) identification codes which can be found on most packaging products sold in the market.

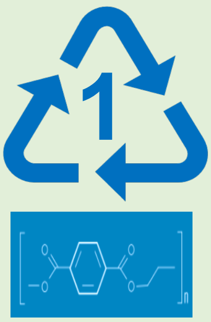
There are seven types of plastic (6 types found in the majority of applications plus "all other").

These types and their typical uses include:

Table 1.1. Symbols and properties of plastics

Polymer Name	POLYETHYLENE TEREPHTHALATE	HIGH-DENSITY POLYETHYLENE	POLYVINYL CHLORIDE	LOW-DENSITY POLYETHYLENE	POLYPROPYLENE	POLYSTYRENE	All Other plastics, including acrylic, fiberglass, nylon, polycarbonate, and polylactic add (a bioplastic)
Resin Identification Code	1	2	3	4	5	6	7
Abbrevia-tion	PET or PETE	HDPE	PVC	LDPE	PP	PS	OTHER
Recyclable?	Commonly Recycled	Commonly Recycled	Sometimes Recycled	Sometimes Recycled	Occasionally Recycled	Commonly Recycled (but difficult to do)	Difficult to Recycle
Maximum Temperature	70°C (158°F)	120°C (248°F)	70°C (158°F)	80°C (176°F)	135°C (275°F)	90°C (194°F)	Polycarbonate: 135°C (275°F) Polyactic acid: 150°C (302°F)
Brittleness Temperature	-40°C (-40°F)	-100°C (-148°F)	-30°C (-22°F)	-100°C (-148 °F)	0°C (32°F)	-20°C (-4°F)	Polycarbonate: -135°C (-211°F) Polylactic acid: 60°C (140°F)

POLYETHYLENE TEREPHTHALATE (PET or PETE)



PROPERTIES

- Good gas and moisture barrier
- High heat resistance
- Tough
- Good microwave transparency
- Solvent-resistant

COMMONLY USED FOR

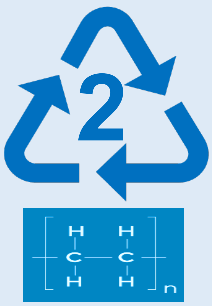
- Soda bottles
- Water bottles
- Beer bottles
- Salad dressing bottles
- Peanut butter jars
- Jelly jars
- Rope
- Combs
- Tote bags
- Medicine jars
- Clothing and carpet fiber
- Prepared food trays and roastingbags
- Some shampoo and mouthwash bottles

CAN BE RECYCLED INTO

PET is commonly recycled. .
It can be recycled into:

- Garments
- Other plastic bottles
- Carpets
- Stuffing for pillows, winter jacket, sleeping bags
- Bean bags
- Storage containers
- Rope
- Car bumpers
- Tennis ball felt
- Combs
- Cassette tapes
- Sails for boats
- Furniture

HIGH-DENSITY POLYETHYLENE (HDPE)



PROPERTIES

- Excellent moisture barrier
- Excellent chemical resistance
- Hard to semi-flexible and strong
- Soft waxy surface
- Permeable to gas
- HDPE films crinkle to the touch
- Pigmented bottles are stress-resistant

COMMONLY USED FOR

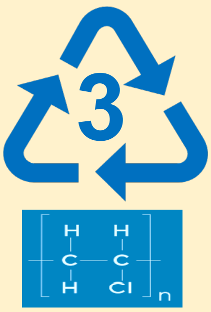
- Milk jugs
- Non-carbonated drink bottles
- Motor oil containers
- Shampoos and conditioner bottles
- Soap bottles
- Detergent bottles
- Bleach bottles
- Snack food boxes
- Cereal box liners
- Toys
- Buckets
- Rigid pipes
- Crates
- Plant pots
- Garden furniture
- Refuse bins and compost containers
- Park benches
- Truck bed liners

CAN BE RECYCLED INTO

HDPE is the most commonly recycled plastic and can also be reused. It is recycled into:

- Plastic bottles and jugs but it are not suitable to be recycled into food applications
- Plastic lumber
- Outdoor furniture
- Playground equipment
- Fencing
- Rope
- Toys

POLYVINYL CHLORIDE (PVC)



PROPERTIES

- Excellent transparency
- Hard and rigid (flexible when plasticized)
- Good chemical resistance
- Long-term stability
- Good weathering ability
- Stable electrical properties
- Low gas permeability

COMMONLY USED FOR

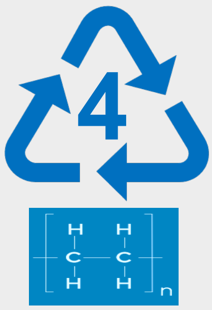
- Plumbing pipes
- Credit cards
- Carpet backing
- Floor covering
- Window and door frames
- Rain gutters
- Pipes and fittings
- Wire and cable sheathing
- Synthetic leather products
- Clear plastic food wrapping
- Cookingoilbottles
- Teethingrings
- Children's and pets' toys
- Garden hoses

CAN BE RECYCLED INTO

Almost all products using PVC require virgin material for their construction; less than 1% of PVC material is recycled. Specialized programs do recycle PVC and use it for:

- Flooring
- Paneling
- Roadside gutters
- Traffic cones
- Credit cards
- Pipes

LOW-DENSITY POLYETHYLENE (LDPE)



PROPERTIES

- Tough and flexible
- Waxy surface
- Soft;scratches easily
- Good transparency
- Low meltingpoint
- Stable electrical properties
- Good moisture barrier

COMMONLY USED FOR

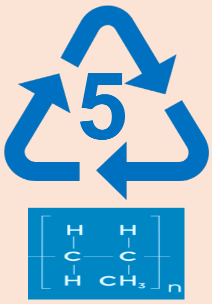
- Plastic wrap
- Sandwich bags
- Bread bags
- Squeezable bottles
- Plastic grocery bags
- Garbage bags
- Food storage containers and lids
- Bubble wrap
- Irrigation pipes
- Thick shopping bags
- Wire and cable covering
- Coatings for paper milk cartons
- Hot and cold beverage cups

CAN BE RECYCLED INTO

LDPE is difficult to recycle, although more plastic recycling programs are gearingup to handle this material.When recycled, LDPE is used for:

- Plastic lumber
- Compost bins
- Trash cans
- Floor tiles

POLYPROPYLENE (PP)



PROPERTIES

- Excellent chemical resistance
- High meltingpoint
- Hard but flexible
- Waxy surface
- Translucent
- Strong

COMMONLY USED FOR

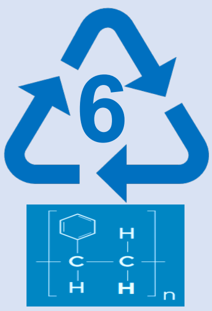
- Prescription bottles
- Most bottle tops
- Ketchup and syrup bottles
- Yogurt and margarine containers
- Potato chip bags
- Drinking straws
- Hinged lunch boxes
- Fabric/carpet fibers
- Heavy-duty bags
- Hot food containers
- Packing tape
- Thermal vests
- Car parts
- Disposable diapers
- Sanitary pad liners

CAN BE RECYCLED INTO

Recycled PP is used for:

- Shippingpallets
- Automotive battery cases
- Brooms
- Shovels
- Watering cans
- Mixing bowls
- Cutting boards
- Ice scrapers
- Storage bins

POLYSTYRENE (PS)



PROPERTIES

- Clear to opaque
- Glassy surface
- Rigid or foamed
- Hard
- Brittle
- Hight clarity
- Affected by fats and solvents

COMMONLY USED FOR

- Disposable foam cups
- Take-out food containers
- Plastic cutlery
- Eggcartons
- Fast-food trays
- Video cases
- Seed trays
- Coat hangers
- Low-cost,brittle toys
- Foam packaging (packing peanuts)
- Rigid foam insulation
- Underlay sheeting for laminate flooring

CAN BE RECYCLED INTO

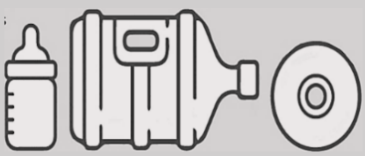
Recyclingis not widely available for polystyrene. It can be recycled into:

- Cassette tapes
- Rigid foam insulation
- Eggcartons
- Picture frames
- Moldings
- Home decor products
- Foam protective packaging.

OTHER

PROPERTIES

This category is a catchall for other plastic resins not described above or a combination of these plastics.



COMMONLY USED FOR

- Baby bottles
- Sippy cups
- Large, multiple-gallon water bottles
- Medical storage containers
- Eyeglasses
- Exterior lighting fixtures
- Metal food can linings
- CDs and DVDs
- Dental sealants

CAN BE RECYCLED INTO

Items made from #7 plastics are a combination of various plastics and are difficult to recycle,but some can be recycled into plastic lumber and specialized products.

1.2. SOURCES OF PLASTIC WASTE IN VIETNAM

1.2.1. Sources of plastic waste generation in Vietnam

Plastic waste in Vietnam is mainly generated from domestic, industrial, agricultural and construction activities. The generation source and path of waste plastic are summarized in the following diagram:

DIAGRAM OF PLASTIC WASTE IN VIETNAM

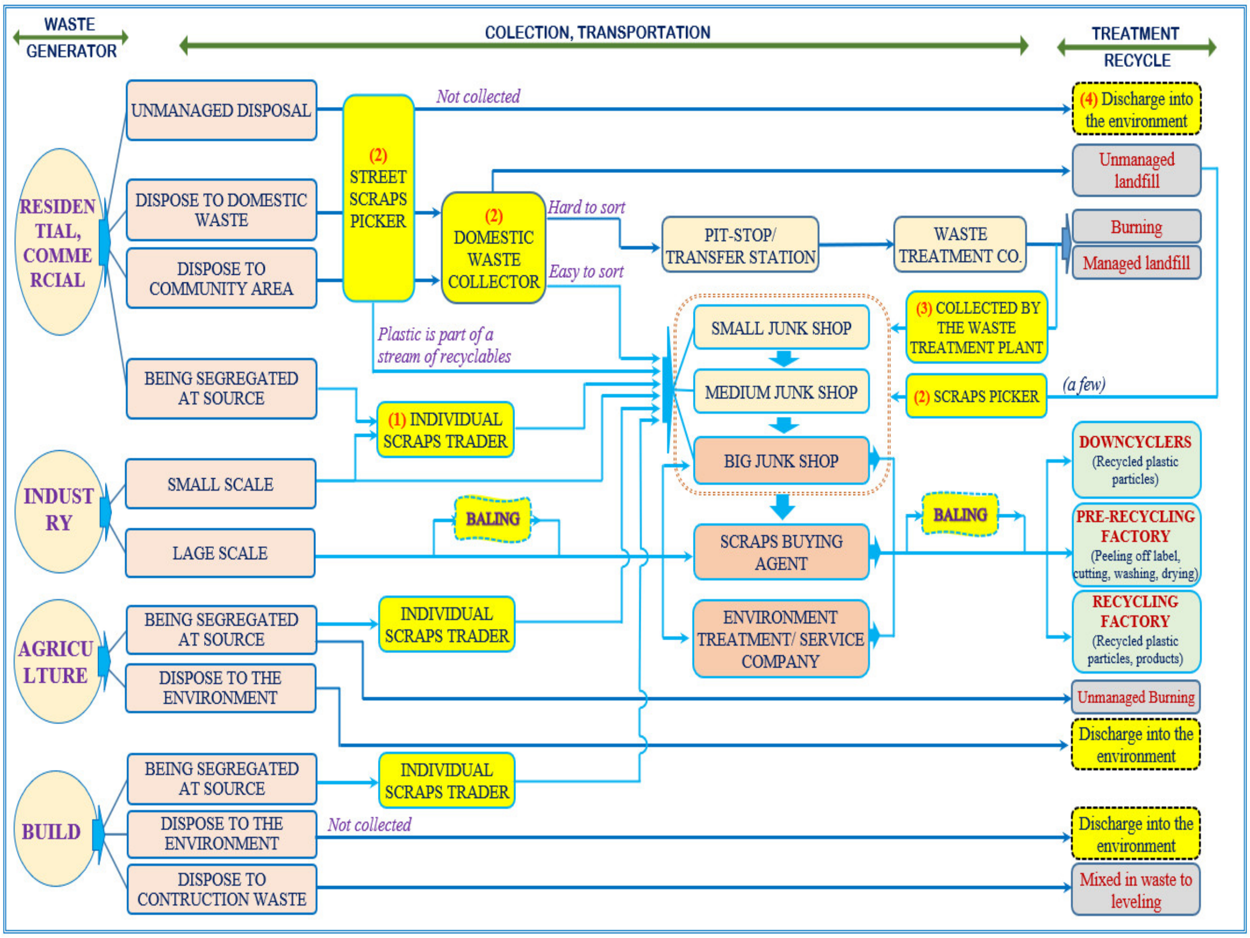


Figure 1.1. The generation source and path of waste plastic

(i) Plastic waste from daily activities

Plastic waste from daily activities includes the following sources

(1) First source: plastic waste from households, commercial centers, tourist areas, etc. This is a source of high-value plastic, most of which is collected by individual scraps traders, and waste pickers, separated, and then sold to junk shops (bottle rack), which is eventually recycled as shown in the diagram above.

(2) Second source: plastic waste mixed in household waste that has not been separated, most of which is also collected by sanitation formal/or informal workers and waste pickers, then sold to the junk shops (bottle rack).

(3) Third source: waste plastic is collected, and sorted at waste treatment plants.

(4) Waste plastic mixed with domestic waste is not collected, dumped in unmanaged landfills, and discharged into the environment.

(1) First source : plastic waste from households, commercial centers, tourist areas, etc.

(2) Second source: plastic waste mixed in household waste that has not been separated, most of which is also collected by sanitation formal/or informal workers and waste pickers

(3) Third source: waste plastic is collected, and sorted at waste treatment plants

(4) Waste plastic mixed with domestic waste is not collected, dumped in unmanaged landfills

(ii) Source of waste plastic from industrial activities

Plastic waste generated from industrial activities is mostly sorted at the source. For large sources of waste, they are usually collected and treated through environmental technology service companies and recycling plants. The waste plastics are baled at the waste source, transported directly to the recycling plant. For small wastes, they are usually taken to recycling facilities by individual scraps traders (bottle collectors) or junk shops (bottle rack).

	
Waste generated from industrial activities, including waste plastic.	*Waste generated from industrial activities is separated at source*

(iii) Source of waste plastic from agricultural activities

Waste plastic from agricultural activities is mainly generated from the packaging of pesticides, etc., after being used. This type of plastic is considered hazardous waste and the management is still inadequate. In addition, a significant source of plastic waste generation is PE plastic films covering agricultural soil, packaging for aquatic food, packaging for animal feed, broken fishing gear such as nets and ropes when fishing …

	
Waste plastic packaging in agriculture	*PE plastic film used in farming*

(iv) Source of waste plastic from construction activities

Plastic waste from construction activities also accounts for a large amount such as plastic building materials, PVC and HDPE pipes, or other rigid plastics. Much of it is also collected by waste pickers or individual scraps traders or bottle racks to be taken to recycling plants. However, there is still a small amount mixed with construction debris and buried in the leveling process.

	
Plastic waste from construction activities	

1.2.2. Imported plastic and plastic scrap

Plastic imports and estimated net imports of plastic scrap into Vietnam in 2019 according to VPA Data, UN Comtrade and Vietnam Customs Data collected and aggregated by The World Bank Group are as follows:

Table 1.2. Plastic imports and estimated net imports of plastic scrap enter Vietnam in 2019

Type of plastic	Plastic imports (tonne)			Estimated net imports of plastic scrap into Vietnam (tonne)
	VPA	UN Comtrade	Vietnam Customs Data	
PET packaging	190,400	30,900	31,800	64,389
PET Polyester	321,300	442,600	528,000	
PP	1,400,400	1,158,300	1,475,000	85,852
PE	2,305,300	1,944,500	3,119,900	150,241

Note:

- *Plastic scrap import data is reported by VPA.*
- *Most recyclers in Vietnam recycle PE, PP and PET, which together account for about 70% of the total amount of imported scrap.*

Source: Market Study for Vietnam: Plastics Circularity Opportunities and Barriers - The World Bank Group, 2021

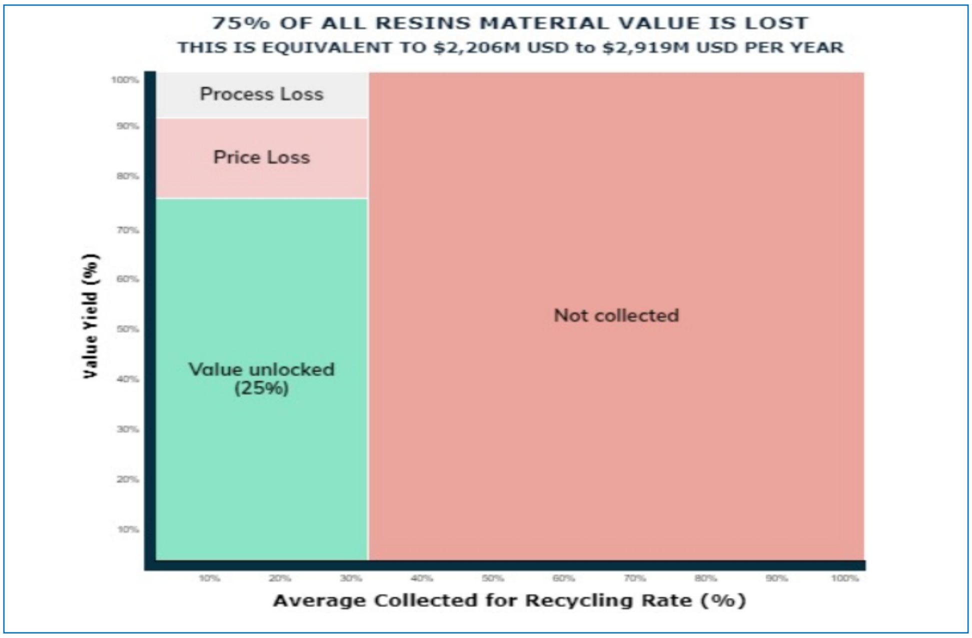
1.2.3. Current status of plastic waste management

According to a study by The World Bank Group, on Market Study for Vietnam: Plastics Circularity Opportunities and Barriers, typical figures in 2019 are as follows [2]:

- In 2019, Vietnam's plastics industry produced 8.89 million tonnes of products, and the industry contributed an estimated US$17.5 billion to the national economy, representing 6.7 percent of GDP.
- As much as 3.90 million tonnes per year (TPY) of PET, LDPE, HDPE, and PP are consumed in Vietnam. Of this, 1.28 million TPY (33 percent) gets recycled.
- As much as 2.62 million tonnes of plastics are disposed of per year, that is, not recycled, resulting in the loss of 75 percent of the material value of plastics, which is equivalent to US$2.2 billion to US$2.9 billion per year.

Source: Market Study for Vietnam: Plastics Circularity Opportunities and Barriers - The World Bank Group, 2021

Material value loss analysis for all key resins (data based on 2019 volumes) shows that:



Source: Market Study for Vietnam: Plastics Circularity Opportunities and Barriers - The World Bank Group, 2021

According to the assessment of The World Bank Group, 2021:

- *A significant portion of this market opportunity could potentially be captured through public and private sector investments to improve waste management infrastructure, an enabling environment to improve recycling economics, and other systemic interventions to address market failures.*

CHAPTER 2

PLASTIC WASTE RECYCLING OVERVIEW

2.1. OVERVIEW OF PLASTIC WASTE RECYCLING IN VIETNAM

2.1.1. Situation of Waste Plastic Recycling

2.1.1.1. Collected for Recycling (CFR) Rates of major Plastics

According to research by The World Bank Group, 2021 is presented in section 1.2.2, Vietnam recycled about 1.28 million tons (33%) of major plastics in 2019. In which: PET packaging has the highest Collected for Recycling (CFR) among all major plastics, at 50%. The remaining plastics such as LDPE/LLDPE, HDPE, PP have collected-for-recycling (CFR) of about 35% for each type. PET Polyester is almost unrecyclable.

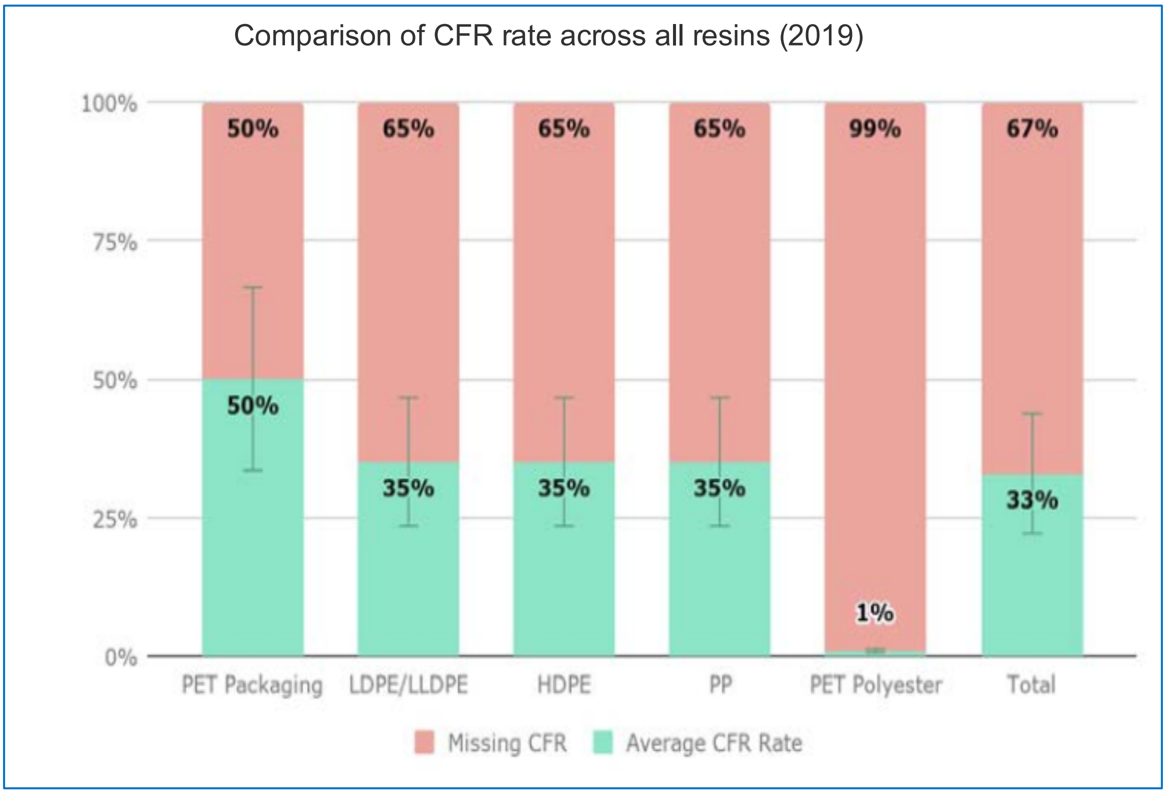


Figure 2.1. Comparison of Collected for Recycling (CFR) rates of major Plastics (2019)

Source: Market Study for Vietnam: Plastics Circularity Opportunities and Barriers - The World Bank Group, 2021

2.1.1.2. Calculation of the missing capacity compared to the current installed recycling capacity

According to research by The World Bank Group, 2021, the calculation of the missing capacity compared to the current installed recycling capacity is as follows:

Table 2.1. Calculation of the missing capacity compared to the current installed recycling capacity

Resin	PET Packaging	PET Polyester	PP	PE	**Total**
Consumption (TPY)	389,500	410,600	1,427,800	1,671,700	**3,899,600**
Estimated Installed Formal Recycling Capacity (TPY)	248,800	0	412,400	506,200	**1,167,400**
Current Missing Capacity (TPY)	140,700	410,600	1,015,400	1,165,500	**2,732,200**
Current Missing Capacity (%)	36%	100%	71%	70%	**70%**
Verified Planned Additional Formal Recycling Capacity (TPY)	93,200	0	36,200	87,500	**216,900**
Missing Capacity after factoring planned Additional Capacity (TPY)	47,500	410,600	979,200	1,078,000	**2,515,300**
Missing Capacity after factoring planned Additional Capacity	12%	100%	69%	64%	**65%**
Estimated Informal Recycling Capacity (TPY)	78,500	0	232,900	326,100	**637,500**
Missing Capacity after also factoring Informal Recyclers	0	410,600	746,300	751,900	**1,908,800**
Missing Capacity after factoring Planned Formal Expansions & Current Informal Recyclers	0%	100%	52%	45%	**49%**

Comment:

- *PET Packaging recycling capacity is enough compared to current demand, so recyclers need to consider carefully when investing in recycling this plastic. Meanwhile, PET Polyester recycling capacity is lacking.*
- *PP, PE plastic also lacks recycling capacity, therefore, priority should be given to investing in recycling this type of plastic.*

2.1.1.3. Recycled Content Volumes to meet recycled content targets

According to research by The World Bank Group, 2021, Recycled Content Volumes with the recycling target of 20% and 30% is as follows:

Table 2.2. Recycled Content Volumes to meet recycled content targets

Resin	2030 Estimated Plastic Consumption (TPY)	Recycled Content Volumes (TPY) Based on 2030 Recycled Content Targets		Estimated 2019 Local Formal Recycling Capacity (TPY)
		20%	30%	
PET Packaging	511,015	102,203	153,304	248,800
PET Polyester	538,713	107,743	161,614	NA
PP	1,873,373	374,675	562,012	412,400
HDPE	978,001	195,600	293,400	506,200
LDPE/LLDPE	1,215,360	243,072	364,608	
Total	5,116,462	1,023,292	1,534,939	1,167,400

Note: 2030 estimated consumption is based on 2.5% Compound Annual Growth Rate (CAGR).

Thus, the existing recycling capacity can meet the Recycled Content Volumes for PET Packaging, HDPE, LDPE/LLDPE. However, there is a shortage with PP and PET Polyester.

2.1.2. Existing problems affecting the Plastic recycling industry

The plastic waste recycling industry in Vietnam has been established for a long time. Though recycling has long been considered a necessary factor for the long-term development of Vietnam, the domestic recycling industry is still spontaneous, not strictly controlled, with a high risk of causing pollution.

The main reason is due to the following problems:

- The first and foremost problem lies in waste collection infrastructure. Garbage collection in Vietnam has long faced many obstacles, leading to difficulties in subsequent treatment stages, including recycling. Currently, the waste collection force in the provinces includes both private and state-owned cities. In particular, the private sector is mostly small-scale, using rudimentary equipment, leading to a lack of synchronization in the waste treatment system.
- There is no policy to encourage recycling of dirty plastic, not creating favorable conditions or not even licensed plastic recycling for small and medium enterprises, so there are many informal businesses, and most of them lack long-term investment, do not comply with regulations and law.
- Solid waste management systems prioritize collection and disposal by landfill over recycling. Up to now, there have been policy adjustments, but the recycling capacity has not been improved because the infrastructure has not been built or synchronized.
- The waste collection infrastructure is not synchronous such as collection trucks, transfer vehicles, sorting centers are not connected... Therefore, it causes difficulties in material recovery and recycling.
- Waste separation at source in households is almost inactive.

- Many recycling activities in Vietnam are carried out by small-scale establishments, most of which are recycling craft villages, without sufficient technology and environmental awareness. The recycling craft villages have existed for a long time, with certain relationships and links with formal and informal garbage collectors. That makes it difficult for recyclers to ensure the quantity and quality of input supplies.
- There are no standards for waste plastic recycling industry.
- Other problems are the involvement of technology in recycling. Recycling is not a focus of training in Vietnam. Education facilities do not specialize in recycling, which leads to a serious lack of specialists in the field.

2.2. OVERVIEW OF PLASTIC WASTE RECYCLING METHODS

There are three main types of recycling process and in addition a recovery process: primary recycling, secondary recycling, tertiary recycling [5]. Primary recycling involves extruding pre-consumer polymer or pure polymer streams. Secondary recycling requires sorting of polymer waste streams, reduction of polymer particle size, separate/wash/dry, followed by extrusion. With proper control over processing conditions, many polymers can undergo several cycles of primary and secondary mechanical recycling. Tertiary recycling is used on polymers no longer suitable for these straightforward mechanical recycling methods. This chemical recycling is often complementary to traditional recycling methods, and can retain significant value if this process is selective (by returning the polymer to its monomeric feedstocks). The recovery process is applied to plastics that are unsuitable for any other type of recycling and are used for energy recovery via co-processing, e.g. in a cement kiln.

Table 2.3. Common definitions of plastic recycling

Process	ISO 15270:2008 standard definitions	Example
Primary recycling	Mechanical recycling	Bottle to bottle closed loop recycling
Secondary recycling	Mechanical recycling	Recycling into lower value plastic
Tertiary recycling	Chemical recycling	Depolymerization of polyesters
Recovery	Energy recovery	Pyrolysis

(1) Mechanical recycling

Mechanical recycling involves only mechanical processes (grinding, washing, separating, drying, re-granulating and compounding). The obtained recyclates can replace virgin plastics in the fabrication of new plastic products. Common processing techniques after re-melting are injection moulding, extrusion, rotational moulding and heat pressing.

This technique is only applicable on thermoplastic materials, as thermosets will not re-melt. Examples of mechanical recycling of post-consumer plastics waste:

– Collection and grinding of sorted, clean PP crates and blending of the regrind with virgin polymer to mould new crates;

- Collection of low density polyethylene (LDPE) films used in agriculture and industrial packaging, pre-washing, grinding, washing, separating, drying and melt-filtration/ regranulation and processing into refuse bags;
- Collection and sorting of PET bottles used for drinks packaging, grinding, washing, separating, drying and processing into polyester fibres, sheets or containers.

(2) Chemical recycling [5]

Also called thermochemical or feedstock recycling, chemical recycling involves mechanisms in which the collected plastic waste is chemically degraded into its monomers or other basic chemicals. The processes involved are amongst others hydrolysis, pyrolysis, hydrocracking and gasification. The output may be reused for polymerisation into new plastics for the production of other chemicals or as an alternative fuel.

Although various techniques have been successfully established in the promising field of feedstock recycling, the industry suffers from high investment levels, high energy consumption and high input levels, making only very large plants economically viable at the current time.

(3) Energy recovery [5]

Incineration of polymers utilizes the caloric value of the polymers is the recovery process. It is a common and highly practiced method for waste reduction and energy recovery, often used upon highly contaminated or complex polymers waste streams, such as medical waste and hazardous-goods packaging. While energy recovery unavoidably terminates the lifecycle of a polymer product, it remains preferable to landfill.

Among the above-mentioned recycling methods, mechanical recycling is the simplest and most common method used for most types of plastic waste. Therefore, the scope of this Manual is focused solely on the content related to mechanical recycling.

2.3. OVERVIEW OF MECHANICAL RECYCLING

2.3.1. Mechanical recycling process

Plastic waste can be recycled in a different ways depending on types of polymers, product and packaging design, if the products consist of the single polymer or mixed polymers. Mechanical recycling is the most common methods for recycling of thermoplastic polymers such as PP, PE and PET. This process implies collection, sorting, recycling. A schematic overview is presented in Figure 2.2.

The first stage is a collection. Currently, in Vietnam, this is done by many units (scrap collectors, private companies with licenses for scrap trading...), individuals (waste pickers, sanitation formal/or informal workers...). In this stage, plastic has been basically pre-sorted and separated into different types.

The next stage is separation, and sorting at the recycling facility/plant: based on density, shape, size, color, thickness or absorption spectrum (PET, HDPE, PP…). Here, plastic waste can be sorted manually, or automatically (near-infrared technology - NIR, density separation, rotary drum sieving...)

After sorting, the plastic waste can be preliminarily chopped/shredded to reduce the size for greater efficiency in the plastic cleaning process.

Separation of impurities and washing of plastic is an important next step in the recycling line, as it determines the quality of the resin. This stage is to remove impurities in waste plastic such as leftover labels, glue, dirt, mud, sand... There are several different techniques for removing residues such as pre-washing with stirring with water, hot washing (intensive washing), and friction washing. After that, plastic is dried.

The plastic is grinded to reduce the size. Next, the plastic can be melted through the extruder and agglomerated into granules/pellets. For some factories, this is the final stage, these recycled plastic flakes or beads are the secondary raw materials of plastic product plants.

Some plastic factories use locally recycled flake plastics and granules to make recycled plastic products.

Waste plastic recycling process is a series of many stages as above. Depending on the conditions as well as many different factors, the above stages may be separated and performed separately at each different facility. In addition, depending on financial capacity and context at each time, each factory can invest in appropriate technology.

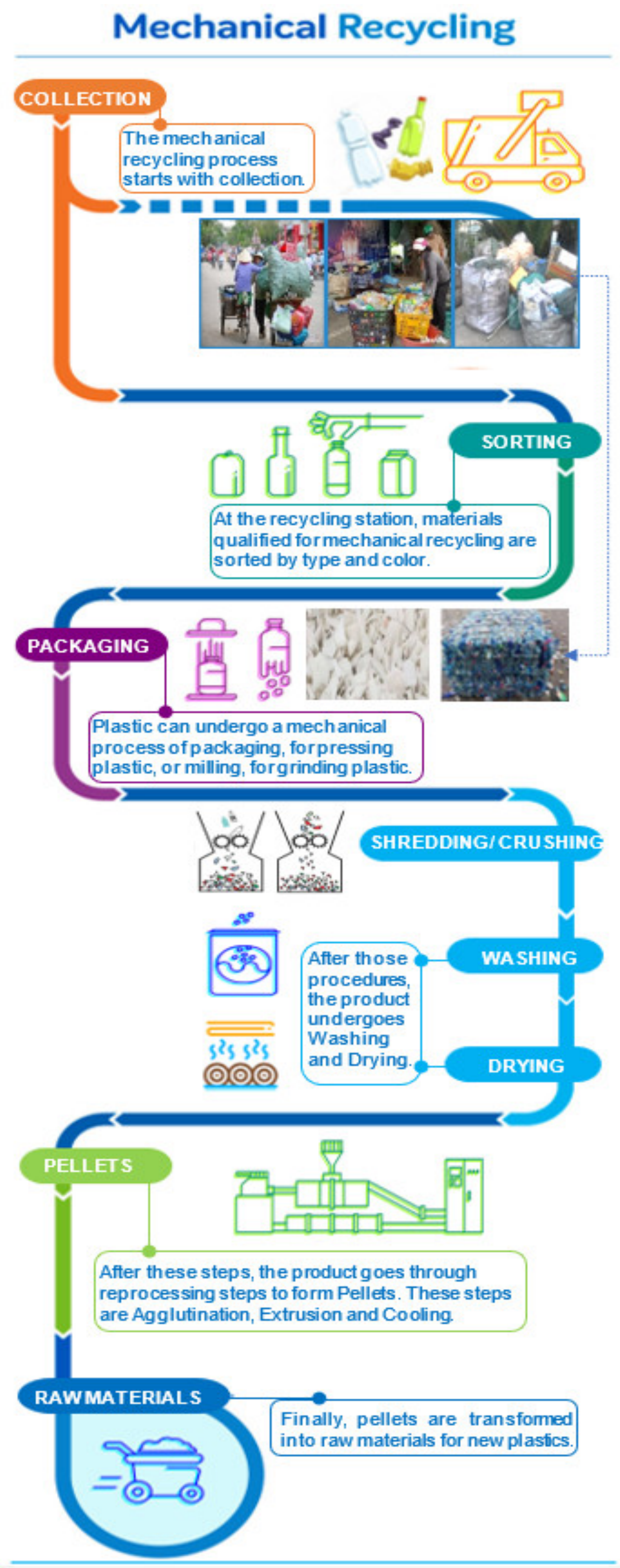


Figure 2.2. Description general diagram of waste plastic mechanical recycling process

2.3.2. Input materials

Waste plastic materials for recycling come from many different sources and types, including imported sources. In which, plastic waste from generated sources is mostly collected and pre-sorted by type of plastic. Waste plastic goes through the process of trading in the market such as such as individual scraps trader sell to junk shops or recycling facility.... In the process of this exchange of business, plastic is basically manually sorted by type (PET, PP, or a mixed colored plastic LDPE + PP + PE...). The waste plastic is then transported to a pre-recycling, or recycling plant. To reduce shipping costs, some collection centers or recycling facilities may bale these materials.

Waste plastic is collected to make raw materials for recycling

Waste plastic is collected and pre-sorted/or sorted before being recycled

Waste plastic is imported to be used as raw material for recycling

2.3.3. Recycled Plastic Products

Recycled plastic products include many different types, which can be in the form of flakes, pellets, granules or finished consumer products, pellets for energy recovery...

Some pictures for recycled plastic products:

Products are secondary raw materials

100% transparent flake PET. Thinness: (0.5-2) cm, Viscosity: 0.085 (Cst), impurities content <0.2%, PVC: < 0.02%.

Transparent PET bottles are ground/crushed < 14 mm, pre-washed through 3 troughs with water, then hot chemically washed in a mixing bath, at 80 degrees Celsius, to remove glue and dirty impurities, finally washed with 3-4 water troughs, then dried and packaged.

As a recycled plastic material for industries: Granulating, blowing PET bottles, Extruding PET preforms, extruding PET films, spinning and polyester fibers,...

Recycled plastic products

Mono-color flake plastic

flake plastics sorted by color

Examples of products made from recycled plastic

Plastic household items / plastic furniture

Injection molding: bucket/pot

2.4. MATERIAL REQUIREMENTS

2.4.1. Sorted polymers

In order to facilitate the exchange of waste plastic between the supplier (collection and primary processing) and the reprocessor, various standards for waste plastics are introduced. Typically, Germany's quality standards for sorted plastic waste are referenced and used by many European countries and other countries. Currently, Vietnam does not have a standard for sorted plastic waste, so the Vietnamese plastic recycling industry should refer to this standard to apply. The basic content of those quality standards is summarized in the following table.

Table 2.4. Quality standards for sorted plastic wastes for recycling

Sorted plastic wastes	Plastic Foils (mostly LDPE)	Plastic hollow body (mostly HDPE)	PP	PET bottles	PE	PS
Metal [w%]	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5
Other plastic particles [w%]	< 4.0	< 3.0	-	< 2.0	-	< 4.0
Other residues [(1)] [w%]	< 4.0	< 3.0	< 3.0	< 2.0	< 3.0	< 2.0
Dimensionally stable PE Articles [w%]	-	-	< 1.0	-	-	-
Foamed plastics incl. EPS[(2)][w%]	-	-	< 0.5	-	< 0.5	< 1.0
PlasticFoils [w%]	-	-	< 2.0	-	< 5.0	-
PVC [w%]	-	-	-	< 0.1	-	-
Dimensionally stable PP [w%]	-	-	-	-	< 3.0	-

(1) Compostable waste (foods, garden rubbish)

(2) EPS: expanded polystyrene

(3) [% by weight]

Source: GRÜNER PUNKT, 2019

In addition, most recently, December 2021, DIN SPEC 91446 - Classification of recycled plastics by Data Quality Levels for use and (digital) was issued.

The consortium that developed DIN SPEC 91446 has been assembled to address the lack of consistent data quality for recyclates. The classification of recyclates according to Data Quality Levels (DQL) will provide the market with a common language and remove obstacles for the industrial uptake of recyclates — both from a quantitative and qualitative point of view. It also establishes a methodology for identification and labelling of recyclates and provides guidance on consistent specification of plastic waste.

According to international consultants in the plastic recycling industry, in order to improve the quality of recycled plastics, these standards should be applied in Vietnam.

2.4.2. Recyclate

Similar to sorted plastic waste, materials obtained from recycling also have specific quality standards. The specifications or data sheets are illustrated briefly below.

- 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)
- Classification of recycled plastics by Data Quality Levels for use and (digital) trading (DIN 91446 2021 12).

The following table presents some of the above specifications that recyclers can refer to.

Table 2.5. Physical, Chemical and Rheological Properties of The Investigated Recyclates

Properties	LDPE	HDPE	PP	PET	PS
Density [g/cm³]	0.920 - 0.945	0.94 - 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$^{(4)}$
Properties Tensilees (modulus of elasticity) [MPa]	220 - 380	1170 - 1 350	850 - 1450	3400 - 3700	3000 - 3400
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 *$^{(3)}$ 280° C | 5,00 kg*		*$^{(2)}$ 230° C | 2,16 kg* *$^{(4)}$ 200° C | 5,00 kg*			

Source: GRÜNER PUNKT, 2019

2.5. QUALITY ASSURANCE

2.5.1. Sorted polymers

Quality control personnel have an important role in the process of ensuring the quality of mixed plastic scrap materials delivered to the plastic waste sorting plant. Based on their experience, the quality of the offered plastic scrap bales can be assessed by visual inspection.

An important element of input control is the color distribution of the plastic waste bales.

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

In some case plastic waste bales will be rejected if the basic standards are not met in terms of type, dirt, moisture content, etc. And increased humidity can affect the surface of the particles and foaming during injection molding can occur.

In general, bales of plastic waste that do not conform to quality requirements often lead to price reductions. If the contaminant content is too high, the treatment is less efficient (the material may be altered).

2.5.2. Quality assurance for re-granulate

In addition to assessment by visual inspection, the quality of the recyclates is sampled at random and sent to the laboratory. The physical, rheological, and mechanical properties of recyclables are important.

The following characteristics are analyzed in the course of a random sample inspection: [3]

- 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 usually ongoing control over recyclables and checks for any traces, emissions, mechanical value and color of the recyclables.

The hardness of the recycled material allows an initial prediction of the impurity (other plastic) content, the shape of the plastic particles and the density indicating that it may contain gases or vacuoles.

The color and smell of recycled plastic pellets can indicate the extent of previous thermal decomposition of the material.

Test devices and methods commonly used in quality assurance related to specifications are as follows:

- Melt index testers
- Differential scanning calorimetry (DSC)
- Ash furnaces
- Residual moisture scales
- Density analyzers
- Capillary rheometers
- Tensile testing and notched-bar impact test machine

Some other criteria determined to value recycles:

- 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

2.6. BIODEGRADABLE POLYMERS / BIO-PLASTIC

2.6.1. Term

The term “bio-plastics” encompasses two broad concepts: [4]

- ***Biodegradable plastics*** are materials that can be broken down by microorganisms to form water and carbon dioxide (aerobic conditions) or water and methane (anaerobic conditions). They can be produced from either biogenic or fossil carbon sources.
- ***Bio-based plastics*** are made from contemporary biological sources such as sugar cane, beet sugar, corn, potatoes, grains or vegetable oils. These plastics are not necessarily biodegradable.

As illustrated in Figure 2.3, there is considerable overlap between bio-based plastics and biodegradable plastics. Not all bio-based plastics are biodegradable and some fossil-based plastics are biodegradable.

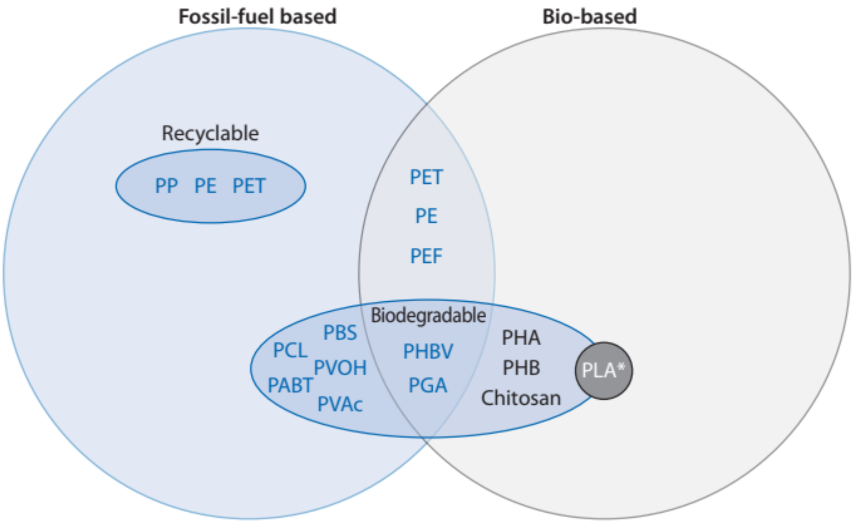


Figure 2.3. Recyclability and biodegradability of fossil fuel- and bio-based plastics

** PLA is only biodegradable in conditions that allow hydrolysis, like industrial composting for example.*

Source: Moss, Eidson and Jambeck (2017[20]), Sea of Opportunity: Supply Chain Investment Opportunities to Address Marine Plastic Pollution, http://bit.ly/2pxLHVf.

2.6.2. Bio-based plastics

Some bio-based plastics have identical chemistry to fossil-fuel derived plastics. They can be both substituted and mixed with their fossil derived equivalents in existing production lines. Examples include PET, PP, and PE. The benefit of these plastics is that they can also be recycled. Conversely, they do not biodegrade [4]. Most other bioplastics are biodegradable but cannot be substituted for conventional fossil-derived (other than possibly Poly–(γ-butyrolactone) (poly (GBL)).

2.6.3. Biodegradable plastics

All plastics are thought to be biodegradable given appropriate conditions and sufficient time. However, in the natural environment, most commonly used polymers only biodegrade over periods of tens or even hundreds of years. This means that empirical evidence for the biodegradation of plastics is limited, and that the long-term fate of plastics is largely unknown. It is worth noting that, although most fossil fuel- and bio-based plastics are considered to be biodegradable, a number of important polymers – PET and PE for example – are not.

In this context, it is also important to recognize the distinction between *degradability* and biodegradability. Plastics that are biodegradable can be broken down by micro- organisms into water and carbon dioxide. *Degradability*, of which biodegradability is a subset, also includes degradation via other mechanisms such as oxo-degradation (exposure to oxygen) and photo degradation (exposure to sunlight). It is not clear whether plastics that *degrade* in this way *degrade* into benign compounds, such as water and carbon dioxide, or whether they just fragment into smaller and smaller particles over time.

Claims about biodegradability should therefore be qualified with: [4]

- A timeframe under which biodegradation can take place;
- A specified set of conditions; and
- The extent to which the material is no longer in its previous form.

2.7. OXO-DEGRADATION

OXO-degradation is the degradation of polymers such as plastic by an oxidative process. Such degradation breaks down plastic into small pieces that are easier to biodegrade but not necessarily enough to be called "biodegradable".

"Oxo-degradable" plastics fragment but do not biodegrade except over a very long time; "Oxo-biodegradable" plastics degrade and then biodegrade. The European Committee for Standardization (CEN, for *Comité Européen de Normalisation*) has established the following definitions, in TR 15351:

- Oxo-degradation is degradation resulting from "oxidative cleavage of macromolecules";
- Oxo-biodegradation is "degradation resulting from oxidative and cell-mediated phenomena, either simultaneously or successively.

Oxo-biodegradable plastics which are made from polymers such as polyethylene (PE), polypropylene (PP), or polystyrene (PS) contain a prodegradant catalyst often a salt of manganese or iron, and are tested in accordance with ASTM D6954 or BS8472, or AFNOR Accord T51-808.

If a plastic is merely OXO-degradable but the fragments remain non-biodegradable, it can instead worsen pollution by creating microplastics. In 2019, by the EU directive 2019/904 (Article 5) of the European Parliament and of the Council (5 June 2019) the introduction of single use plastics made from oxo-degradable plastics was prohibited. Also, the amendment of the EU packaging directive (30 May 2018, 2018/852 Directive) says that oxo-degradable plastics are not considered biodegradable (“Oxo-degradable plastic packaging shall not be considered as biodegradable”).

2.8. BARRIERS IN PLASTIC RECYCLING

The following section presents barriers in plastic recycling.

Economic barriers	
Characteristics of Waste Plastic	The source of waste plastic is very diverse; combinations of polymers of different types, together with other materials (additives such as colorants, glues, printing inks, flame retardants,...) in them; and the high level of pollution of plastic after consumption has a strong impact on costs in the recycling process[4].
High cost of investment in recycling equipment line	In order to increase efficiency and ensure good quality of recycled plastics, recycling plants need to be equipped with appropriate, modern technical equipment (e.g. intensive washing system, one-step extrusion technology with necessary components for good temperature control, degassing, etc.). However, this equipment is expensive and requires skilled operators, sometimes exceeding the financial capacity for small and medium enterprises.
The source of plastic waste for recycling is not stable	The input material for recycling is scrap/waste plastic which is really unstable because domestic and imported collection depends on many factors. This results in at times recycling plants not being able to produce efficiently or producing below their capacity due to lack of recyclates or poor quality recyclates resulting in poor economic efficiency.
Limited resilience of the sector to market shock.	The recycling industry is characterized by many-scale operators who are unable to withstand in market prices. This issue is further compounded by a recycling sector that has limited control over the quality of its inputs and over demand for its products[4].
The global market for plastic scrap/waste depends on the policies and regulations of each country	The global market is easily affected by shocks in demand for import and export of scrap/plastic waste due to sudden changes in policies and regulations of countries. For example, the import restriction measure implemented by China in early 2018 has had a great impact on the recycled plastic market[4].
Lack of differentiated demand for recycled plastics	Recycled plastics are generally treated as a replacement material for primary plastics. Although demand for recycled plastics is influential in the short term, it is the price of oil and primary plastics price that drive recycled plastics market prices over the long term. Demand can be created by regulations (EPR).
Poor data on the structure and performance of the sector	Poor data on the plastics recycling sector limits the extent to which market actors can make evidence-based decisions and dissuades new market entrants.
Technical barriers	
The separation of plastic waste at source has not been done well	Because the separation of waste from households has not been done well, waste plastic is mixed with domestic waste, then collected by garbage collectors, and taken to a waste treatment plant. Such

	waste plastic sources are already highly contaminated, which will strongly affect the technical problem in the recycling process.
Manual plastic sorting	Pre-sorting of waste plastic in Vietnam is mainly manual (at the shop junks, collection center) so there is still confusion between polymers of different types. In addition, the recycling plant lacks an efficient and intensive washing and sorting system, which will greatly affect the quality of the recycled plastic.
Information on plastic recycling is missing and poor	Due to the lack of regulations and technical standards on recycling information on plastic products, it is difficult for recyclers to determine the recycled content, recycling life cycle (how many times the plastic is recycled), additives, mixed polymers, etc. in recycled materials. This is a huge technical problem that affects the quality of recycling.
Waste plastics are often contaminated and mixed with other materials	Contamination of post-consumer waste plastics is high, necessitating removal using appropriate equipment. Also, identifying and successfully separating polymers that are mixed together in the waste stream is technically challenging, and the very large number of different types of polymer and additives used also increases the challenge.
Problematic additives	Some additives used in primary plastics can have a detrimental effect on the physical characteristics of recycled plastics (for example, affecting brittleness, flame retardancy and oxidation). A critical issue is that of degradability enhancers which can significantly affect the strength and durability of recycled plastics and, if they were to become widespread in primary plastics would potentially prevent plastics recycling entirely. The issue is compounded by the lack of transparency around the presence and nature of additives that may be present in primary plastics[4].
Biodegradable plastics mixing with other plastics	Biodegradable plastics cannot be recycled using conventional mechanical recycling techniques. Some biodegradable plastics are easily mistaken for and mixed with conventional plastics, contaminating both recyclate streams and biological treatment facilities alike.
Poor or no polymer marking	Polymers are not marked, which leads to their wrong identification by sorting staff.
The traceability	The traceability of the plastic is what will help to sort correctly and to judge correctly what to do with it. Especially for European or US market which need to comply to REACH or other legislations. This is a huge barrier in the current conditions of waste plastic management in Vietnam. (REACH includes an authorization required to ensure that the risks from substances of very high concern (SVHCs) are properly controlled and that those substances are progressively replaced by suitable alternative substances or technologies).

Environmental barriers	
Hazardous additives.	Hazardous additives used in primary plastics can make their way into recycled plastics where they may pose a health risk, particularly where they are present in products that are used for sensitive applications such as toys and food packaging. This concern is compounded by the lack of transparency in the use of additives in plastics[4].
Competition between recycling and energy from waste.	In the future when waste - electricity technology develops, energy-from-waste will compete for access to waste plastics as a feedstock thus pushing plastics towards a less-preferred option in environmental terms.
Plastic is dirty and contains many impurities	Plastic is dirty and contains many impurities Recycling dirty/contains many impurities plastic waste is often not economical, so many recyclers will consider rejecting it. As a result, dirty plastic continues to be released into the environment. If state agencies do not have incentive or financial support mechanisms, plastic pollution to the environment will still exist as it is today.
Emission	If the waste plastic recycling process is carried out properly with the support of appropriate equipment and technology that allows control of emission sources, then air pollution is negligible. However, if we still use outdated crushing, washing and extrusion technology, this is an inevitable problem. Air pollution will arise at the extrusion, and filter processing of the extruder.
Wastewater	The plastic treatment process uses a lot of water, which generates wastewater, especially in the washing stage. Where the treatment system does not meet the treatment capacity, the treatment technology is not suitable, or the recycler is not operating properly. This is a significant source of environmental pollution, especially microplastic.
Illegal trade in plastic waste	The phenomenon of illegal waste trade is beyond the control of the environmental management agency. This has a significant effect on compliance with environmental protection regulations, and significantly affects the plastics trade as it undermines the quality of the compliant material.

CHAPTER 3

TECHNOLOGY AND EQUIPMENT

❖ Explanation of words

Table 3.1. Explanation of words

Process	Description
Cutting	Large plastic parts are cut by saw or shears for furtherprocessing
Shredding	Plastics are chopped into small flakes, allowing the separation of materials (e.g. metals, glass, paper) and plastictypes (e.g. PET bottles from PP lids).
Sorting	Additional sorting (e.g. NIR) once the material has beenshredded.
Contaminants separation	Contaminants (e.g. paper, ferrous metals) are separated fromplastic in cyclone separators and magnets. Liquids/glues can be separated in a wet phase.
Floating/Cleaning	Different types of plastics are separated in a floating tank according to their density. The density of the liquid can be modified to enable separation (e.g. adding salt to water). Thewet phase can also be used for washing residuals (e.g. organic)
Extrusion	The flakes /pellets/agglomerates are fed into an extruder where they are heated to melting state and forced through,converting into a continuous polymer product (strand or pellets).
Filtering	The last step of extrusion may be filtering with a metal mesh(e.g. 100-300 micron)
Pelletizing	The strands are cooled by water and cut into pellets, whichmay be used for new polymer products manufacturing.

Source: Villanueva & Eder, 2014

3.1. SORTING

3.1.1. Why sorting is necessary

Contamination of recycled material contributes to the decrease in quality and increase in variability of the regenerated polymer. While often thought of as being extraneous polymers, these contaminants are often associated with the polymers themselves.

Example: Pigments used to color plastics can accelerate degradation reactions within extruders. Printing inks and plastic or paper labels can introduce volatile ink components within the final recyclate pellet. Fatty acid based plastic lubricants, often used to facilitate the easy opening of plastic bags in shops, can be oxidized to produce unwanted odors in the recyclate. Extraneous plastics from incorrect sorting can exacerbate these issues or even lead to process failure. Trace amounts of PVC in PET streams induces hydrodechlorination at PET processing temperatures [6]

The resultant release of HCl in turn accelerates PET degradation and damages processing equipment.

The presence of polyamides can also catalyze the aminolysis of PET which increases chain scission. If a polymer blends is produced, due to accidental processing of mixed polymer waste streams, both the food-grade safety standards and mechanical properties are compromised., such as polyolefin and PET blends [6]. Effective plastic sorting is key to efficient recycling.

3.1.2. Sorting methods Overview

Quality sorting is essential to avoid introducing contaminants in the recycling streams and retain high safety standards for recycled materials.

Plastics are currently sorted using a combination of automated and manual processes. Near infrared (NIR) technologies are used to determine the polymer type, with optical color recognition sorting plastics into clear and colored fractions.

There are numerous other complementary sorting technologies including X-rays, density, electrostatics, melting point, hydrocyclons, selective dissolution, and manual sorting. Plastics may then be flaked by grinding. These flakes can then be further separated using sink/float methods, air elutriation and heat discoloration for further optical separation [7].

Each of these methods depends upon the chemical nature of the bulk polymer.

Table 3.2. Summary of sorting methods for separating different polymer types and colours

Sorting type	Description of process	Prevalence
Manual	Materials are sorted positively or negatively by people either from a static surface, conveyer belt, or from the floor or dumpsite.	Predominantly in low and middle-income countries, but also, to some degree in advanced mechanical plants for negative picking (removal of contaminants). Issues around worker's safety, rights and welfare. Manual sorting is quite common in Vietnam in the process of collecting waste plastic.

Sorting type	Description of process	Prevalence
Induction sorting	Inductive sensors detect metals which are positively from other materials via fast air jets (“air knives”).	Uncommon.
Eddy current	Counter-rotating magnetic field repels non-ferrous metals; positively selecting them from other materials	Very common.
Drum separator (trommel)/screen	Separates material via particle size. Perforated drum or screen causes smaller particles to fall whilst larger particles remain in the drum.	Very common.
Sink-float separation	Separation of plastics based on specific weight – often in water where PET, PVC, and PS will sink and PE, PP, and EPS will float.	Very common in middle and high-income countries
X-ray	X-rays are directed at the material, which cause a unique peak in the x-ray spectrum which is detected by a camera, which is connected to an air jet,and positively selecting the materials being detected.	Useful for sorting very dirty bottles or those with large labels as it can detect through, reducing in use in favour of Near infra-red
Near infra-red (NIR)	Light shined on materials which are detected by camera based on the way the reflect that light in the NIR spectrum.	One of the most common sorting technologies used in high and, increasingly, middle-income countries. One of the drawbacks of this technology is its inability to identify black plastics against the background of a similarly coloured conveyer belt. This is a subject of much debate in Europe and has led to several attempts to intervene in the market to encourage manufacturers to either stop making it or include additives to make the plastics detectable (Waste Management World, 2017).

Source: Summary and reference Handbook of Recycling: State-of-the-art for practitioners, analysts and scientists, http://bit.ly/2xO4SNt.

3.1.3. Challenges in Sorting

The recyclers may have to contend with a number of bottlenecks peculiar to plastic waste.

Below is an outline of possible challenges recyclers must overcome at plastic recovery facilities depending on the stream composition: [8]

- Separation of films from rigid plastics, and thereafter the sorting of the films
- Detection of PET bottles covered with PVC sleeve labels
- Elimination of PVC bottles from PET stream
- Colour separation of PET for bottle to bottle applications
- Separation of multilayer bottles (e.g. PE/PA/EVOH)
- Separation of PET grade (PET-G) from bottles and trays
- Separation of black or dark plastics which cannot be sorted by NIR
- Separation of unwanted or restricted substances such as BFR and POP-PBDE
- Separation of PP filled Talc
- Separation of PAs
- More recently, separation of important polymer composite materials

3.1.4. Automated sorting technologies

In tackling these challenges, combined sorting, predominantly of automated separation technologies have proven to be handy and successful in most cases (not in all cases). Existing automated sorting machines based on optics (i.e. sensor) and density separation are being largely used by recyclers, material recovery centres and other users for this purpose. Apart from providing sorted fractions with high quality and purity levels, these technologies, are also crucial to removing materials containing unwanted substances, thus, reducing uncertainties in the composition of the target material. However, these and other existing technologies such as electrostatic based technologies have failed to completely address recycling problematics. Consequentially, attempts at numerous research works are currently ongoing to develop technologies able to tackle BFR related issues, remove all particles containing POP-PBDEs and sort black plastics with equally high and even higher yield and purity near complete close-loop levels compared to the existing technologies [5].

Sorting and separation of the collected plastic have the overall purpose to enable high quality recycling, preferably of single polymers. The sorting and separation technologies are aiming at:

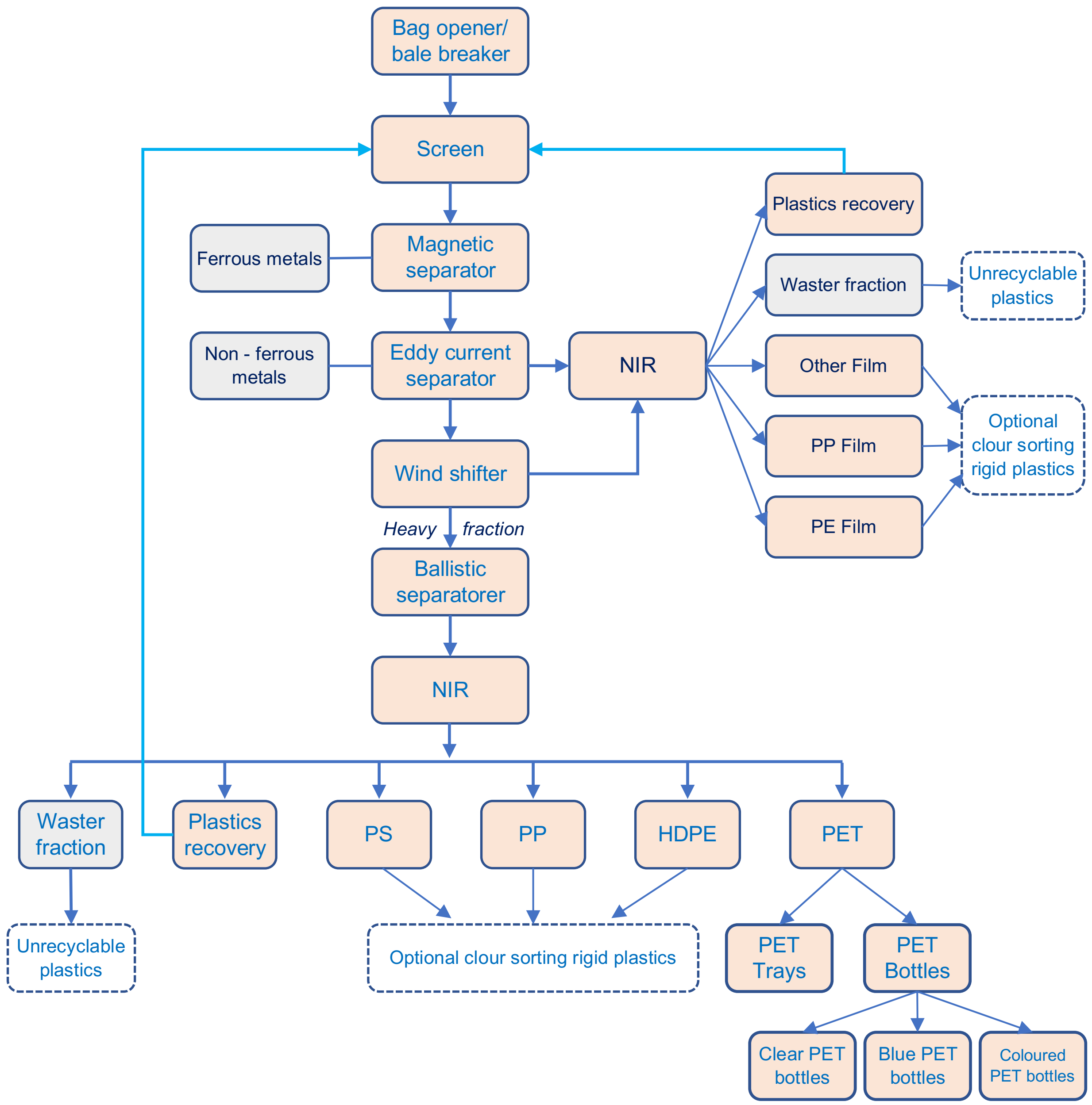
- Reducing the quantity of non-targeted plastic polymers
- Reducing the quantity of non-plastics as:
    - *Other recyclables such as metals or glass*
    - *Oil, soil or other contaminants*
    - *Additives within the plastic matrix*

Many of the technologies will typically be applied in a certain combination depending on the input material and the quality requirement for the output material. The output from the sorting plants can be single polymer or different mixes of polymer types (single colours or mixed colours). Below is presented a brief description of major types of separation technologies/equipment covering.

- Size separation
- Gravity/density separation
- Metal separation (Magnetic and eddy current separation)
- Optical/sensor separation
- Manual separation/quality control

The overall goal of these processes are simply to reduce the quantity of non-targeted plastic polymers and recyclable non-plastics such as metals, glass, and other contaminants (e.g. oil, soil, stones, and sometimes dead animals) as well as additives within the plastic matrix.

Here is the generic configuration of an advanced sorting plastics plant: [9].



(Source: COWI, 2013)

Figure 3.1. The generic configuration of an advanced sorting plastics plant

In an optimal sorting centre, plastic packaging is automatically sorted through a series of consecutive steps, refining the streams. Contamination is separated out while the material is sorted according to polymer types, and optionally by colour or product types.

First, at the sorting center, separately collected recyclable waste is uploaded to trommel /screen to sort materials by size, to increase efficiency in the next steps.

Screened packaging is later carried through metal detection and eddy current machines, which remove any ferrous and non-ferrous metals contaminating the waste streams.

The material then passes through wind shifters, which separate light fractions from heavier ones and ballistic separators, which separate 2D fractions from 3D fractions. After these steps, the material is further refined using Near-Infrared (NIR) technology.

NIR technology separates the PE film from other films and plastics in the light and 2D fractions. The rigid plastics are separated into PP, PE, PET and PS streams. These fractions represent the most commonly used polymers for packaging applications. For instance, PE film is often used for wrapping of various goods, while detergents and other cleaning products are packaged in HDPE containers.

The material can go through more than one sorting operation or be further sorted by colors and product types, for instance, PET bottles can be separated from PET trays, while clear PE film can be separated from the colored PE film. Certain applications such as food contact require very high purity levels and are guided by European quality standards; therefore, the collected material undergoes several sorting and decontamination steps both in the sorting facilities, as well as in recycling plants themselves.

Materials discharged during the sorting operation are either fed back to the system or discarded along with other contaminants.

3.1.5. Introduction to the equipment of the sorting

3.1.5.1. Technological introduction of sorting machines

Based on the generic configuration of an advanced sorting plastics plant described above, in this section we will introduce the above mentioned this equipment, including:

1) Bag-opener / Pre-shredder
2) Foil separator
3) Size separation
   - *Drum screen / Trommel screen*
   - *Vibrating screen*
4) Iron separator
5) Eddy current separator
6) Air classifier
7) Ballistic separator
8) Optical/sensor separation
   - *NIR Infrared*
   - *Colour Line camera*
   - *X-Ray Fluroscence*

3.1.5.2. 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. [3]

Figure 3.2. Photo Bag-opener

*Source: https://vseomusore.com/pererabotka-otkhodov/retsikling-eto-pererabotka-othodov-utilizatsiya-musora-ponyatie-sposoby-pererabotki-i-*otsenka-ekonomicheskoj-vygody-na-proizvodstve-i-v-domashnih-usloviyah/

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

3.1.5.3. 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 [3].

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 3.3. Photo film remover / Company Matthiessen Lagertechnik Gmbh

Source: https://www.bagsplitter.com/en/oversize-remover/

3.1.5.4. Size separation

Size separation is an operation unit that separates a mixture of materials of different sizes into two or more parts by means of screening surfaces. Size separation is also known as sieving, sifting, screening. This technique is based on physical differences of the particles such as size, shape and density. The input material for size separation equipment is often mixed municipal waste but it can also be comingled recyclable packaging waste. The size separation equipment normally performs the first primary sorting after shredding or bag opening [3]. Shredding is not always necessary.

Typically, the screen splits up the incoming waste in three fractions:

- Undersize: < 50 mm
- Middle size: 50/300 mm
- Oversize: > 300 mm

Plastics will normally appear in the middle size and oversize fractions. Middle sized 2D (2-dimentional plastic, mainly foils, plastic bags ...) and 3D (3-dimentional plastic, such as pots, tubs and trays...) normally will be further sorted in a ballistic separator and maybe also an air classifier. The oversize fraction normally continues into a manual sorting cabin for handpicking of the large 2D plastic films. Size separation equipment is widely used in sorting facilities to enhance the performance of subsequent equipment installed at the facility.

Typical types of equipment for this are:

- Drum screen / Trommel screen
- Vibrating screen

Below is shown a drum screen and a vibrating screen

(1) Trommel screen

Figure 3.4. Drum screen

Source:https://www.sutco.de/en/components/trommel-screen

One of the proven classification systems is the trommel screen. It can be used for primary screening as well as for the final screening of the material after the size reduction. Trommel diameter, rotational speed, the size of the screen openings, the type and number of baffles and the inclination of the cylinder are factors which have an influence on the input and screening efficiency. Since the effective screen area is relatively small, deflectors and other wall assemblies are installed to carry the waste as high as possible up the trommel wall in order to receive the maximum screening potential. To increase the screen efficiency rating, spiral shaped deflectors are installed on the trommel walls to transport the material through the trommel regardless of the degree of the trommel. It is also possible to classify the material in more than two fractions (up to 4) by installing different screen openings in succession inside the trommel [10].

(2) Vibrating screen

Vibrating screen is a mechanical equipment that uses vibrating screen panels to classify the mixture which contain different material according to the size of them.

Working Principle: The two motor axes of the linear vibrating screen have an angle of inclination in the vertical direction relative to the screen panel. Under the combined force of the exciting force and the self gravity of the material, the material is thrown on the screen surface to jump or move forward in a straight line. Through the multi-layer screen panels, a variety of specifications of materials are generated, and discharged from their respective outlets, so as to achieve screening and classification [10].

Figure 3.5. Vibrating screen (Source: COWI, 2013)

3.1.5.5. Iron separator

Iron separators are used when large quantities of iron scrap must be separated from other materials. Permanent magnets and electromagnets are used in this process. Iron separators can be of either the belt-type or the drum-type. In the drum, a permanent magnet is located inside a rotating shell. The material passes under the drum on a belt. A belt separator is similar except that the magnet is located between pulleys around which a continuous belt travels [3].

Figure 3.6. Picture Overband

Source: https://steinertglobal.com/magnets-sensor-sorting-units/magnetic-separation/suspension-magnets-self-cleaning/steinert-ume/

3.1.5.6. Eddy current separator

Eddy current separators are used to separate non-ferrous metals in the recycling plant. This step generally follows the primary magnetic separation process, and it exploits the electrical conductivity of non-magnetic metals.

When a feed of mixed materials is fed down the ramp, non-metallic items slide straight down, while metals are deflected sideways by the interaction of the magnetic field with the induced eddy current. The two streams are then collected separately. Variations of the eddy current separator include the rotating disc separator, in which magnets are arranged around a rotating axis. Yet another system uses a conveyor with a head pulley fitted with magnets. Both systems rely on the varying trajectories of materials either affected or unaffected by magnetic fields, to make the separation [10].

Figure 3.7. Eddy Current separator (IUT, 2010)

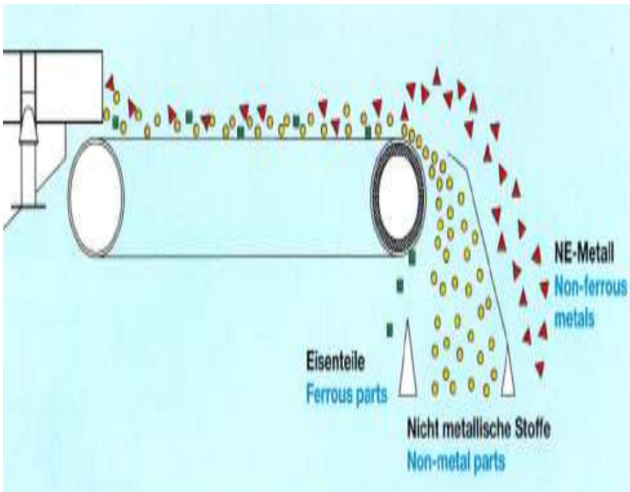


Figure 3.8. Eddie Current separator - principle of function (IUT, 2010)

Eddy current separator is applied to classify non-ferromagnetic metals such as aluminum, copper, magnesium and silver. Separators are not effective for separating zinc, brass and tin as well as stainless steel alloys.

The separation efficiencies of metal separators are shown in the table below [10]

Table 3.3.. Efficiency of metal separators. IUT, 2012

Machine	Material	Separation *(% of input)*	Output purity from dry residualwaste	Output purity from Co-mingledwaste
Magnet	Ferro-metals	85 - 95%	85 – 90%	90 - 95%
Eddy Current	Non ferro-metals	85 – 95%	85 – 92%	85 – 92%

Source: COWI - 2013 "Report on assessment of relevant recycling technologies"

An iron separator is recommended in order to extract ferromagnetic particles (e.g. bales wires) prior the washing process.

3.1.5.7. Air classifier

Separate according to materials "falling velocity" in an air stream. The function is to separate in light and heavy parts. Different types of air classifiers are available. The figure below illustrates the type of air classifier typically used for waste sorting plants [10].

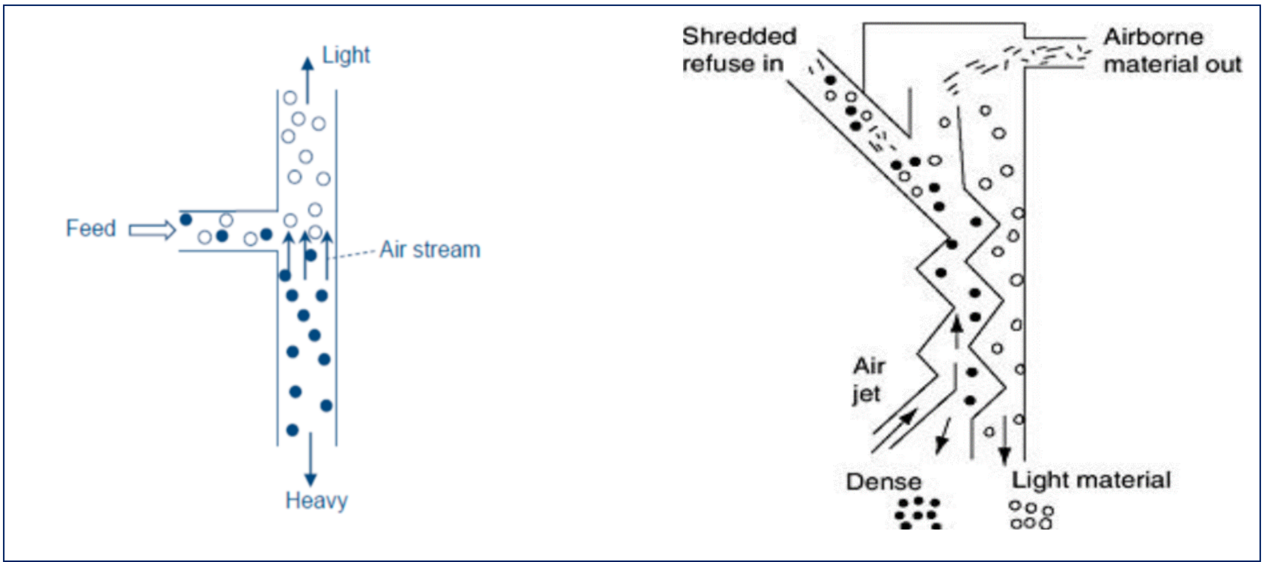


Figure 3.9. Air Classifier

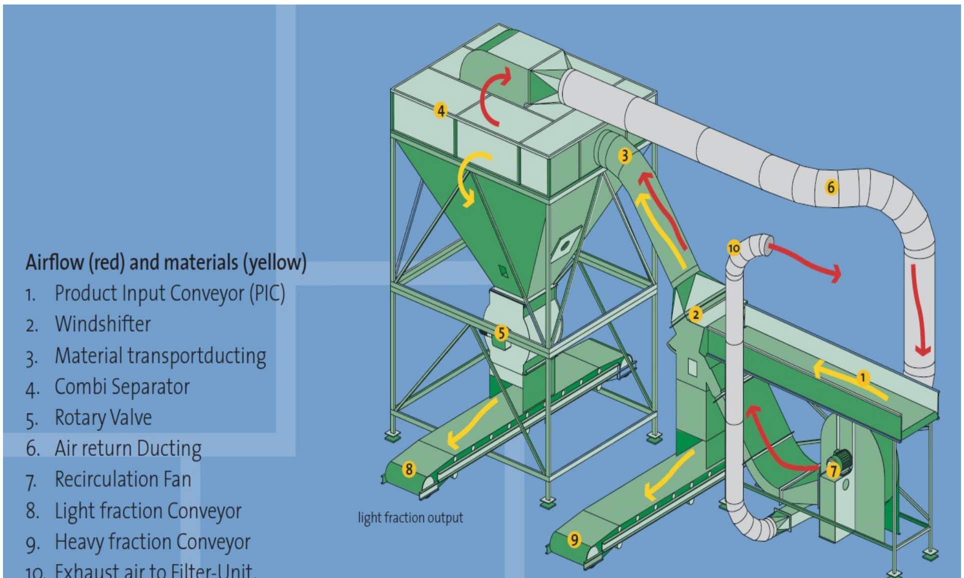


Figure 3.10. Typical air classifier

Source: COWI - 2013 "Report on assessment of relevant recycling technologies"

The particle size distribution is important for air classification of plastic packaging waste streams. Air classifiers split a material stream depending on particle size, density of the material and shape of the particle. As most plastic packaging has similar densities the splitting process can be most efficient if most of the objects have also a similar size. It is then possible to sort the waste depending on the shape of the objects, i.e. flat objects like films versus three dimensional objects like bottles.

3.1.5.8. Ballistic separator

The ballistic separators were developed for the separation of household and commercial wastes. It allows a separation into 3 fractions: fine, light and heavy. The operation of this aggregate can be described as screening classifier. The main working part of a ballistic separator is the moveable, inclined and perorated plate screen deck. The deck is divided into rows of vibrating elements and the material, depending on gravity and form, is transported up or down. The heavy parts of the waste move to the lowest level. The lighter particles (e.g. plastic foil and paper) move in the opposite direction toward the highest level of the deck. Falling through the perforated bottom of the deck, the third, fine fraction is produced [3].

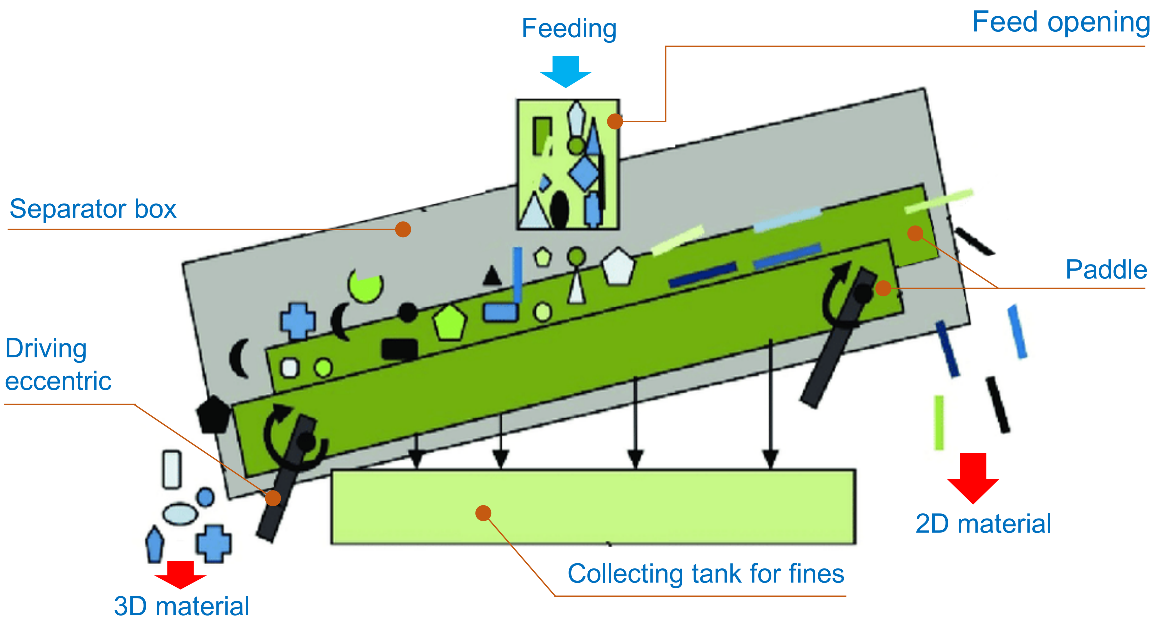


Figure 3.11. A ballistic separator (adopted from Martens & Goldmann, 2016)

2D materials are conveyed upward the paddle (e.g. Plastic Film, Paper, Textile)

Fine fractions are discharged through paddle holes (e.g. Sand, Glass Cullet, Food Garbage).

3D materials are flipped downward the paddle (e.g. PET bottle, Can, Tin, Stone).

3.1.5.9. Optical /sensor separation

The optical sensor separator consists of the following key parts: [3]

- NIR Infrared
- Colour Line camera
- X-Ray Fluroscence

The optic sensor equipment separates materials as paper, cardboard, wood, glass, electric scrap, minerals as well as individual plastic polymers (as PE (LDPE, HDPE), PP, PVC, PET, EPS and ABS) and colours. Black items can normally not be separated due to no reflection.

Among the optical techniques for plastic classification, NIR is the most widely used. IR Spectroscopy is one of the most widely used analytical techniques for identifying different types of polymers and, in some cases, different grades and/or additives within the same polymer family.

Therefore, the following presentation is for this technology only

NIR Principle

Near infrared spectroscopy is based on the analysis of a reflection spectrum whose signature reveals the structure of molecules. It is able to recognize materials. The object is illuminated and reflects a certain amount of light. This information is retrieved by a read head which sends it to a spectrometer, which breaks the light signals into different wavelengths and then sends this information to the computer that processes it and performs the calculations. The nozzles eject objects, which are sorted into two or three categories.

NIR operates in the frequency range of 14,300-4,000/cm (2500-700 nm wavelength). The light absorption is due to overtone or combination vibrations in the molecules. It is a good method to use for identification of plastics in household waste and for engineering plastics in mass consumer products, such as electronic products and tools, because there are distinct NIR spectra to be found for the common polymers in post-consumer and post-industrial waste. The identification is reliable and quick and the equipment is robust enough, without moving parts, to be operated in the dirty and vibration prone sorting industry.

Near infrared spectroscopy (NIR) is the most commercially available technology that offers effective polymer identification in less than one second (and less than 100 milliseconds in some cases) and is widely used in MSW sorting facilities for plastic packaging recycling. [REMIX Interim reports 1 and 2].

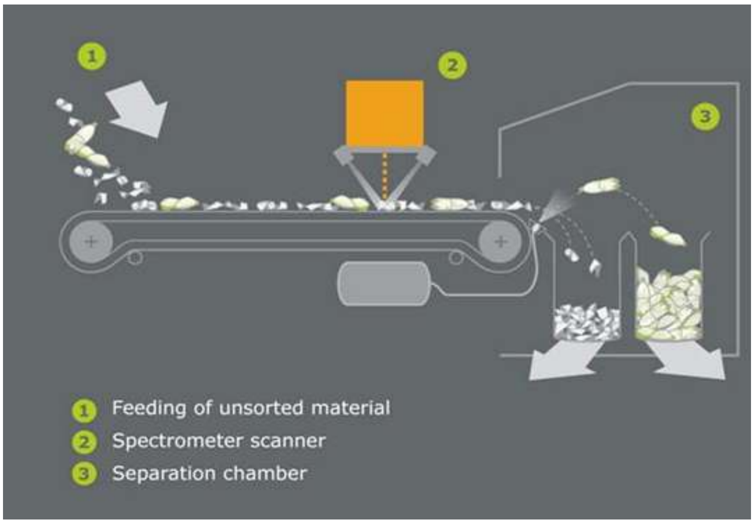


Figure 3.12. Near Infrared Spectroscopy sorting (NIR). Source: Company TiTech

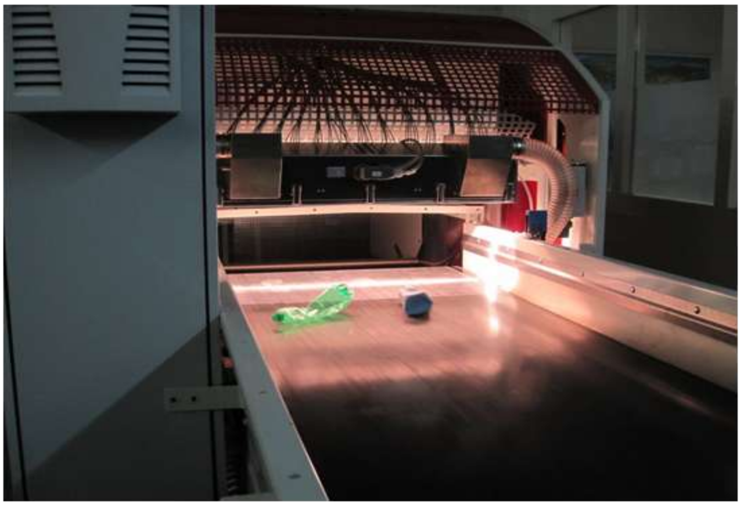


Figure 3.13. RedWawe NIR infrared sorter (Source: COWI-2013).

The NIR Infrared separator is typically applied for separation of

- Mixed plastics by polymer type (except those coloured with carbon black)
- Wood and textiles
- Paper, cardboard and packaging PVC in RDF

Near-infrared (NIR) spectroscopy can readily be used when identifying transparent or lightly coloured plastics.

- **Strength / weakness**

✓ *Strength:*

NIR is commonly used in combination with an eddy current separator for conduct a comprehensive sort of blends multi-material (e.g. packaging).

✓ *Weakness:*

Biggest weakness of NIR: high CAPEX.

The NIR does not "see" metals; the brominated flame retardants (BFR); dark, black objects, especially the parts containing carbon black. This is frequently the case parts PS. An estimated 50% of plastics in WEEE are dark gray or black. Black plastic can be separated on the basis of their color (colorimetric), but their material recognition with the NIR is not possible;

The measurement signal is performed by reflection at surface material: if a wood product is covered by plastic, it is detected as a plastic and sorting is wrong.

A problem with these spectroscopic methods is that they suffer from insensitivity when the mixed materials are contaminated by dirt and/or paint as well as by paper labels.

The size of the pieces to sort has long been a limiting factor in the use of NIR spectroscopy on plastics. The equipment does not allow for high-speed sorting of pieces smaller than 30 mm or 60mm, produced by grinding.

The plastic and paper separation efficiency of NIR Infrared separators are shown in the Table 3.4. [10]

Table 3.4. Efficiency of NIR separators for separation from input stream and purity of output stream (depending on input)

Machine	Material	Separation (% of input)	Output purity from dry residual waste	Output purity form Co-mingled waste
NIR	3D plastic	80 - 90%	80 - 90%	85 - 92%
NIR	2D plastic	85 - 92%	80 - 90%	85 - 92%
NIR	Paper	70 - 90%	75 - 90%	85 - 92%

(Source: COWI - 2013 "Report on assessment of relevant recycling technologies")

Typically, each run of NIR sorting can sort for two parameters (output fractions). Sorting into more than 3 streams thus requires more runs or more NIR scanners.

3.1.5.10. Baler

After sorting, if the waste plastics are not put into on-site recycling, a baler is required to optimize the transport weight of the material to the recycling plant as well as to minimize the storage volume. In addition, baling and wrapping minimize the possibility of a fire in the storage area and its spread.

Figure 3.14. Picture Baler / Company Bollegraaf / Picture Source: Internet

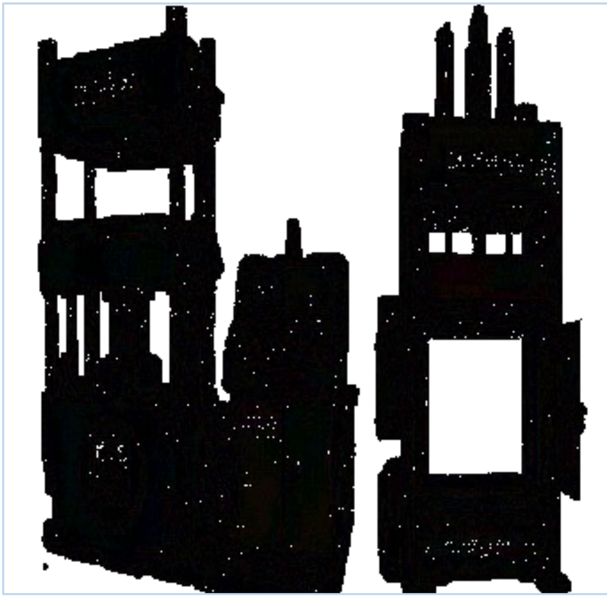


Figure 3.15. Picture Baler / Company hitech.vn / Picture Source: Internet

3.1.6. Manual sorting

As described in Chapter 2, in Vietnam, the informal labor force in the process of collection pre-sorts the types of plastic for sale to the junk shops and collecting agents (collecting center). The typical and very common pre-sorted at junk shops, and plastic collection agents are as shown below.

PET bottles are sorted at junk shops

Colored plastics of all kinds are sorted at the junk shops (HDPE, LDPE, PP,...)

Waste pickers (sellers), bottle collectors/ individual scraps trader and junk shops, (buyers) have also sorted out plastics before transport to the recycling facility

However, there may also be a lot of waste plastic mixed with many different components or types of plastic that need to be further sorted, if the factory is not equipped with sorting systems, the role of manual sorting is really necessary.

With this waste plastic line, it is necessary to be further classified before recycling

In general, manual sorting is very similar between factories depending on the source of raw materials, the purpose of sorting, and recycling.

Typical separations:

- Separate large items such as 2D plastic films, plastic foils from other plastics
- Separate different types of plastic by color
- Separation of waste plastic materials that are too large in size.
- Remove impurities or other scraps from the target plastic
- And remove impurities or other scraps from the target plastic.

The ability to perform manual grading is highly dependent on the actual objective and purity of each material, as well as the type of material being graded and sorted.

In manual sorting, occupational health and safety issues are important, some of which need attention include:

- Work in a sheltered place,
- Effective ventilation in the workplace
- Use protective gloves, masks, etc.
- Safe handling of environmental issues during classification.
- Periodic health checks, etc.

3.1.7. Proposed sorting lines under Vietnamese conditions

It is forecasted that in the near future, plastic sorting and recycling factories will also gradually apply advanced technology in waste plastic sorting to increase production efficiency and meet new and increasingly stringent requirements that manual plastic sorting cannot meet.

The following presentation proposes a number of sorting procedures at different levels that combine manual classification and automatic classification systems that can be appropriately applied under the conditions in Vietnam.

Based on these proposed classification processes, factories can also vary according to customer requirements, regulatory requirements, different types of machinery and potential suppliers.

Infrastructure, logistical and legal requirements such as weighbridges, balers, exhaust gas treatment systems, etc. not shown in these block diagrams.

3.1.7.1. Concept – Basic 1

This line combines some basic sorting machines and manual labor.

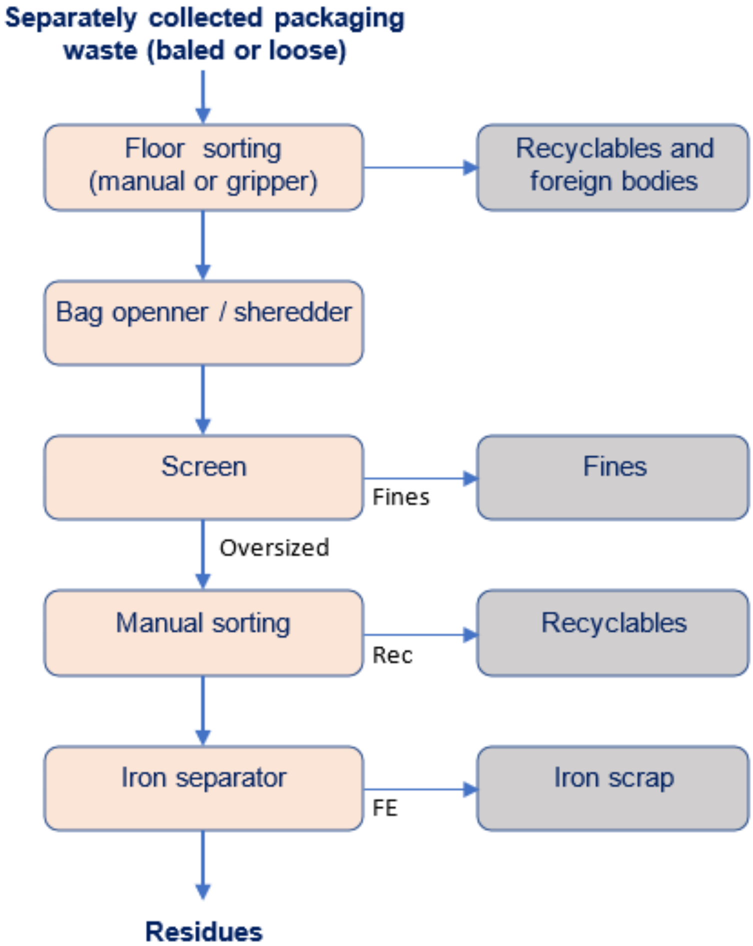


Figure 3.16. Block diagram - Sorting concept basic 1

3.1.7.2. Concept – Basic 2

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.

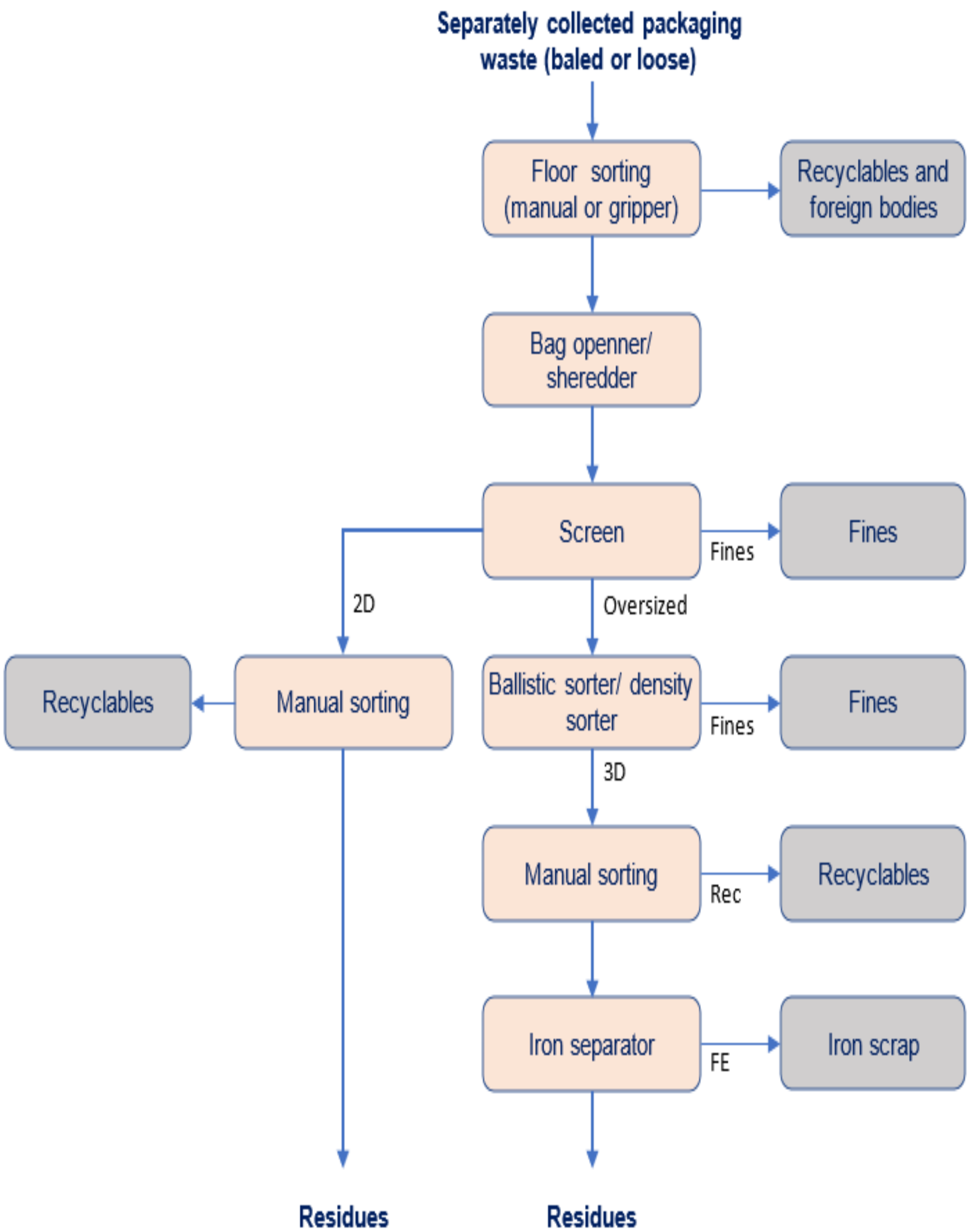


Figure 3.17. Block diagram - Sorting concept basic 2

3.1.7.3. Concept – Advanced

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

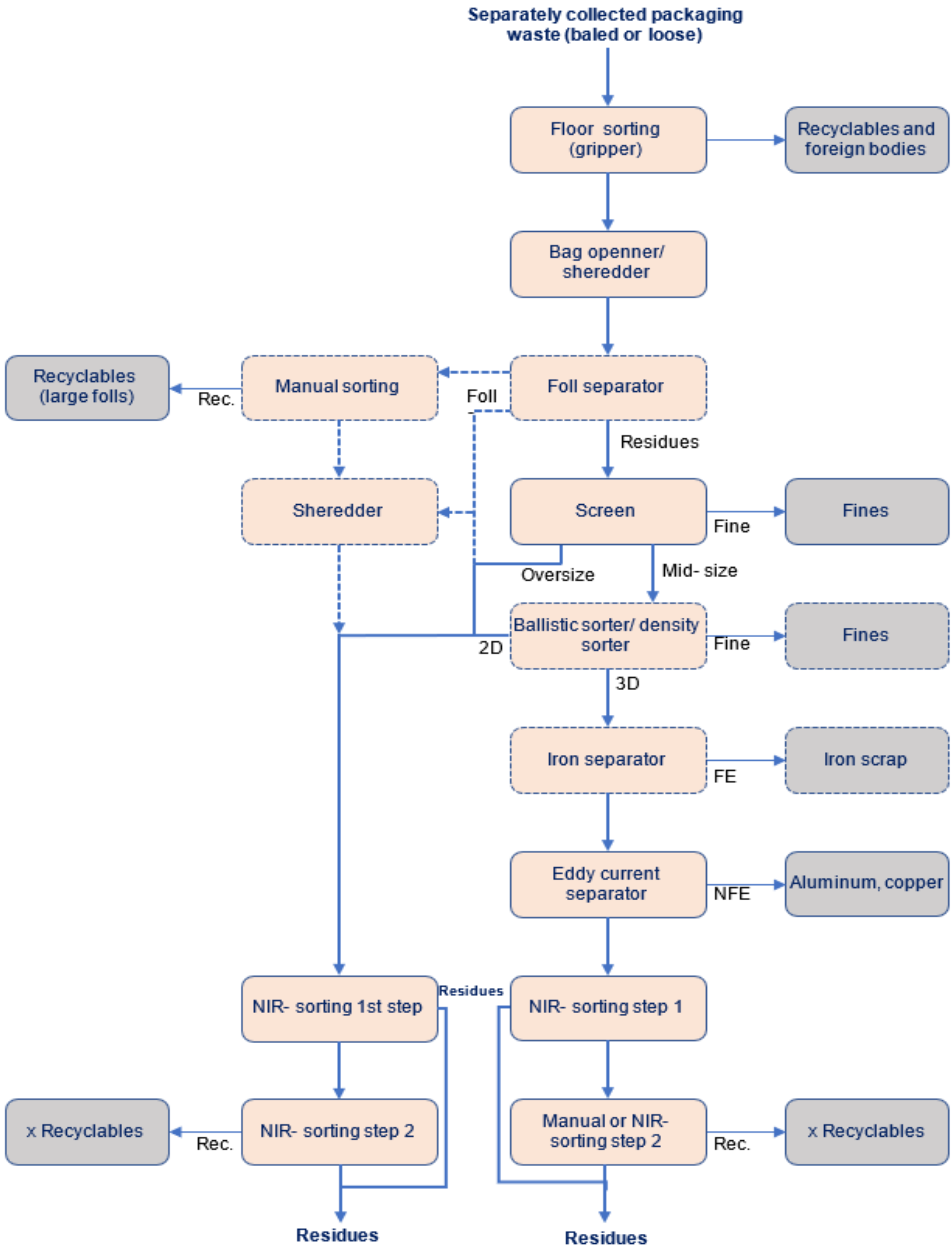


Figure 3.18. Block diagram - Sorting concept basic 3

3.2. RECYCLING

3.2.1. Introduction of recycling equipment

This section describes the following recycling equipment:

1. Pre-shredding
2. Iron separation
3. Shredder
4. Granulator
5. Pre-washing
5. Grinding
6. Intensive washing
    - *(6.1)* Sink-float tank
    - *(6.2) Hydrocyclones*
    - *(6.3) Friction washer*
7. Hot wash
8. Mechanical drying and thermal drying
    - *(8.1) Mechanical Dryer*
    - *(8.2) Thermal Dryer*
9. Extrusion

3.2.1.1. 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.

3.2.1.2. 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.

3.2.1.3. Shredder

a) **Function:** shredded to reduce size and homogenize material [11]

The shredder can be used stand-alone and the produced flakes can be sold directly to the plastic industry.

Applications: LDPE, HDPE, PP

b) Machine construction

The main parts of the Shredder:

c) Key features [11]

- The Shredder has diameter profiled rotor made of solid steel.
- Operating with low speed, high torque geared drive

- The concave ground, aggressive 4-way rotating knives are mounted in the grooves of the profiled rotor with special knife holders. This enables a reduction of the cutting gap between the counter knives and the rotor which guarantees a high flow rate, low power consumption and maximum output of shredded material
- The hydraulically operated ram feeds the material automatically in the rotor's cutting chamber by load-related controls. The hydraulic system is equipped with high-pressure valves and volumetric flow controls which can be set according to the requirements of the input material
- Extremely robust pedestal bearing housings are mounted outside the machine and separate to the cutting chamber to prevent dust and dirt penetrating into the oversized bearings. This ensures a long service life andminimum service and maintenance
- Power is transmitted from the motor by a drive belt via an oversized gearbox which islocated on the shaft end on one end of the roto
- A safety switch prevents machine startup when the front panel is open and the machine features emergency stop buttons on the machine body and control panel.

3.2.1.4. Granulator

a) Function:

Granulators reduce material to a much smaller size than shredders, with dimensions of 0.2mm or less.

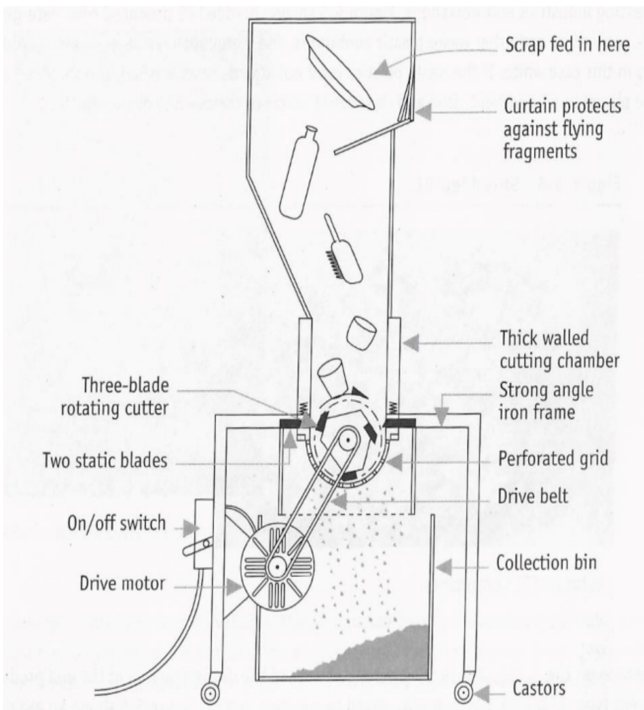
Applications: plastics films / plastic bottles / thin walled hollow plastics / thin walled plastic components

b) Machine construction

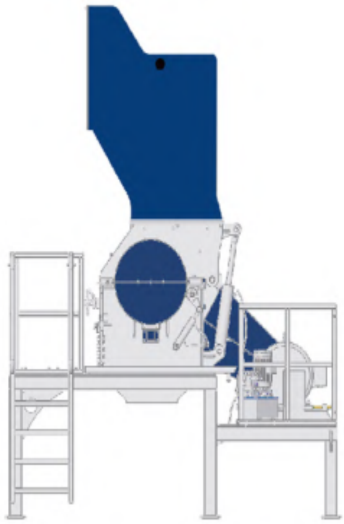
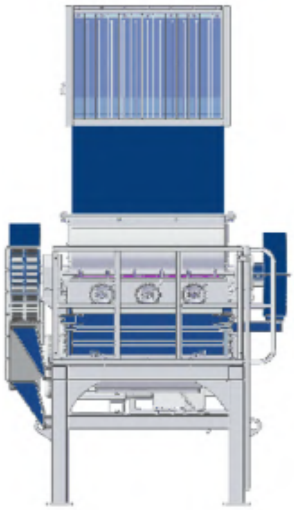
- ***Small capacity machine series*** [12]

Production capacity: 50 to 350 kg/h

Mechanical power: 5.6KW to 22.4KW



- ***Large capacity machine series*** [11]

c) **Key features** [11]

• Anti-wear machine housing • Ladder blade rotor configuration for films and hollow plastics • Suitable for wet and dry granulation • Heavy duty bearings • Oversized external bearing housings • Knives are externally adjustable • Robust welded steel construction • Wide choice of rotor variations • Electrical hydraulic control to open housing • Replaceable wear plates • Amp meter control	***OPTIONS*** • - Extra flywheel • - Double infeed hopper • - Roller feeder • - Mounted screw feeders in hopper • - Winding protection • - Metal detector • - Metal separator • - Bespoke colour scheme • - Increased motor drive

3.2.1.5. Pre-washing/density separation

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 and separation 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 and separation system is usually based on the swim-sink-principle, i.e. on the separation according to the difference of the specific density of polymers 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 [3].

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 3.19. Photo Pre-Wash (Swim-Sink)

Source: https://www.alibaba.com/product-detail/High-Quality-Waste-Plastic-Washing-Recycling_62230096950.html

Figure 3.20. Photo Pre-Wash-Drum

Source: https://www.plasticrecyclingmachine.net/trommel/

3.2.1.6. 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 3.21. Photo Wet Granulator

Source: https://www.indiamart.com/glow-plast-machines/grinder.html#13671328188

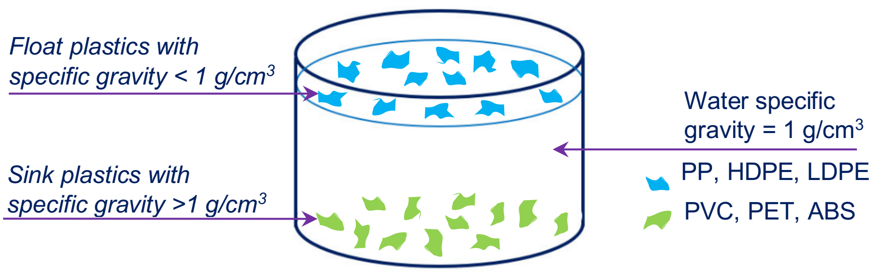
3.2.1.7. Intensive washing

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

- *Swim sink tank /* sink-float *tanks*
- *Hydrocyclone*
- *Turbo washers / Friction washer*

(1) Swim-sink tanks / sink-float tanks

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 [13].



In the sink-float separation the plastics are in a fluid that has a density in-between the materials making it possible for less dense materials to float and the heavier to sink. Different plastic materials can be separated from each other resulting in a purity of up to 98 % for mixed plastics. The difference of density to allow good rate of separation is around 0.2 g/cm. Common fluids used are: water (for separation of polyolefins from other plastics). Float tanks can be arranged in a series, with each tank set at a desired specific gravity to sort the materials. Pumps provide circulation and direct the flow [13].

Table 3.5. Lists the density of the base resins of those plastics classified by SPI RICs

Plastic Symbol	Name	Density/g/cm^3	Uses
5	Polypropylene	0.90 - 0.92	Yogurt cups, plasticware
4	Low Density Polyethylene	0.91 - 0.93	Squeezable bottles
2	High Density Polyethylene	0.94 - 0.96	Milk bottles, bags
6	Polystyrene	1.03 - 1.06	Egg cartons, packing peanuts
1	Polyethylene Terephthalate	1.35 - 1.38	Water bottles
3	Polyvinyl Chloride	1.32 - 1.42	Cling wrap
7	Often Polycarbonate or Acrylonitrile butadiene styrene (ABS)	1.3 1.06	Auto body parts

A sample of density properties of different polymers and their floatability in different solution media usually utilized in density separation technologies is as seen in Table 3.6 below.

Table 3.6. Floatability sample of plastics in various solution media

Plastic	**Plastic Number**	**Alcohol Solution** 0.9 g/cm^3	**Water solution** 1 g/cm^3	**NaCl solution** 1.1 g/cm^3	**$CaCl_2$ Solution** 1.3 g/cm^3	**Literature value for plastic density** g/cm^3
PET	1	Sink	Sink	Sink	Float	1.31
HDPE	2	Sink	Float	Float	Float	0.96
PVC	3	Sink	Sink	Sink	Sink	1.4
LDPE	4	Sink	Float	Float	Float	0.88
PP	5	Float	Float	Float	Float	0.86
PS	6	Sink	Sink	Float	Float	1.05

(Source: Siena Green Chemistry Summer Institute)

Note: The use of filler especially in plastics bags (retail or household) is leading to higher densities and even a PE waste could be mistaken for PVC.

Figure 3.22. Swim sink tank

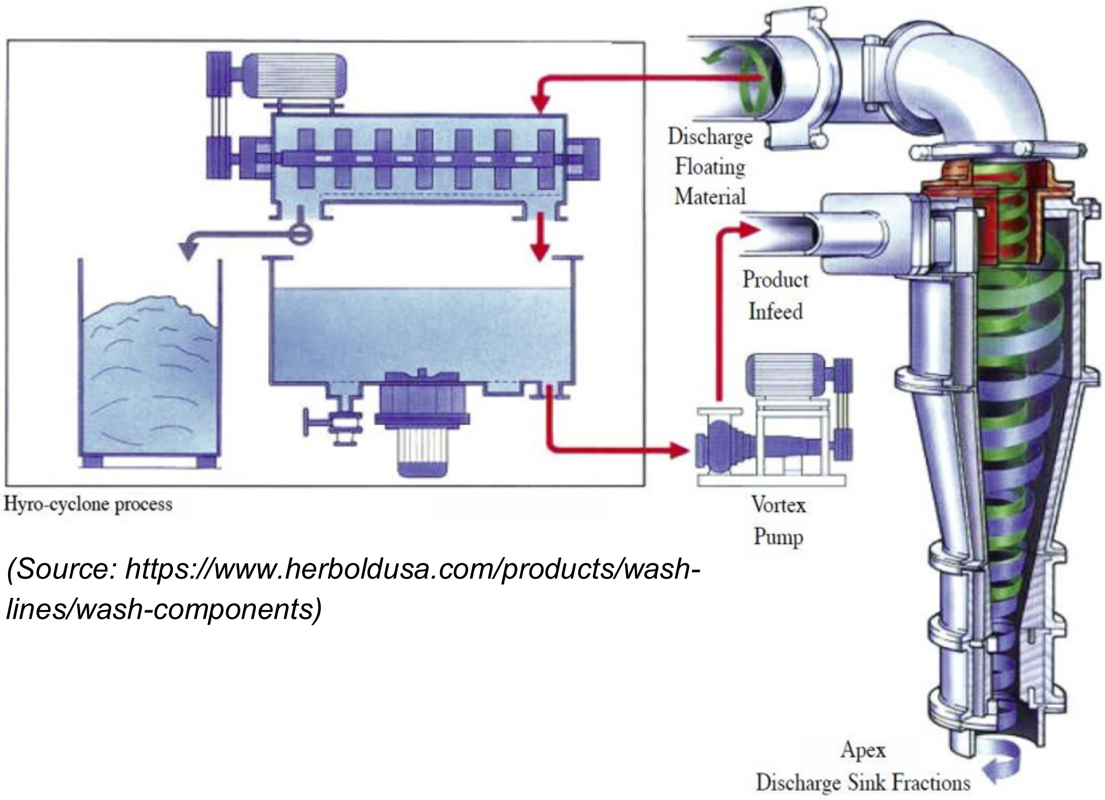
(*Source: https://www.bub-anlagenbau.de/products/)*

Figure 3.23. Sink-float tank in a PET bottles recycling line (Courtesy of OCI GmbH)

(2) Hydrocyclones

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 [3].

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.



(Source: https://www.herboldusa.com/products/wash-lines/wash-components)

Figure 3.24. Picture Hydrocyclone / Company Herbold Meckesheim

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

(3) Flottweg Sorticanter

Flottweg Sorticanter is a waste plastic sorting equipment using innovative centrifugal technology [14].

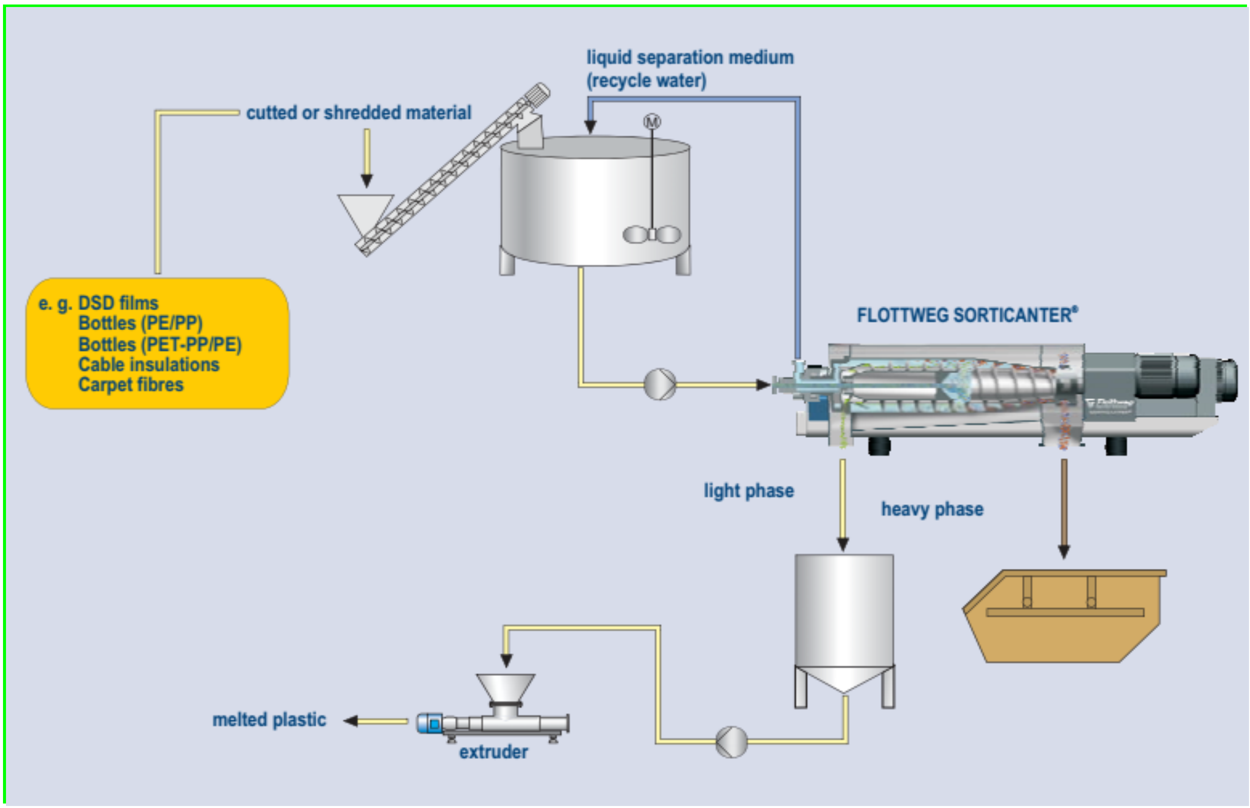


Figure 3.25. Photo Flottweg Sorticanter

Source: https://www.flottweg.com/fileadmin/user_upload/data/pdf-downloads/Sorticanter-EN.pdf

The same principle is also used in a centrifuge. In the container, separation is by gravity (1 g), while in a centrifuge the plastics are separated by centrifugal force (a multiple of the earth's gravity). Sorting in a centrifuge is therefore much faster and the sorted plastic phases are much drier. The "heavy" plastic phase is centrifuged onto the bowl wall and from there conveyed by the decanter scroll to the discharge (heavy phase). The "light" plastic collects on the liquid. The liquid flows off along the scroll and takes the light plastic particles with it. A special scroll design ensures that even the light phase is conveyed in the direction of the solids discharge (light phase) and dehumidified. The liquid runs off under pressure via an impeller.

Before the sorting process, the raw material is shredded to a particle size between 2 and 16 mm, and then washed of adhering impurities (e.g. paper labels). The shredded and pre-cleaned material is then mixed with the carrier liquid, which is also called a liquid separation medium, in specially developed homogenization tanks. Next, the homogenized suspension is fed via a static feed pipe into the rotating bowl of the Sorticanter where it is accelerated to the circumferential speed of the centrifuge bowl.

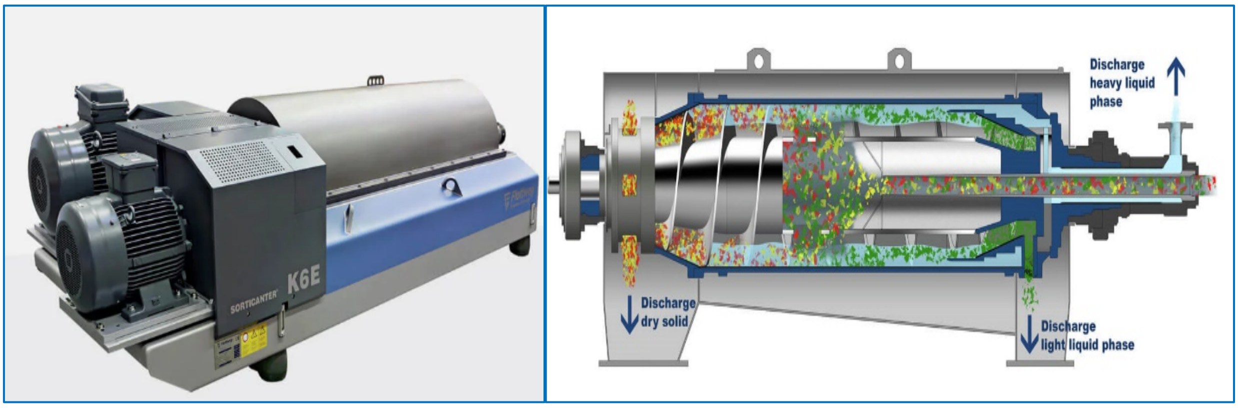


Figure 3.26. Photo Cross-section of a Sorticanter

Source: https://www.flottweg.com/product-lines/sorticanterr

Advantages of the Sorticanter in comparison to other equipments

- High separation efficiency and capacity
- Separation of substances that cannot be separated via static separation
- No air bubbles or other effects interfere with the separation
- Minimal manpower requirements
- Operating times of more than 8000 hours per year
- Limited consumption of freshwater - Minimal waste water production
- Closed design which reduces odor emissions

(4) Friction washer

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[3].

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 3.27. Photo Friction Washer

Source: https://www.herboldusa.com/products/wash-lines/wash-components/friction-washer

3.2.1.8. Hot wash

Figure 3.28. Photo Hot-Wash

Source: https://www.bub-anlagenbau.de/products/washing/plastic-hot-washer

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 [3].

3.2.1.9. 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 [3].

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

Figure 3.29. Photo Mechanical Dryer (Centrifuge)

Source: https://www.bub-anlagenbau.de/products/

Figure 3.30. Photo Thermal Drying

Source: https://www.bub-anlagenbau.de/products/drying/thermal-dryer

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.

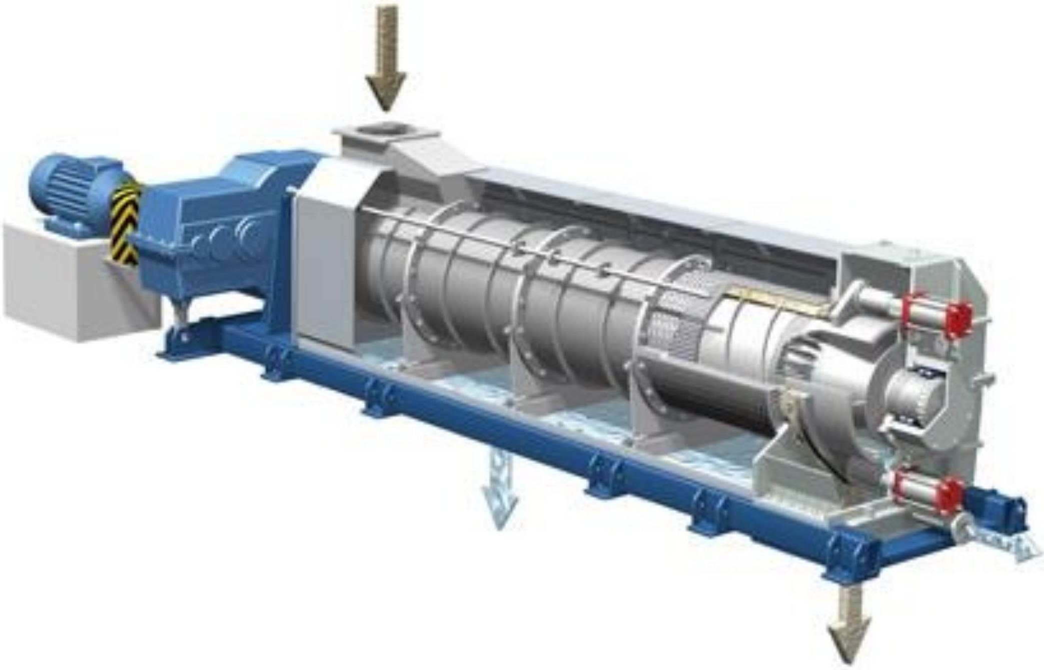


Figure 3.31. Photo Screw Press

Source: https://www.andritz.com/products-en/group/pulp-and-paper/pulp-production/kraft-pulp/pulp-drying-finishing/dewatering-machines-fiber

3.2.1.10. Extrusion

Extrusion is the foremost method used in mechanical recycling industries to produce regranulated material from the common waste plastics. The advantage is that it can be produced with large-scale, solvent-free, and applicable to many polymers.

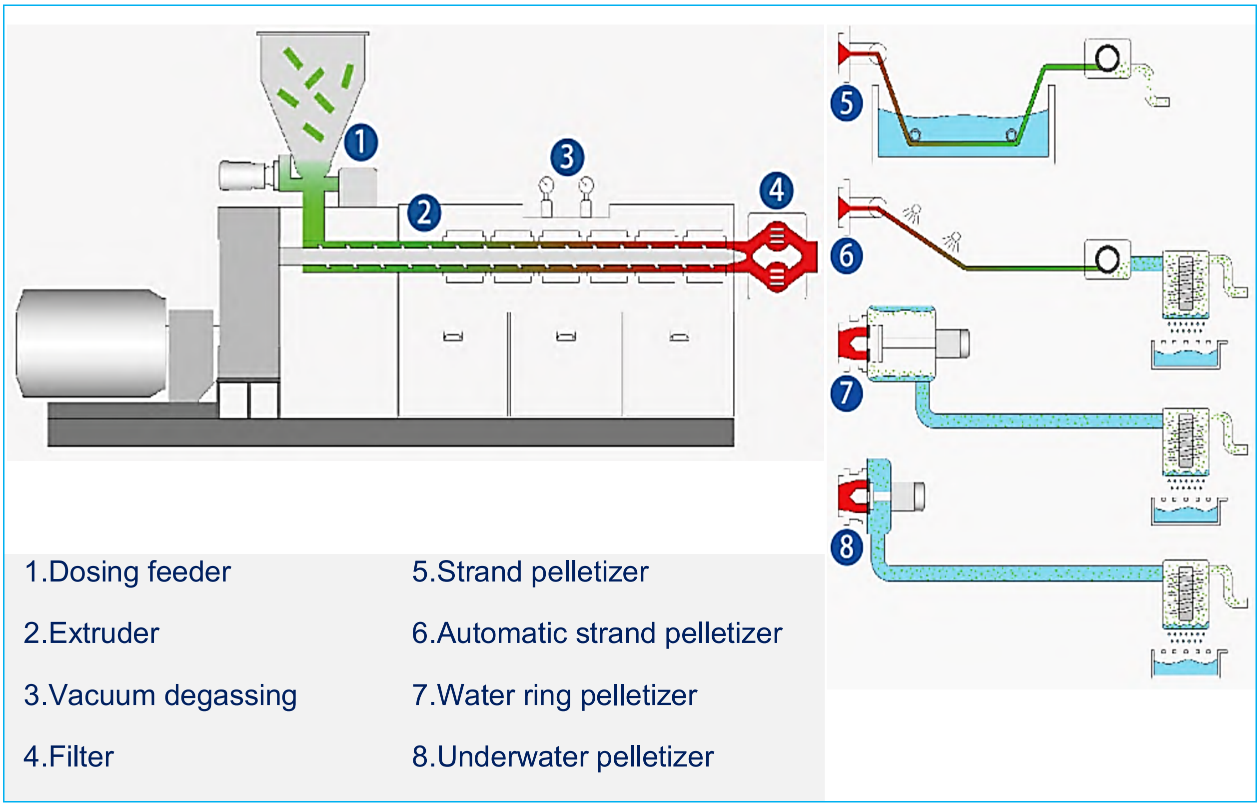
An extruder uses heat and rotating screws to induce thermal softening or plasticization, after

which it is fed through temperature-controlled barrel sections to produce fixed cross-section extrudate.

a) *Extruder construction*

The extrusion process consists usually of following components [11]:

- Dosing feeder
- Extrusion including:
  - Extruder screw
  - Melt filter
  - De-gassing
  - Die-face (Pelletizer)



Source: https://www.kitechpm.com[11]

b) *Description of the activity* [3]

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 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.

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

c) Some issues to note in the extrusion

- Melting temperature of different types of plastic is different, so it is necessary to know the melting temperature parameters of each type of plastic in order to choose the right extruder and operate it in compliance with the design requirements. The following figure depicts the melting temperature ranges of common plastics [6].

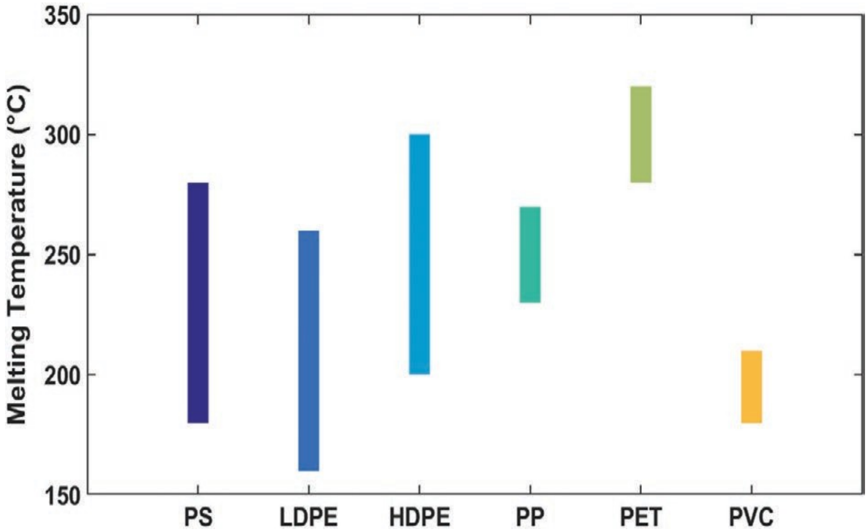


Figure 3.32. Melting temperatures of common plastics

- In the extrusion process, Environmental oxygen has the ability to penetrate and react in the polymer chain leading to thermal oxidation (degradation reactions) that makes the material susceptible to degradation, so a degassing unit is necessary during the extrusion process.
- In the extruder, there is an extruder filter design to improve the quality of the melted polymer, but this filter can only filter dust, dirt or gel particles, but cannot filter foreign polymers. Efficient plastic sorting is therefore the key to efficient recycling.

d) Some improved features in current new models

Nowadays, polymer recycling has been further improved with innovation in extrusion technology. Extruders can be built to include:

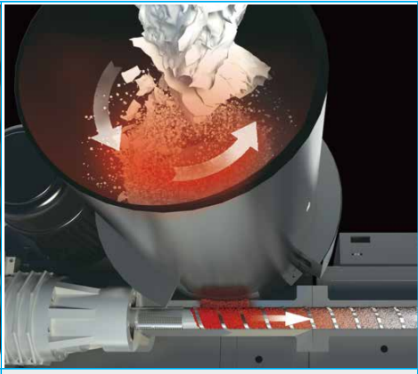
- Extruded plastic filter to improve melt polymer quality. The polymer melts through the filter to remove larger, non-volatile contaminants, such as dust or gel particles, and improve mixture uniformity, mechanical and optical properties. Melt filters are selected according to the specific extrusion contamination and can include: Sliding Plate Filters, Filter with dual channel system, Dual Piston Filters described in the next section.
- Vacuum degassing or open vent on the extruder allows release of some volatile compounds in the melted polymer. The removal of volatiles minimizes hydrolysis; reduces acid breakdown and improves the odor of the melted polymer, increasing the value of the recycled plastic.

In addition, the extrusion system is made flexible in operation such as:

- The stages are operated on an extrusion system including: cutting + extrusion + pelletizing
- Easy installation in disassembly, operation and maintenance
- Flexible operation settings can be made between different materials

The following section describes some of the improved features mentioned above

► *Feeding quickly into the agglomerator and into the extruder feeding area*[15]



Dosing feeder unit

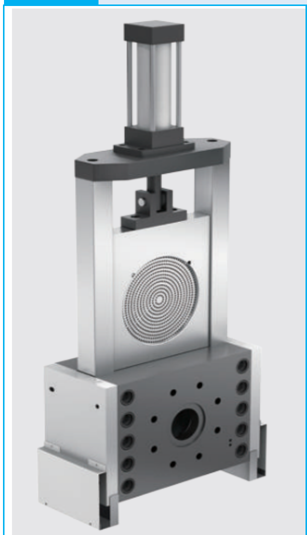
- Frequency control belt conveyor or screw conveyor are optional as loading device according to different material form.
- Ferrous and nonferrous metal separating at feeding unit, which provides efficient protection of the whole line.
- Dosing feeder with PLC intelligent controller, which ensures.

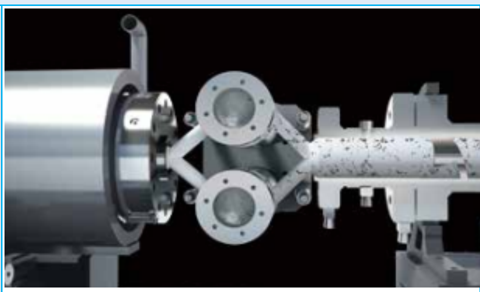
Cutting & Compacting

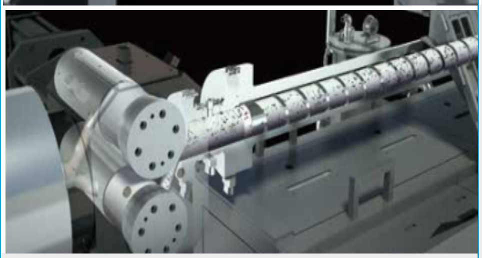
- Very fast and stable feeding from the compactor directly into the extruder.

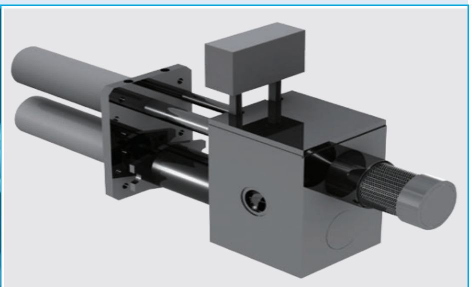
- Smart feeding system designed for different material types and forms.
- Efficient processing of material from light to heavy.
- Cutting, mixing and preheating the material and feeds it into extruder by centrifugal force.

► *At the outlet of the extruder, the melted plastic leaves the screw and passes through Filtration to remove any impurities in the melting process*[15]









- Plate Filter: The mesh can be re-used after cleaning up

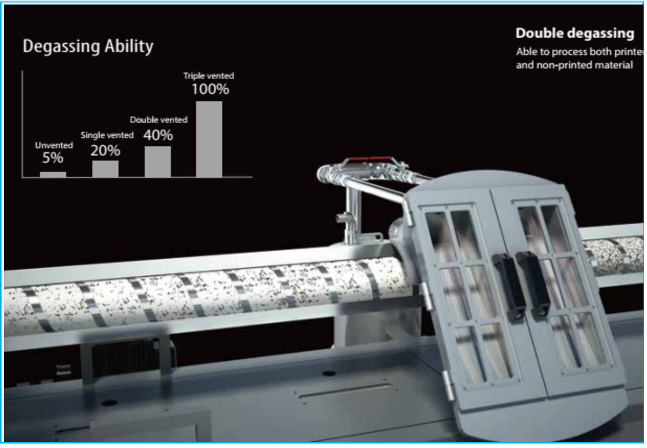
- Filter with dual channel system For non-stop operation and reduces machine down time

Dual-Piston Filter

The dual-piston screen changer is made in a continuous style with two filter flows. There is at least one filter working when the screen is changing. The piston moves slowly when the is changed. This allows the polymer melt to be filled in the filter area gradually to ensure low fluctuation of the extrusion pressure

► *The extruder is equipped with a degassing unit (1 or 2 steps) to remove unwanted gases and moisture*[15]

Advanced technology: Triple degassing.
In addition to the double degassing in the first extruder, the venting area (the connection between the first and second extruder) serves as a third degassing section to further remove the ink and extra humidity level from the material.

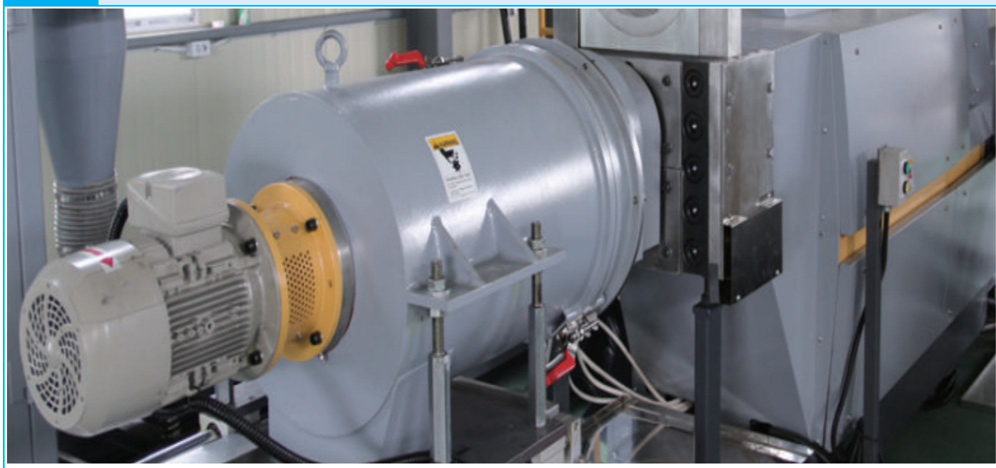


► *Controller: activity monitoring and measurement data connection*

Intelligent control unit

- PLC intelligent control system available for remote diagnosis, control and monitoring to ensure that all user's systems can be updated
- Weighing and metering system, All data can be connected to ERP system for quantitative assessment.

► *Hot Die Face Pelletizing System*



- Applicable Materials: PE, PP, PS, and more
- The molten polymer from the extruder is passed to the die head. A rotating blade cuts the hot material as it exits the die hole and falls into a water ring for cooling.
- The cutter adjusts the blade automatically during operation.

► *Introduction of a typical extruder system*[16]

1. Belt Conveyor
2. Metal Detector
3. Nip Roller
4. Cutter Compactor
5. Main Extruder
6. Degassing Section
7. Filtration System
8. Pelletizing System
9. Vibrating System
10. Dewatering System
11. Storage

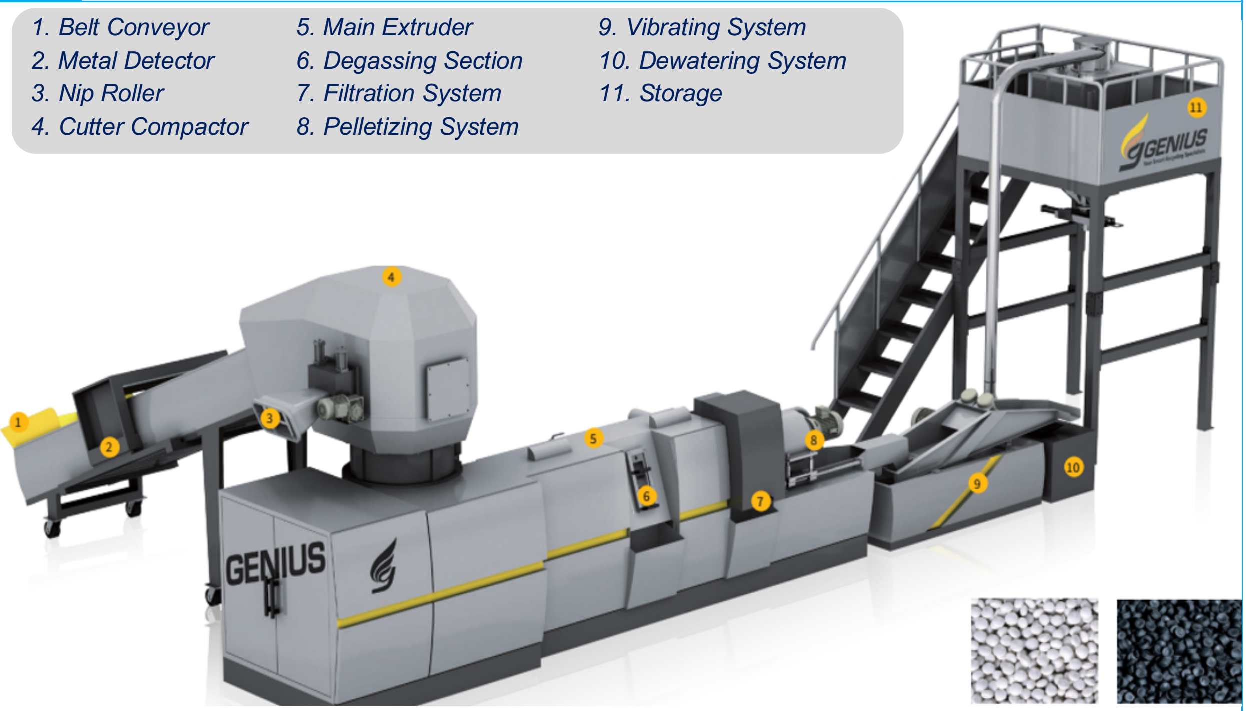


Figure 3.33. Picture Extruder

Source: https://www.geniusplas.com

3.2.2. Proposing Plastic Recycling lines

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

3.2.2.1. Concept - LDPE//FILM Recycling Line

At LDPE//FILM film recycling facilities, the Line can be customized depending on the quality of the input materials, production needs, or customer needs. In general, the proposed LDPE/ film recycling line diagram is as follows:


Feeding
Shredding
Screw feeder
Floating washing
Friction washing
Fine washing
Squeezing
Thermal drying
LDPE flakes
Feedi Buffer/ Silo
Extrusion
Plastics granulates

3.2.2.2. Concept - Rigid Plastic (PP, HDPE) Recycling Line

In general, the proposed Rigid Plastic (PP, HDPE) recycling line diagram is as follows:

3.2.2.3. Concept - PET Recycling Line

In general, the proposed PET recycling line diagram is as follows:

CHAPTER 4

LEGAL COMPLIANCE AND ENVIRONMENTAL PROTECTION MEASURES IN PLASTIC WASTE RECYCLING INDUSTRY IN VIETNAM

4.1. LEGAL REGULATIONS ON ENVIRONMENTAL PROTECTION FOR PLASTIC RECYCLING FACILITIES IN VIETNAM

PROJECT PREPARATION	PROJECT IMPLEMENTATION	OPERATION OF THE PROJECT
- Investment Certificate, Business License; - EIA Report - The Decision Approving the EIA	- Adjust the Investment plans (if there is a change) - Adjustment of EIA - Public posting on environmental management plan - Establishment of environmental protection measures and performance of environmental protection works according to approved EIA. - The certificate of completion of environment protection works, Report on performance of environment protection works serving the operation phase - Make an application for an environmental permit	General report on environmental protection related to: - Environmental monitoring. - Hazardous waste management - Solid waste management - Compliance with environmental protection regulations for wastewater, emissions, solid waste, noise, vibration ... - Declare and pay environmental protection fees for wastewater

Requirements on environmental protection and responsibilities of Institutes and individuals importing scrap from abroad as raw production materials.

Institutes and individuals may only import scrap from abroad as raw production materials for their investment projects or production facilities and must satisfy the requirements for environmental protection according to the following regulations:

1. Having a production facility with technology and equipment for recycling and reusing scrap that meets environmental protection requirements as prescribed.
2. Having technology and equipment to handle impurities accompanying imported scrap up to environmental technical standards. In case there is no technology or equipment to treat impurities attached, it must be transferred to a unit with appropriate functions for treatment.
3. Ensure conditions for warehouse or storage yard for imported scrap as prescribed.

Source: Article 45, Decree 08/2022/ND-CP

4.2. WASTE STREAMS IN THE PROCESS OF PLASTIC RECYCLING

In this section, plastic recycling technologies and processes are described and indicate the risks associated with human health and the environment, as well as the potential to improve this situation.

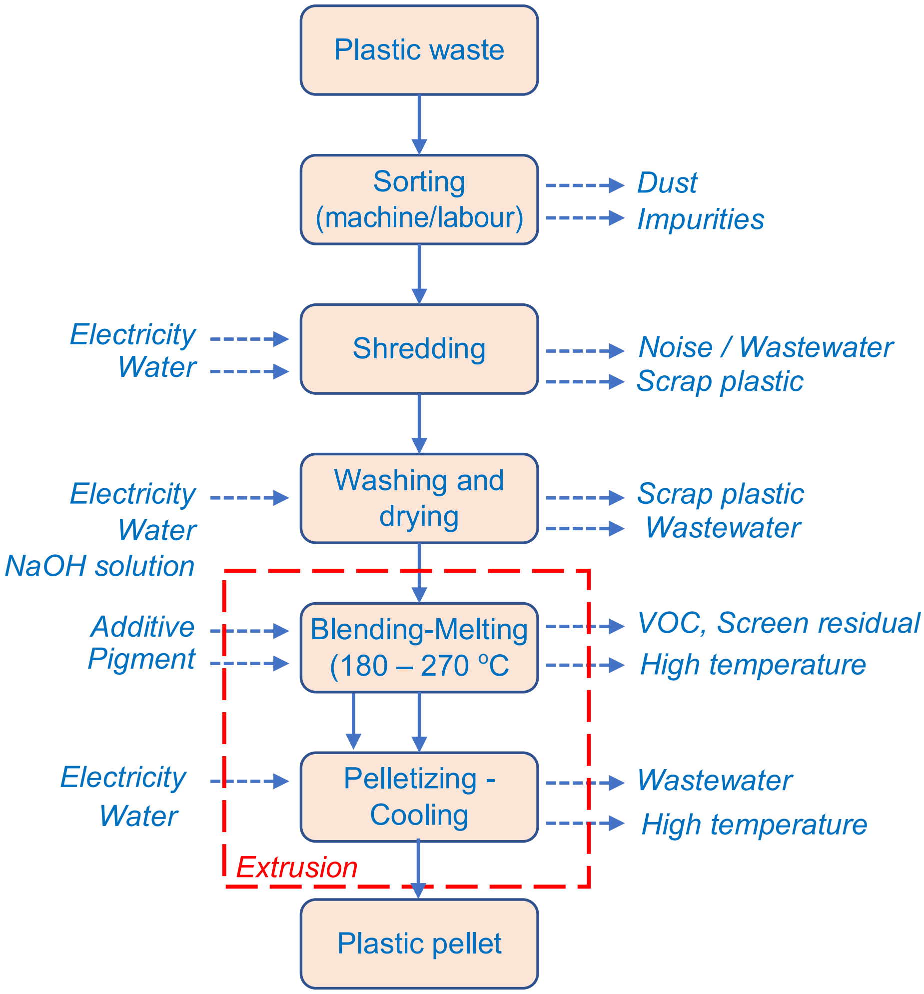


Figure 4.1. Flow chart of the plastic pellet production process with energy and waste stream

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4.2.1. Microclimate conditions in the working environment

The microclimate at plastic processing and recycling facilities is often hot and humid due to the climatic conditions in Vietnam. Especially in small and medium-sized factories with limited production area, ventilation is not suitable.

The survey results of the National Institute of Occupational Safety and Health of Vietnam (NIOSH VN) [18] show that:

(1) The working environment temperature at plastic recycling factories is distributed in the range of 30°C to over 38°C.

The average temperature at the stages of material control, shredding, heating of molten plastic - extrusion, and cooling of plastic are all higher than the allowable exposure limit of workers according to QCVN 26: 2016 / BYT about (0.3 to 1.9) °C. Therefore, these workshops need mechanical ventilation or insulation of heat-generating equipment to reduce the working environment temperature.

(2) For heat radiation intensity, only working positions (VLVs) in raw material warehouses have radiation intensity that meets Standard 5508:2009 on requirements for microclimate conditions at work, all remaining VLVs exceed the Allowable Standards, a level higher than the limit of heat radiation intensity by area of contact for the average type of worker at their workplace from 0.3 to 11, 4 W/m2

Table 4.1. Microclimate factors in plastic recycling plants

Working place	Temperature (°C)	Humidity (%)	Wind speed (m/s)	Heat radiation (W/m^2)
	Mean (SD)			
Checking and counting materials	33,4 (2,32)	59,6 (3,44)	0,303 (0,051)	75,4 (19,8)
Shredding	32,3 (1,73)	62,7 (4,59)	0,336 (0,092)	81,1 (15,1)
Melting Extrusion - Cooling	34,9 (2,03)	63,0 (1,58)	0,343 (0,071)	75,5 (28,7)
Cooling for plastic	33,6 (1,35)	57,3 (2,69)	0,771 (0,556)	75,9 (21,5)
Pelletizing	33,2 (0,961)	62,5 (4,61)	0,321 (0,175)	81,4 (12,2)

Note:
SD: Standard Deviation is a statistical tool that measures the dispersion of a data set relative to its mean and is calculated as the square root of the variance.
- Mean: average value.

In general, the microclimate in the working environment at plastic recycling facilities is often higher than the allowable exposure limit, so there is a need for improvement solutions, which will be presented in section 4.3.1.

4.2.2. Dust

Dust generated from classification stages such as dry screening, shredding or crushing.

Table 4.2. Average concentration of dust in the working environment

Region / **Parameter**	North	South	Central region	Mean value	**QCVN 02 : 2019/BYT (*)**
	Mean (SD)				
Total dust (mg/m^3)	1.36 (0.937)	0.866 (0.428)	0.887 (0.795)	1.04 (0.722)	2-8
Respiratory dust (mg/m^3)	0.621 (0,444)	0.371 (0.184)	0.428 (0.333)	0.466 (0.334)	1-4

(*) QCVN 02: 2019/BYT - Limits on working shift exposure (TWA) - depending on the type of dust source

The survey results of VN NIOSH showed that the average total dust of the plastic recycling industry was 1.04 ± 0.722 mg/m^3, and the average respiratory dust concentration was about 0.466 ± 0.334 mg $/m^3$ are all within the normal dust exposure limits as prescribed in QCVN 02:2019/BYT. However, to prevent risks and protect workers' health, the investor needs to equip them with more labor protection tools.

4.2.3. Emissions

In industrial plastic recycling facilities, VOCs, Vilnyl Chloride, and PolyBrominated Diphenyl Ether (PBDE) commonly generate from the extrusion process to create plastic granules. Under high temperature conditions of 180 – 270 °C, even 290 °C with PET plastic, molten plastic and additives are chemically and mechanically decomposed by shear force - friction force. The results of measuring VOCs from 15 facilities and recycling plants are shown in the following table.

Table 4.3. Average concentration of VOCs in the working environment

Stage \ Region	**Benzen** mg/m^3	**Toluen** mg/m^3	**Xylen** mg/m^3	**Vinyl chloride** mg/m^3
	Median [Min, Max]			
Washing	0.057	0.164	-	-
Shredding / Crushing	0.122 [0.122; 0.122]	0.173	-	-
Feeding	0.484 [0.087; 0.628]	0.216	39.5 [30.8; 48.7]	-
Extrusion: (Melting – Stringing) Pelletizing	0.867 [0.068;0.992]	-	25.0 [12.7;27.5]	0.05 [0.02; 34.5]
	0.972 [0.058; 1.41]	0.0670	55.7 [31.5; 89.2]	5.2 [0.06;10.6]

(Source: VN NIOSH -2021)

Note:
Median: The median value is the middle one in a set of values arranged in order of size.

The average concentration values of toxic organic gas vapors at selected stages of sampling and analysis are within the allowable exposure limits as prescribed in QCVN 03:2019/BYT.

However, the analysis data from the table above fluctuates quite a lot, especially Vinyl chloride. This may be due to the working condition of the extruders at different material recycling facilities. Other important factors are heat control in the extrusion process and technology to avoid the generation and control of harmful vapors and gases.

Currently, in Vietnam, there are no in-depth studies on health risk assessment due to exposure to volatile organic compounds (PAHs), toxic substances contained in exhaust gas components as well as the environment. workers in plastic recycling facilities. However, according to Tang et al. - 2016, road dust was investigated in an area with high mechanical waste plastic recycling intensity in Wen'an, northern China. The analyzed dust samples showed concentrations of PolyBromated Diphenyl Ether (PBDE) one to two orders of magnitude higher than that of outdoor and road dust samples from areas with no recycling activity. Commercial Deca-BDE was the dominant species for about 85% of all PBDEs detected.

4.2.4. Wastewater

4.2.4.1. Wastewater source

It should be emphasized that depending on the type of recycled plastic and the pre-extrusion treatment processes (pre-washing or intensive washing) will determine the quality and quantity of wastewater. Wastewater can be divided into 3 types as follows:

(1) Waste water with low concentration of pollution: wastewater from the process of washing the dust of previously treated and cleaned plastics, or industrial waste is not significantly dirty. This wastewater has the main components of SS and COD, BOD is only at low concentration. The proper disposal solution is to reuse and backwash in batches

(2) Wastewater with medium pollution concentration: wastewater from the cleaning process of plastic waste is contaminated with dirt, soil, sand, inorganic components, glue. This wastewater has the main pollutant component, which is high SS, but COD and BOD are at medium concentrations. A common treatment solution is a physico-chemical treatment for recycling and reuse in a continuous backwash line.

(3) Wastewater with high concentrations of pollution: wastewater from washing processes such as contaminated food wrap plastic films, plastic bottles for sugary drinks (PET), or bottles for detergents, softeners, shampoos, etc (HDPE) files are processed on the same recycling machine. The cleaning process uses hot water, detergent, or caustic soda (NaOH). This wastewater has main pollutant components such as SS, COD, BOD, oil, grease, nitrogen, phosphorus, and microorganisms... at high pollutant concentrations. The treatment solution is a combination of Physico-chemical treatment, biological treatment, and subsequent Physico-chemical treatment if necessary.

4.2.4.2. Concentration of pollution

Contaminants arise mainly during the preliminary washing phase, followed by thorough washing (e.g. intensive washing or friction washing). This wastewater stream contains all kinds of labels, glue, food residues, soil, sand and microorganisms, etc. The composition and concentration of pollution commonly encountered in this waste source compared to allowable levels are as follows:

Table 4.4. Composition of pollutants in wastewater from plastic recycling

TT	Parameter	Unit	Inflow	QCVN 40:2011/BTNMT (B)
1	pH	mg/L	6.2-8.0	5.5-9
2	COD	mg/L	450-3200	150
3	BOD	mg/L	150-1000	50
4	TSS	mg/L	500-2800	100
5	Total mineral fats and oils	mg/L	5-8.5	10
6	Total nitrogen	mg/L	10-70	3
7	Total phosphorus (as P)	mg/L	3-10	0.5
Note: QCVN 40:2011/BTNMT: National Technical Regulation on Industrial Wastewater				

(Source: compiled by NREC – 2021)

This waste source exceeds the permitted discharge standards, so it should be collected and treated according to regulations.

4.2.4.3. Volume of wastewater

Depending on the type of plastic recycled, the degree of contamination and cleaning processes as well as the efficiency of recycling and reuse… determines the amount of wastewater.

Data on water consumption of this sector is collected and presented in the following table:

Table 4.5. Water consumption in the plastic recycling sector

Production scale/type	Input	Water consumption (m3/ton)	Note
Household/Small	Sorted waste plastic	39	(*)
Product factory from recycled plastic granules	Recycled plastic granules	3.7	
Centralized plastic recycling plant	Sorted waste plastic	2 - 5	(**)

(*): Anh Tuyet et al - Inventory and emission assessment in trieu khuc plastic recycling village and proposing solutions

(**): COWI A/S – 2019 - Report - Study about Plastic Sorting and Recycling

Small and medium scale plastic recycling facilities are usually located in suburban areas where the water supply network is not covered, often using groundwater. In the plastic washing process, often the water circulation coefficient is low, so the wastewater flow is quite high. In contrast to some large companies, which have invested in local physico-chemical treatment systems in the plastic washing area, the high water circulation coefficient has contributed to reducing the flow per unit of treated product. Therefore, it is important to consider the plastic washing process and have an appropriate wastewater treatment technology approach.

4.2.5. Solid waste and hazardous solid waste

The sorting and pre-treatment process in recycling such as removing dirt, separating labels, etc. will generate solid waste such as sand, stones, garbage mixed in plastic, waste paper packaging, etc. In addition, hazardous waste may arise in the production process such as greasy rags, batteries mixed in waste plastic, waste plastic packaging contaminated with hazardous chemicals, etc. The amount of waste will depend on the source of recycled materials and the actual operation process at each recycling facility. Control measures are presented in section 4.3.5. and 4.3.6.

4.3. POLLUTION CONTROL MEASURES

4.3.1. Controlling the microclimate in the working environment

High temperature working environment and heat radiation

To minimize the negative impact and stress on workers, plastic recycling facilities need to consider a number of measures to improve the ambient factors.

- The design of the workshop should take into account the sudden and seasonal temperature changes of the makeup air from the outside. If the air temperature is below 36°C, increased air movement (eg by means of a fan) will cool the worker; above that temperature (36°C) it will heat them up even more.

- Employers can increase the distance between equipment and worker exposure,
- Reduce the temperature of the surface by changing the plant operating temperature, insulating the surface or reducing the emissivity of the surface.

Technical solutions for factory ventilation:

(i) Mechanical ventilation

Figure 4.2. Mechanical ventilation

Based on the volume of the workshop or factory, the enterprise applies the following formula to calculate the airflow:

$$F_{air} = n \times V$$

Where:

F_{air}: Flow of fresh air supplied to the workshop, m^3/h

n: number of fresh air changes, times/h – n = 40-60

V: Volume of workshop (LxWxH), m^3.

Due to the specificity of the plastic recycling workshop with the equipment and machinery that give off heat, the number of times the fresh air changes in factory, "n" fluctuates between 40 - 60 times/hour.

In addition, the ventilation ball is an additional option, the ball operates on the principle of air convection, taking in natural wind, creating ventilation for the space, sucking hot air out and bringing in cool air from outside and is often used for workshops with high roofs.

(ii) <u>Evaporative cooling system</u>

An evaporative cooling system making negative pressure is a system combining the following pieces of equipment:

- Exhaust fan system (axial fans)
- Frames of evaporative cooling pads including. Cooling-pad is made from high-molecular-weight polymer materials with a honeycomb structure that allows water and air to be in easy contact, enabling air to exchange heat with water, and dust removal.
- PVC pipes supply water to frames of evaporative cooling pads, PVC pipes take back water from frames of evaporative cooling pads to circulative tanks, and water distribution PVC pipes
- Water pump and Circulative tanks

At the factory's gable, an exhaust fan system with large airflow is installed to suck all the hot air, pollutants, and dust inside the workshop to the outside. At the opposite gable of the workshop is installed the frame system of the evaporative cooling plate, including: the water distribution compartment, and the evaporative cooling plates with standard sizes together, accompanied by the water collection trough.

This system reduces the factory temperature by 5-8°C compared to the outside ambient temperature.

To calculate the required cooling-pad area to cool the workshop, the following preliminary calculation formula can be applied:

$$S = \frac{n \times V}{(5000 \div 9000)}$$

Where:

S: Required area of cooling-pad, m2.

n: number of fresh air changes, times/h – n = 40-60

V: Volume of workshop (LxWxH), m3.

5000÷9000, corresponding to the wind speed through the cooling-pad: 1.5 ÷ 2.5 m/s (According to design and installation experience)

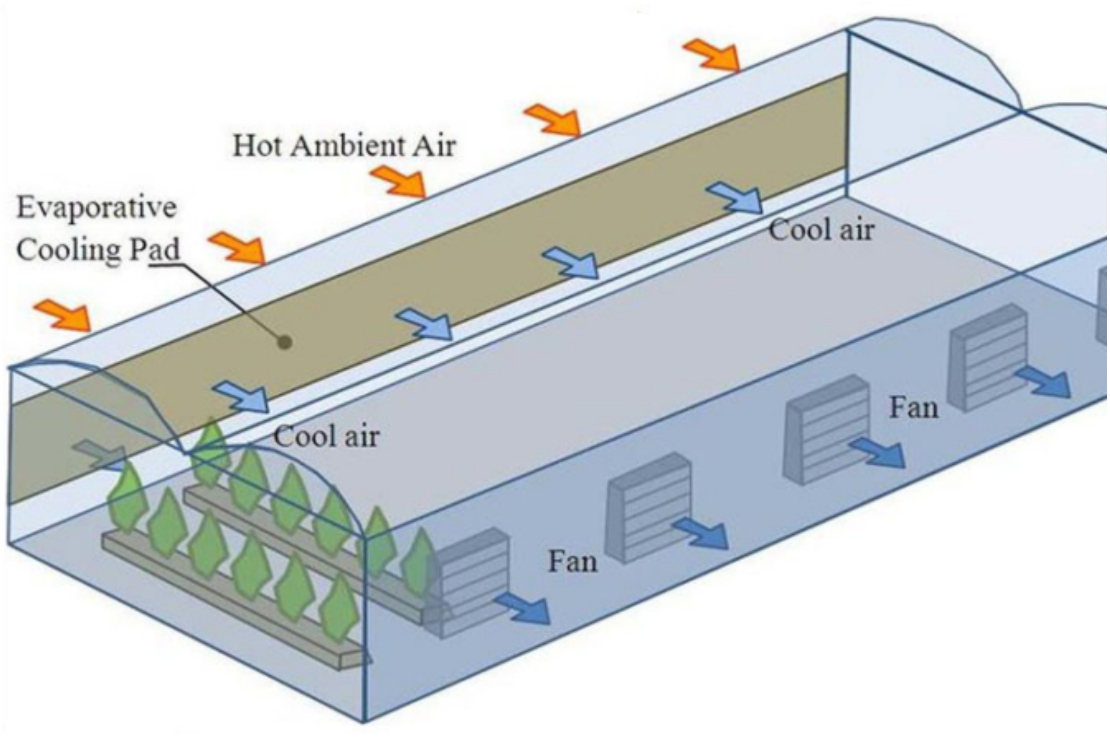


Figure 4.3. Evaporative cooling system

4.3.2. Emission Control and Dust

4.3.2.1. Dust

As mentioned above, dust and fine dust generated in plastic recycling plants are not high. The main stages that discharge dust into the environment are:

- Plastic sorting with sieves (vibrating screen, trommel screen, ...)
- Shred or grind plastic

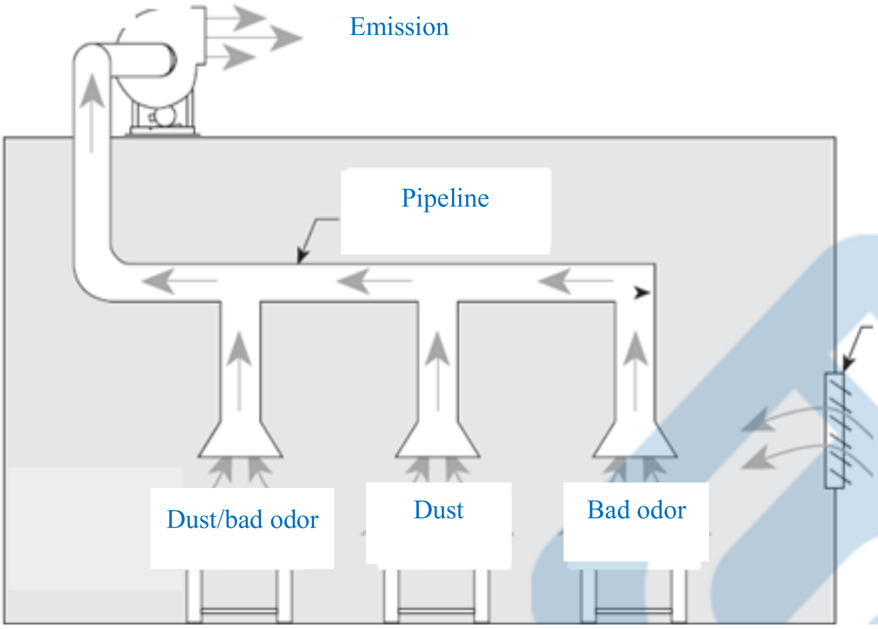


Figure 4.4. Dust collection diagram

In order to improve the working environment, in addition to the solutions mentioned in Section 4.3.1, it is necessary to arrange a single dust collection system at the above stages such as: suction hood, pipeline and exhaust fan. This solution helps to reduce dust concentration and limit local odors very effectively.

4.3.2.2. Hazardous gas and vapor

During the thermal treatment of plastics, e.g. extrusion, organic gases and vapors (VOCs) may be released. Depending on the type of plastic and the temperature at which the materials are being processed, these may be monomers, volatile additives, and a large number of different decomposition products through to carbon monoxide (CO) and carbon dioxide (CO2).

Extrusion includes the following processes:

- shredding: make the plastic the proper size
- drying: separating moisture from plastic
- melt and blend: make plastic melt and homogenize
- degassing: removing oxygen, toxic gases
- filter: remove impurities
- pelletizing: shaping the product

In order to well control the hazardous gas and vapor generated in the above series of processes, recycling plants need to consider a number of factors such as:

- The recycled material before entering the extrusion machine must be cleaned well to avoid clogging the filter, or making high back pressure which can lead to overheating and burning the plastic,
- The extruder temperature is well controlled, suitable for each type of recycled plastic,
- The technician operating the extrusion machine must have specialized knowledge and practical experience to master it.

Besides, recyclers consider investing in new generation extruders with modern technology. Nowadays single-screw extruders are widely used, production can be made more reliable by recording flux by weight and using a melt pump. These generally fulfill several tasks at once, one-step technology, such as the shredding and drying of the material fed in, melt degassing, and filtration and granulation. Different one-step technologies have been developed using a single screw extruder for regeneration and compounding of mixed plastic wastes.

Within the limited scope of this document, we introduce the TVEPLUS one-step technology. Erema GmbH has developed a one-step technology based on a single-screw extruder for plastic recycling. Using this technology, it is possible to achieve high-quality regrind from difficult-to-process materials such as these in a single operation. The TVEplus extruder system has set new standards in filtration, homogenization, and degassing performance with plastic melts through the patented design of melt filtration upstream to achieve ultrafine filtration and degassing.

Advantages:

- Enhanced filter performance thanks to reduced shearing upstream of the melt filter
- Optimised triple degassing with the patented EREMA cutter compactor, optimum screw design, and extruder degassing ensure highly effective degassing of the filtered melt
- Higher homogenization efficiency downstream of filtration and upstream of degassing enhances the subsequent degassing performance and improves the characteristics of the melt
- High-quality end product even with materials that are difficult to process such as heavily printed films and/or very moist materials. End products can contain a considerably higher share of recycled pellets.
- Reduces energy consumption by up to 10% as well as production costs and CO2 emissions as a result
- Considerably higher outputs with the same screw diameter compared to conventional degassing extruders
- Compact, space-saving design

4.3.3. Wastewater treatment

4.3.3.1. Removal of plastic pieces and plastic fibers

First of all, it should be noted that in the process of plastic recycling, there will be cutting and grinding of materials, which will generate small parts of plastics, foils, caps, plastic fibers, etc in the wastewater stream. Therefore, it is necessary to have a device to recover this waste source. The device commonly used is a screen.

The first step might employ coarse screening with openings of 10 to 50mm. The retained material is usually highly polluted and destined to end up in a waste dump.

The second step should be to use a rotary drum screen with much thinner openings to retain any particles beyond 1 to 10mm.

4.3.3.2. Backwash and recirculation - wash water reuse

As a golden rule, to control wastewater well in production, plastic recycling plants need to use clean water efficiently. This logical approach has prevailed in many industries.

(1) *Backwash in batches:* Batch backwashing: usually applied to wastewater with low contaminant concentration.

According to this rule, clean water enters the last plastic washing tank and stays for a while as required, then it is reused as feed water for the previous wash tank... Wastewater from the first tank is passed through a centrifugal settling tank or a Lamella clarifier.

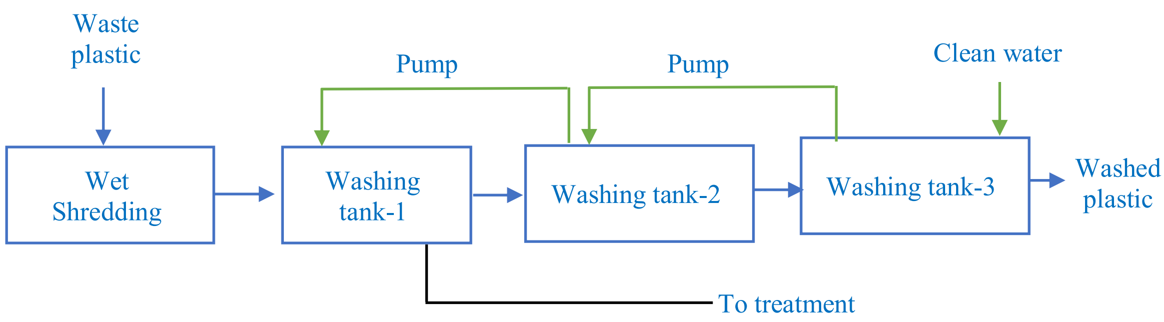


Figure 4.5. Flow chart of backwash in batches

(2) *Backwash continuously:* usually applied to wastewater with medium pollutant concentration

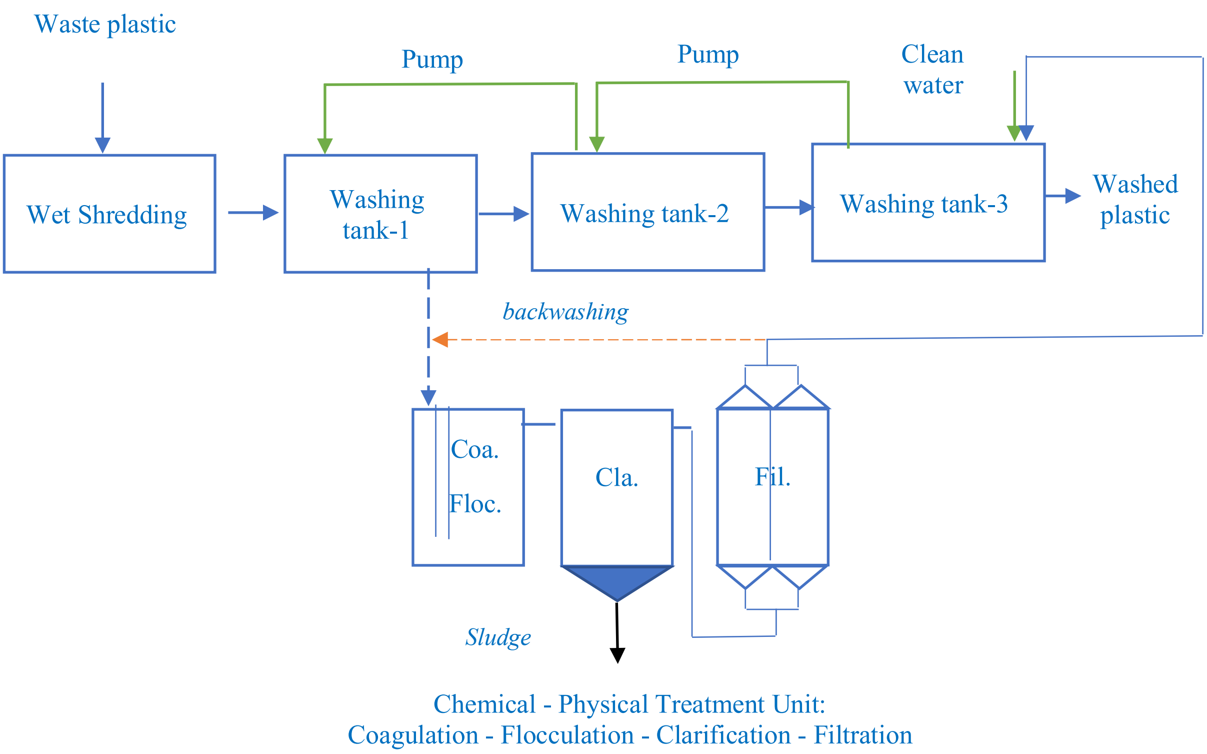


Figure 4.6. Flow chart of backwash in batches

The continuous backwashing process is usually connected to a physicochemical treatment system to treat the wash water and this treated water is recirculated and reused in a closed circuit, and clean water is replenished at the water supply tank.

The physicochemical treatment unit is usually designed to include a reaction tank, flocculation, coagulation, sedimentation, and filtration. The cluster of physicochemical treatment of flocculation, and coagulation, includes 3 stages:

- Chemical mixing stage: chemicals are mixed with a certain ratio and concentration, filled with a sufficient amount into the reaction tank.
- Reaction stage: Reacting tank with agitator speed 120-140 rpm, creating the necessary disturbance for suspended solids and chemicals to come into contact with each other.
- The flocculation stage: The flocculation tank with the paddle speed of 20-40 rpm will help the chemical pull the flocs down under the effect of gravity.

The water in the flocculation tank will be led through the settling tank, where, under the action of gravity, the flocs will settle to the bottom, the sludge is collected at the bottom of the tank and treated periodically. Wastewater after the settling process is led through the Filter tank and reused in the plastic washing process. Sludge and impurities are collected into the sludge tank for separate treatment, backwash water is returned to the flocculation - flocculation tank.

4.3.3.3. Combination of physico-chemical treatment - biological treatment and circulation - reuse of washing water

Flowchart of treatment technology combined with physico-chemical treatment - biological treatment is as follows:

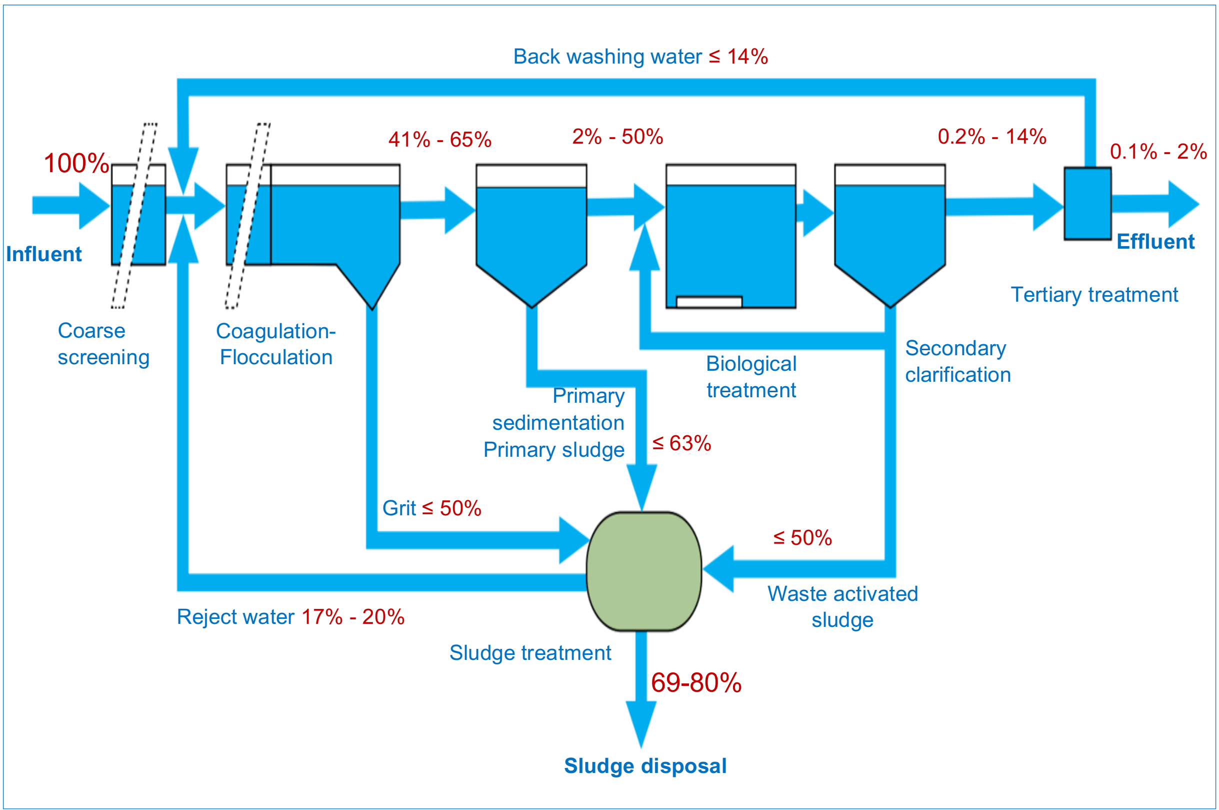


Figure 4.7. Technological scheme combining physico-chemical treatment - biological treatment and medium flow of microplastics in liquids and slurries in a wastewater treatment plant with primary, secondary and tertiary treatment processes

Source: Sun et al. (2018)

First, wastewater is led to a centralized collection pit with screening equipment. From here, the wastewater is submersible pumped to a physicochemical treatment cluster, including a reaction tank, flocculation-coagulation combined with sedimentation. The cluster of flocculation-coagulation chemical treatment works includes 3 stages as described above.

Wastewater after leaving the primary settling tank (primary settling tank) is led to the aerobic tank for further biological treatment. In this tank, biochemical oxidation of dissolved and colloidal organic substances in wastewater takes place under the participation of aerobic microorganisms. Aerobic microorganisms will consume colloidal and soluble organic substances in the water to grow. Microorganisms grow to form activated sludge. The aerobic biological tank is continuously supplied with oxygen from the outside through the air blower. After being biologically treated, the suspended activated sludge mixture is led through the sludge settling tank (Second settling tank). The separated sludge in the settling tank is recirculated back to the aerobic biological tank, and the excess sludge is taken to the sludge storage tank or mud drying yard. This residual sludge is periodically sucked for treatment.

The waste stream after settling is continued to lead to the next stage of treatment, which can be pressure filtration and disinfection. After treatment, wastewater meets column A standards of QCVN 40: 2011/BTNMT. This water can be recycled back into the plastic washing process.

Another important problem for this wastewater is microplastics. Existing water treatment processes show that plastic is mainly removed during primary treatment, microplastics can be removed through fine screening (primary treatment), sedimentation (primary treatment or secondary), flotation (primary treatment) and filtration processes (primary, secondary or tertiary). In addition, coagulation, flocculation (primary treatment) can help remove microplastics during primary sedimentation easily.

The above general wastewater treatment technology diagram (Figure 4.7) is often applied in centralized plastic recycling plants, the sequence of processes and objectives are summarized through the following.

Table 4.6. Description of removal of macroplastics and microplastics (MPs) during wastewater treatment processes

Treatment stage	Preliminary	Primary	Secondary	Tertiary
Sequence of processes and objectives	Screening with metal grids as preliminary treatment to remove fine and coarse debris, i.e. > 10 mm in size	Grit removal (to remove sand, silt and other heavyparticles) 1. Skimming tank for grease, oil and fat removal 2. Coagulation and flocculation to create large flocs of heavy metals and phosphorus 3. Primary sedimentation to remove particulate	Biological and physical treatment removes: • Suspended particles • Dissolved nutrients • Dissolved and colloidal organics Examples of processes are: 1. Aerobic, anoxic or anaerobicbiological treatment, such as: *Activated sludge* 2. Secondary sedimentation	It may ensure final effluent meets the required quality standard. Also usedto remove nutrientsor heavy metals (if necessary) Examples of processes are: • Wetlands • Membrane filtration • Biological aerated filter • Slow sand filtration

Treatment stage	Preliminary	Primary	Secondary	Tertiary
		matter and flocs 4. Flotation to remove floating materials, volatile organic compounds (VOCs) (e.g. those which are strong-smelling) and grease		
Plastics removal	Removal mainlyoccurs during this step	Some of the macroplasticsare removed during fine screening, skimming, grit removal and other processes if these processes are implemented	Smaller plastic items such ascotton swabs may remain inthe wastewater	Not expected because most plastics would have been removed already
MPs removal	Up to 59 per cent	42-82 per cent in general;exceptionally, 78-95 per cent. • (major route) skimming of grease (for floating MPs) • (minor route) filtration and gravity settling for heavier • MPs trapped in flocs	86-99.8 per cent, cumulatively • Removal mechanisms are uncertain. • MPs fragments are more easily removed compared with MFs, possibly because MFs were largely removed during the primary step	Typically, cumulative removal is 95-99.9 per cent. Effluent concentrations are 0.01-91 MP per litre.

(Source: 2020 United Nations Environment Programme - Water Pollution by Plasticsand Microplastics: A Review of Technical Solutions from Source to Sea) [19]

As described above content, depending on the actual conditions, financial capacity, and wastewater treatment requirements of the management agency, the recyclers apply the following steps: pre-treatment, primary treatment, secondary treatment, and tertiary processing if necessary. This is also a rather difficult problem, requiring serious advice from environmental experts to invest in an efficient and cost-effective wastewater treatment system.

4.3.4. Sewage sludge treatment

While removal of microplastics from treated wastewater can reach 69-99 percent in a WWTP, it is important to remember that this removal is simply a phase transfer of the microplastics from the liquid to the sludge. Therefore, inadequate management of the sludge will lead to environmental contamination.

Thus, the issues that need attention are the sludge discharged from the wastewater treatment plant, and the solid waste generated during the production process. The investor should consider collecting and storing these waste sources at the factory in accordance with regulations. Accordingly, they need to be handed over to legal (licensed) and competent processors through a formal contract.

4.3.5. Solid waste management

Some legal regulations on solid waste management:

1. Non-hazardous industrial solid waste is recovered, classified, selected for reuse, used directly as raw materials, fuels, and materials for managed production activities such as products and goods.
2. Classification of normal industrial solid waste: there are equipment, tools, and storage areas for normal industrial solid waste according to regulations.
3. Transfer of solid waste after sorting to the unit licensed to operate.
4. Using the minutes of handover of normal industrial solid waste according to the prescribed forms.

Source: Articles 65 and 66 - Decree 08/2022/ND-CP

4.3.6. Hazardous Waste Management

Some legal regulations on hazardous waste management:

1. Hazardous waste identification shall be done according to hazardous waste codes, categories, and thresholds.
2. Hazardous wastes must be classified according to hazardous waste codes to be stored in suitable containers or storage devices.
3. Means and equipment for collecting, storing, and transporting hazardous waste must meet requirements on environmental protection.
4. Cooperate with hazardous waste treatment service providers to make hazardous waste documents when transferring hazardous waste as regulated.

Source: Articles 69, 70, and 71 - Decree 08/2022/ND-CP

4.4. RECOMMENDATIONS FOR GOOD WORKING PRACTICE FOR PLASTIC RECYCLING

4.4.1. Safety measures and reduced exposure to hazardous substances

- The machines and installations for plastic recycling must comply with the installation and operating conditions specified by the manufacturer.
- During the erection and operation of machines and installations, the risks which may arise from interactions with other items of work equipment, agents, or the working environment must be taken into account.
- Work performed on machines and installations may only be carried out by workers who are authorized to do so and capable of performing such work independently and safely or who are supervised during such work.
- Covers mounted on the machines and installations and other protective devices which are intended to prevent the release of hazardous substances may not be opened, removed, or otherwise bypassed during operation.
- At existing transport, filling, or decanting devices the dropping heights must be minimized. Where necessary, flexible covers or encasements must be mounted.
- At open mixers and installations in which powdered additives are added, an effective extraction system must be installed to prevent the development of dust and its spread into the working area.
- Extrusion, blowing, deep-drawing and cold chopping installations must have an exhaust gas collection system at the points where hazardous gases and vapors may escape into the workplace air. For working areas with extruders that run hot or may "burn off", personal protective equipment must be provided for the workers.

- In areas where extrusion for PVC is installed, workers must be equipped with appropriate respirators to protect against chlorine-carrying gas exposure.
- Cleaning work, especially works to remove dust deposits, must be performed regularly. To avoid the swirling of particles, industrial vacuum cleaners must be used as far as possible.
- The use of compressed air for blowing is only permissible if the locations to be cleaned are not accessible to industrial vacuum cleaners. In such cases, basic cleaning must invariably be carried out beforehand using industrial vacuum cleaners. It is not permissible to blow-clean the floor.
- In the case of cleaning mixing and grinding equipment that is clogged, they must be dismantled and cleaned, and a dust mask/respirator with a high degree of protection must be worn. Heavy personal protective equipment should not be worn as a permanent measure instead of technical or organized protective measures.
- For all working areas operating instructions must be drawn up. Workers must be given regular instruction.
- Eating, drinking, smoking, and the taking of snuff is not permissible at the workplaces.

4.4.2. Fire and explosion safety

Because of the mainly combustible plastics to be processed there is a high fire risk in facilities that fall within the scope of the present recommendations. The particles released during the processing are mostly combustible and are explosive as a particle-air mixture under certain circumstances.

- Employers or facility owners need to identify fire hazards and develop fire safety measures.
- Further measures regarding structural, technical, operational, and organizational fire and explosion safety may be necessary as the result of the risk assessment.
- In compliance with technical requirements on fire prevention and fighting, industrial construction regulations must meet requirements on fire prevention and fighting.
- Establish fire safety measures at the request of the authorities.
- Ensure optimum equipment maintenance, safe operation, and control of the working environment in good condition.

4.4.3. Other Notes

- Plastic waste may be dirty and could carry disease, especially if it was used for packaging food before and is stored where rats can touch it. It is necessary to establish measures to prevent this risk
- All machines handling plastics, work with blades, heat, screws and the like. This means that hands can get wounded, plastic shreds can fly around, heat causing access water explode and molten plastics can cause serious burns.
- Brominated flame retardants (BFRs) are used in plastic materials in electrical and electronic products to aid fire safety by reducing their propensity for ignition.
  However, in the recycling process requires the segregation and separate treatment of BFR-containing plastics in order to ensure that restricted substances (four specific BFR substances restricted under RoHS) are removed from the material stream and destroyed. The WEEE CEN Standards provide the basis for recyclers to achieve this and ensure that plastics being used again do not contain legacy BFRs.

When you are dealing with plastics:

- Only use the flame test as a last resort.
- Be very careful that you are clear on which type of plastic you are handling and that there are no other types mixed in. This is very important when doing the flame test.

NEVER BURN PVC – IT IS EXTREMELY TOXIC.

CHAPTER 5

NATIONAL POLICY AND INTERNATIONAL INTEGRATION

5.1. NATIONAL POLICY

5.1.1. Extended Producer Responsibility (EPR) system in Vietnam

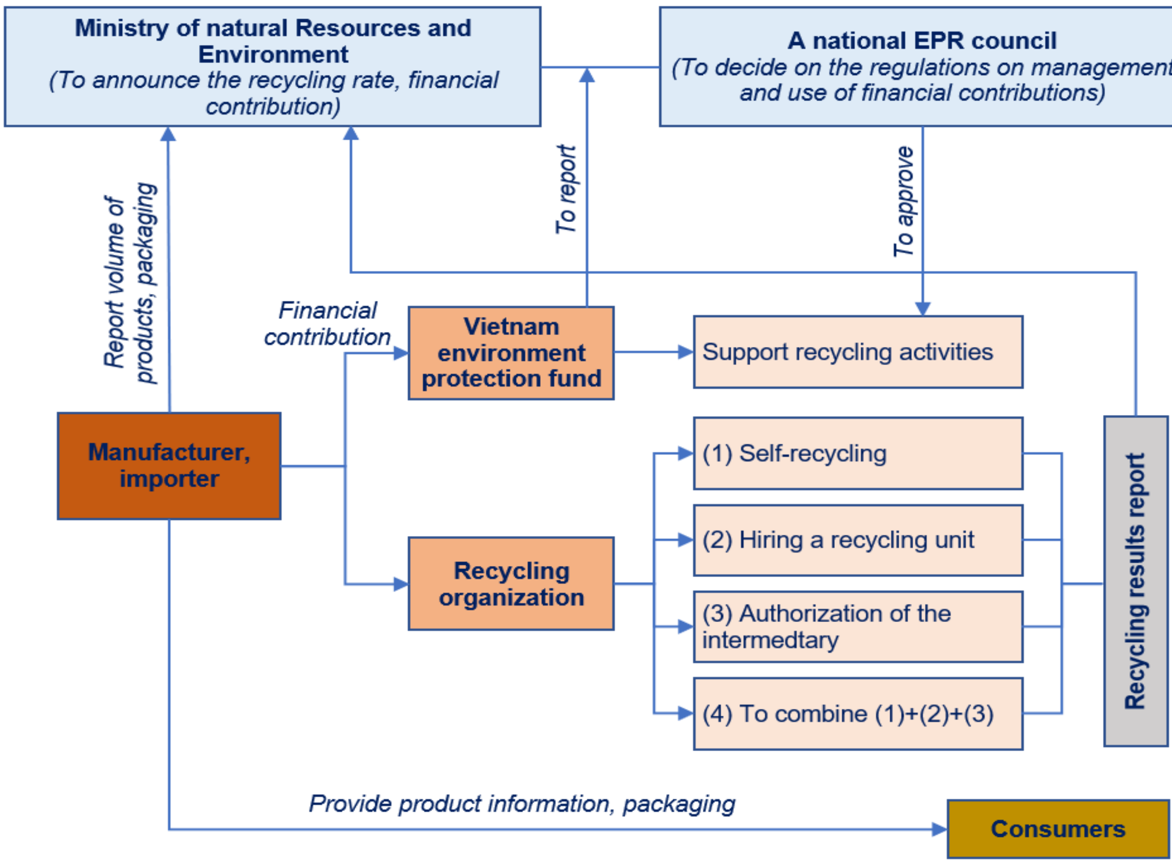
EPR is defined as an "environmental policy approach in which a producer's responsibility for a product is extended to the waste stageof that product's life-cycle".

(United Nations Basel Convention guideline, 2019).

In practice, EPR involves producers taking responsibility for the management of products after becoming waste, including: collection; pre-treatment, e.g. sorting, dismantling or de-pollution; (preparation for) reuse; recovery (including recycling and energy recovery) or final disposal.

In Vietnam, EPR is regulated in the Law on Environmental Protection dated November 17, 2020 in *Article 54. The recycling responsibilities of organizations and individuals producing, importing*, and EPR are detailed in the Decree. 08/2022/ND-CP on elaboration of several Articles of the Law on Environmental Protection.

An overview of the EPR System applicable to manufacturers and importers of products and packages is shown in the following diagram:



The following sections will describe in detail the EPR System in Vietnam

5.1.2. Responsibility for recycling products and packages of producing or importing organizations and individuals

5.1.2.1. Subjects and roadmap for recycling responsibility

1. Producers and Importers of the products and packaging specified in Column 3, Appendix 8 promulgated together with this Decree to put on the Vietnamese market shall assume the responsibility to recycle such products and packaging in compliance with the mandatory recycling rates and specifications in Article 78 of Decree 08/2022/ND-CP.
2. Packaging specified in Clause 1 of this Article includes commercial (inner and outer) packaging of the following items:
   a) Beverages and food in compliance with the law on food safety;
   b) Cosmetics in compliance with the law on conditions of cosmetics production;
   c) Drugs in compliance with the law on pharmacy;
   d) Fertilizers, animal feeds, veterinary drugs in compliance with the law on fertilizers, animal feeds and veterinary drugs;
   e) Detergents, preparations used in households, agriculture and health sector;
   f) Cement;
   g) Other packaging specified by the Prime Minister
3. However, the decree also stipulates that a number of subjects are not required to carry out the responsibility of recycling such as temporary import for re-export or production or import for research, study, or revenue purposes. less than 30 billion VND/year; Packaging importers: less than 20 billion VND/year. (see details in Clause 3, Article 77 of Decree 08/2022/ND-CP.
4. Implementation schedule: from January 1, 2024;

Source: Article 77 of Decree 08/2022/ND-CP

5.1.2.2. Mandatory recycling rates and specifications

1. The mandatory recycling rates for each type of product and packaging in the first 3 years are specified in column 4, Appendix XXII issued with Decree 08/2022/ND-CP. The mandatory recycling rates shall be increased every 03 years to realize the national recycling targets and environmental protection requirements.
2. Mandatory recycling specifications are selected recycling solutions with minimum requirements on the amount of materials and fuel recovered for product and packaging recycling. The mandatory recycling specifications for each product and packaging are specified in Column 5, Appendix XXII issued with Decree 08/2022/ND-CP

Source: Article 78 of Decree 08/2022/ND-CP

Table 5.1. List of products, packaging to be recycled, and recycling rates and specifications

List of products, packaging	**Recycling rate for the first 3 years**	**Mandatory recycling specifications** *(recovery of at least 40% of volume of product and packaging materials collected for recycling in accordance with the mandatory recycling rate)*
1. Solid PET packaging	22%	*Selected recycling options:* 1. For production of recycled plastic pellets used as feedstock for industrial production. 2. For production of other products (including PE fibers). 3. For production of chemicals (including oil).
2. Solid HDPE,	15%	*Selected recycling options*:

LDPE, PP, PS kackaging		1. For production of recycled plastic pellets used as feedstock for industrial production. 2. For production of other products (including PE and PP fibers). 3. For production of chemicals (including oil) .
3. Solid EPS packaging	10%	*Selected recycling options:* 1. For production of recycled plastic pellets used as feedstock for industrial production. 2. For production of other products. *3.* For production of chemicals (including oil).
4. Solid PVC packaging	10%	*Selected recycling options:* 1. For production of recycled plastic pellets used as feedstock for industrial production. 4. For production of other products. *5.* For production of chemicals (including oil) .
5. Other solid plastic packaging	10%	*Selected recycling options:* 1. For production of recycled plastic pellets used as feedstock for industrial production. 6. For production of other products. *7.* For production of chemicals (including oil) .
6. Soft material single packaging	10%	*Selected recycling options:* 1. For production of recycled plastic pellets used as feedstock for industrial production. 2. For production of other products. *3.* For production of chemicals (including oil) .
7. Soft multi-material packaging	10%	*Selected recycling options:* 1. For production of recycled plastic pellets used as feedstock for industrial production. 2. For production of other products. 3. For production of chemicals (including oil).

Source: Appendix XXII issued with Decree 08/2022/ND-CP

Note: Recovery of at least is the required rate of collection for recycling according to the mandatory recycling specification with the recycling solutions selected in Table 5.1.

5.1.2.3. Methods of fulfilling the recycling responsibility

1. Producer or Importer of packaging shall make their own decision on recycling by choosing one of the following methods:
    a) Carry out self-recycling but must ensure the requirements for environmental protection as prescribed by law are met.
    b) Employ a recycler announced by the Ministry of Natural Resources and Environment to carry out the recycling.
    c) Authorize an intermediary to organize the recycling
    d) Carrying out a mix of methods specified in Sub-clauses a, b and c of this Clause.

2. Producers and importers choose the form of financial contribution to the Vietnam Environment Protection Fund according to the provisions of Point b, Clause 2, Article 54 of the Law on Environmental Protection are not required to carry out the above-mentioned forms of recycling.

Source: Article 79 of Decree 08/2022/ND-CP

5.1.2.4. Registration of recycling plans and reporting on recycling results

1. Producers and importers shall register for their annual recycling plans and report on their previous year's recycling results to the Minister of Natural Resources and Environment before March 31st annually; where a producer or importer authorizes an authorized recycler, the latter shall be responsible to register and report on behalf of the former.

   The registration of a recycling plan shall be based on the production and import volume of the previous year. The producers, importers, or authorized recyclers shall be responsible before the law for the accuracy of the data related to the registration of recycling plans and reporting of recycling results.

2. Where the actual volume of produced or imported products and packaging is higher than that in the registered recycling plan, the producer or importer shall include the unregistered recycling rate to the recycling plan for the following year.

   Where the actual volume of produced or imported products and packaging is lower than that in the registered recycling plan, the producer or importer may reduce the recycling rate accordingly in the recycling plan for the following year.

3. Where the recycling plans or reports on the recycling results are not satisfactory, the Ministry of Natural Resources and Environment shall notify in writing the manufacturer, importer, or authorized party to complete the plan and report within 30 working days from the date of notification. There is no need to register the recycling plan, report the recycling results for imported scrap as raw production materials.

4. Producers and importers making financial contributions to the Vietnam Environmental Protection Fund are not required to register and perform the recycling plans and to report on recycling results specified in Clause 1 of Article 80 Nghị định 08/2022/ND-CP.

Source: Article 80 of Decree 08/2022/ND-CP

5.1.2.5. Financial contributions to Vietnam Environmental Protection Fund

1. Financial contribution to Vietnam Environmental Protection Fund for each type of product and packaging (F) shall be determined using the formula: F = R x V x Fs, of which:
   - F is the total amount a producer or importer shall have to contribute to Vietnam Environmental Protection Fund for each type of product or packaging (unit: VND);
   - R is the mandatory recycling rate of each type of product or packaging specified in Clause 1, Article 80 hereof (unit: %);
   - V is the volume of products and packaging placed on the market in the year of performance of the recycling responsibility (unit: kg or piece of product or packaging);
   - Fs is the cost norm for recycling of products or packaging, which is determined based on total reasonable and legitimate costs for segregation, collection, transport, recycling, and disposal of products or packaging; overhead costs for perform producers and importers' recycling responsibility (unit: VND/kg or VND/ piece of product or packaging).
2. The Ministry of Natural Resources and Environment shall submit to the Prime Minister to promulgate the Fs for each type of product, packaging, and adjust it every 3 years.
3. Financial contributions to the Vietnam Environmental Protection Fund by producers and importers are specifically guided in Circular No. 02/2022/TT-BTNMT.

Source: Article 81 of Decree 08/2022/ND-CP

5.1.2.6. Support for product and packaging recycling

1. Financial contribution to the Vietnam Environmental Protection Fund is used to support the activities of classification, collection, transportation, recycling, product treatment, and packaging specified in Column 3 of Appendix XXII issued. issued together with Decree 08/2022/ND-CP and administrative costs to support the implementation of recycling responsibilities of manufacturers and importers.
2. Agencies and organizations that need financial support for recycling activities specified in Clause 1 of this Article compile dossiers according to the guiding form and send them to the Ministry of Natural Resources and Environment before October 30 of each year for approval.

Source: Article 82 of Decree 08/2022/ND-CP

Dossier to request financial support for recycling activities according to the provisions of Form No. 05, Appendix IX issued together with Circular No. 02/2022/TT-BTNMT, dated January 10, 2022 on detailed regulations implement a number of articles of the Law on Environmental Protection.

5.1.3. Responsibility for waste collection and treatment of institutional and individual producers and importers

5.1.3.1. Responsible entities, levels of financial contribution to Vietnam Environmental Protection Fund for support of waste treatment activities

1. Producers and importers of products and packaging specified in Column 2, Appendix XXIII issued together with Decree 08/2022/ND-CP to bring to the Vietnamese market are responsible for making financial contributions to Vietnam Environmental Protection Fund to support waste treatment activities (except for cases where recycling is not required such as temporary import for re-export or production or import for research and study purposes or revenue for the packaging manufacturer: less than 30 billion VND/ year; Importer of packaging: less than 20 billion VND/year).
2. The specific level of financial contribution for each product and packaging is specified in Columns 3, 4 and 5 of Appendix XXIII issued together with Decree 08/2022/ND-CP. Which is related to the plastic industry as follows:

Table 5.2. List of products and packaging and contribution levels for waste recycling

No	Type of products, packaging	Shape	Capacity/ Size	Contribution norms to waste treatment
1	Containers of pesticides	Plastic bottles, boxes	< 500 ml	50 VND / item
			500 ml or large	100 VND / item
		Plastic packs, bags	< 100 gr	20 VND / item
			From 100gr to under 500gr	50 VND / item
			500 gr or large	100 VND / item
2	Products using plastic as the raw material			
2.1	Knives, scissors, spoons, forks, chopsticks, cups, bowls, cups, containers, stirrers, straws, single-use food wrap and other	All	All	VND 1.500 /1 kg of used plastics

	single-use plastic products (except medical instruments)			
2.2	Balloons, duct tape, ear buds, toothpicks, single-use toothpaste, single-use shampoo, conditioner, single-use razor			
2.3	Garment products			
2.4	Leather products, bags, shoes, sandals			
2.5	Children toys			
2.6	Interior furniture			
2.7	Construction materials			
2.8	Non-biodegradable plastic bags with dimensions less than 50 cm x 50 cm and a film thickness of less than 50 μm			

3. The financial contribution level to Vietnam Environmental Protection Fund to support waste treatment activities shall be progressively increased every five years in accordance with the environmental protection requirements.

Source: Article 83 of Decree 08/2022/ND-CP

5.1.3.2. Process for making financial contributions to Vietnam Environmental Protection Fund to support waste treatment

1. Manufacturers and importers self-declare and send a declaration of the amount of contributions to support waste treatment according to the form guided by the Ministry of Natural Resources and Environment to the Vietnam Environmental Protection Fund before March 31 of each year. The declaration of the amount of contribution to support waste treatment is calculated according to the volume of products and packaging produced to the market and imported in the previous year. Manufacturers and importers are responsible before the law for the accuracy of the information in the declaration.
2. Before April 20 every year, producers and importers shall be responsible for making the one-time waste treatment support contribution to Vietnam Environment Protection Fund or can choose to pay in two installments.
3. Where the declared contribution amount for waste treatment support is lower than the actual amount, the difference shall be paid in the following year; where the quantity of products and packages is declared more than it is actually produced for the market or imported, the paid amount will be deducted for the difference in the following year.

Source: Article 84 of Decree 08/2022/ND-CP

5.1.3.3. Support for waste treatment activities

Agencies, institutions that need financial support for waste treatment activities specified in Clause 3, Article 55 of the Law on Environmental Protection shall file applications to the Ministry of Natural Resources and Environment before October 30th annually for consideration and approval.

Source: Article 85 of Decree 08/2022/ND-CP

5.1.4. Provision and management of information, and monitoring of the performance of producers and importers responsibilities

5.1.4.1. Provision of information on products and packaging

1. The producers and importers of plastic products and packages that are subject to the responsibility for recycling as mentioned above are responsible for disclosing information about the products and packages they manufacture or import, including materials; guidelines for separation, collection, reuse, recycling, and treatment; warning of risks during the process of recycling, reuse, and treatment.
2. Tax authorities, customs authorities, business registrars, and relevant agencies and institutions shall be responsible for providing and sharing information on taxation and customs and business registration related to the production and import of products and packaging specified in Appendix XXII and Appendix XXIII issued together with Decree 08/2022/ND-CP at the request of the Ministry of Natural Resources and Environment.

Source: Article 86 of Decree 08/2022/ND-CP

5.1.4.2. National EPR Portal

1. The National EPR Portal is connected to the tax, customs, and business registration databases to ensure the declaration of producers and importers to be in compliance with the law; the database connection shall be conducted in compliance with the law
2. he National EPR Portal shall be opened and decentralized in accordance with the types of account users and registered entities.
3. The Ministry of Natural Resources and Environment shall develop, manage and operate the National EPR Portal.
4. After the National EPR Portal is officially operated, the obligations of producers and importers shall be implemented specified in Decree 08/2022/ND-CP must be registered, declared, reported, synthesized, and managed on the National EPR portal.

Source: Article 87 of Decree 08/2022/ND-C

5.1.4.3. National EPR Council

1. The National EPR Council is an interdisciplinary council with the task of advising and assisting the Minister of Natural Resources and Environment in the management and supervision of the performance of producers and importers' responsibilities as specified in Decree 08/ 2022/ND-CP. The National EPR Council works on the collective working regime, deciding by majority.
2. The composition of the National EPR Council includes representatives from the Ministries of Natural Resources and Environment, Finance, Industry and Trade, Health, Agriculture and Rural Development; representatives of the producers and importers; representatives of relevant institutions, experts, and waste recyclers and treatment establishments.
3. The National EPR Council has an assisting office located at the Ministry of Natural Resources and Environment, working on a part-time basis.

Source: Article 88 of Decree 08/2022/ND-CP

5.1.5. Legal documents related to the field of Plastic Recycling

No	Legal documents related to plastic recycling field	Specific goals to 2025 are related to plastic recycling field
1	Decision No. 491/QD-TTg dated May 07, 2018 of the Prime Minister on approving the adjusted national strategy on integrated management of solid wastes up to 2025, with a vision toward 2050	– Focus on implementing tasks and solutions to achieve the goal of using 100% eco-friendly plastic bags in shopping malls and supermarkets for domestic purposes as an alternative to plastic bags hair is difficult to decompose;
2	Decision No. 1746/QD-TTg dated December 04, 2019, of the Prime Minister on introducing national action plan for the management of marine plastic litter by 2030	– Reduce marine plastic litter by 50%; – Ollect 50% of abandoned, lost or discarded fishing gear; – 80% of coastal tourism areas, tourist attractions, tourist accommodations and other coastal tourism services stop using single-use plastics and non-biodegradable plastic bags – and 80% of marine protected areas are without plastic
3	Decision No. 889 / QD-TTg dated June 24, 2020 of the Prime Minister approving the national action program on sustainable production and consumption in the period of 2021-2030	– Develop legal policy with regards to sustainable consumption and production, specifically: technical regulations, standards on sustainable production, sustainable design, ecological design, reuse-, recycle-oriented design for production sectors; – Develop policy on promotion of production, distribution, and consumption of eco-friendly packaging which replaces single-use, non-degradable plastic items; – Reduce 5 - 8% consumption of raw materials of manufacturing industries. – 85% of supermarkets, commercial centers distribute and use eco-friendly packaging which gradually replaces single-use, non-degradable plastic item;
4	Directive No. 33/CT-TTg dated August 20, 2020, of the Prime Minister on the strengthening of management, reuse, recycling, disposal, and reduction of plastic waste	– Implement the goal: striving to 2025, the whole country will not use single-use plastic. – Researching and promulgating regulations on standards and technical regulations on quality and design of plastic products to ensure recycling and reuse; regulate the minimum percentage of recycled plastic content in plastic products, durability and publicize information on the durability of plastic products; develop guidelines on sustainable production and consumption of plastic products. Promulgating technical standards and regulations on the quality of recycled plastics and toxic additives in plastic materials; – Assess the current situation of plastic industry development and propose orientations and solutions to develop the plastic industry towards sustainable development.

No	Legal documents related to plastic recycling field	Specific goals to 2025 are related to plastic recycling field
5	Decision No. 1316/QD-TTg dated July 22, 2021 of the Prime Minister approving the scheme for strengthening management of plastic wastes in Vietnam	– 100% use of environmentally friendly plastic bags in commercial establishments and supermarkets for domestic purposes to replace non-biodegradable plastic bags; – ensure the collection, reuse, and recycling of 85% of generated plastic waste – reduction of 50% of marine plastic waste; – Striving for 100% of tourist resorts, tourist accommodation establishments, and hotels don't use single-use plastic products and single-use plastic products; – and gradual reduction of single-use plastic products and hardly degradable plastic bags in daily activities.

5.2. INTERNATIONAL INTEGRATION

5.2.1. Plastic waste in international trade

- ***Basel Convention***

The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal is a global treaty that was designed to restrict the movement of hazardous waste between nations. In May 2019, amendments were adopted which mean that, as of January 2021, plastic waste that is difficult-to-recycle will need to be clearly consented to before being imported into receiving countries. While these amendments are an important step in the right direction, they are by no means perfect. They will still allow for Global North countries to dump difficult-to-recycle plastic waste in the Global South, where there is often not the infrastructure and capacity to appropriately manage it. (*https://reports.eia-international.org*).

- ***International trade data***

Until the mid-1950s, plastics were precious commodities that were used and treated carefully. But in just 65 years, plastic production has increased by 18,300 percent – fuelling a relentless convenience lifestyle that produces enormous, and unnecessary quantities of waste.

The global trade in plastic waste has mirrored the growth in global plastic production, allowing high-income, high-consuming countries to avoid the direct social and environmental impacts of their plastic problem and driving the ever-expanding production and consumption of virgin plastics.

To date, humans have produced about 10 billion tonnes of plastic – of which an estimated six billion tonnes is now in landfills or the open environment. Plastics may fragment in the natural environment but do not biodegrade and may persist for hundreds to thousands of years. Plastic pollution is now found in all environmental compartments, in our food and water, and in the air, we breathe.

Until recently, the vast majority of plastic waste in trade was exported to China. In 2018, in response to the pollution caused by imports of dirty and hazardous solid waste, China implemented its "National Sword" policy, effectively banning the import of most plastic waste in order to protect its environment and human health. As a result, the trade has been diverted to new destination countries primarily in South-East Asia, such as Malaysia and Viet Nam.

The illegal trade in plastic waste has grown significantly in recent years as criminal groups have exploited the massive market disruption caused by China's ban on plastic waste imports. Countries in Asia and Eastern Europe, especially Malaysia, Viet Nam, Thailand, Indonesia, India, and Turkey, have seen significant rises in both total volumes of imported waste and the rates of illegal activity. With an estimated worth of up to €15 billion in the EU alone, the illegal trade in plastic waste is facilitated by a serious lack of transparency and accountability that operates in the sector.

While recent amendments to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal have provided some level of regulation to the international trade in plastic waste, the fact is that humanity are producing more plastic waste than the capacity to responsibly deal with it. The plastic waste crisis can only be solved through a holistic strategy that places emphasis on the implementation of Extended Producer Responsibility (EPR) and upstream solutions to reduce production and consumption of virgin plastic, alongside a ban on plastic waste exports. This can be done through an ambitious package of binding measures under a new global treaty to significantly reduce plastic waste generation and leakage while promoting resource efficiency and a safe circular economy for plastics. In the short to medium term, countries should work to ensure traceability and transparency of any plastic waste in trade and significantly improve inspection and enforcement capacity.

Despite the recent amendments to the Basel Convention (see Table 5.3.), trade data analysis comparing the January to April period in 2021 with earlier years shows only a limited decline in exports to non-OECD countries. For example, G7 countries' exports to non-OECD countries declined from 57 percent of exports in the first four months of 2020 to 52 per cent of exports during the same period in 2021. Japan's exports appear unchanged over the period, with 89 percent of exports destined for non-OECD countries. From January 2021 to April 2021, Japan actually increased plastic waste exports to non-OECD countries from 22,000 tonnes to 56,100 tonnes *(The Truth Behind Trash: the scale and impact of the international trade in plastic waste).*

Table 5.3. The export codes, classifications and regulatory controls on plastic waste before and after the Basel Plastic Waste Amendments

	Pre-basel Amendments			**Post basel Amendments**		
	Code	**Classification**	**Control**	**Code**	**Classification**	**Control**
Annex II	none	none	-	Y48	Plastic waste that is either unsorted bypolymer (mixed), contaminated or not destined for recycling (so long as nothazardous)	PIC
Annex VIII	none	Hazardous plastic waste	PIC Banned to non-OECD	A3210	Hazardous plastic waste	PIC Banned to non-OECD
Annex IX	B3010	Solid plastic waste (all)	Free movement	B3011	Plastic waste that is sorted by polymer, almost free from contamination and destined for recycling (so long as not hazardous)	Free movement

- ***Trade patterns in Vietnam***

Vietnam was one of the earliest countries to rapidly increase imports of recyclable plastic waste (referred to as plastic scrap in Vietnam) following China's announcement on the restrictions on imports. The volume of imports steadily increased throughout 2016 and 2017, peaking at approximately 80,000 tonnes per month in late 2017 and again in mid-2018, as shown in Figure 5.1.

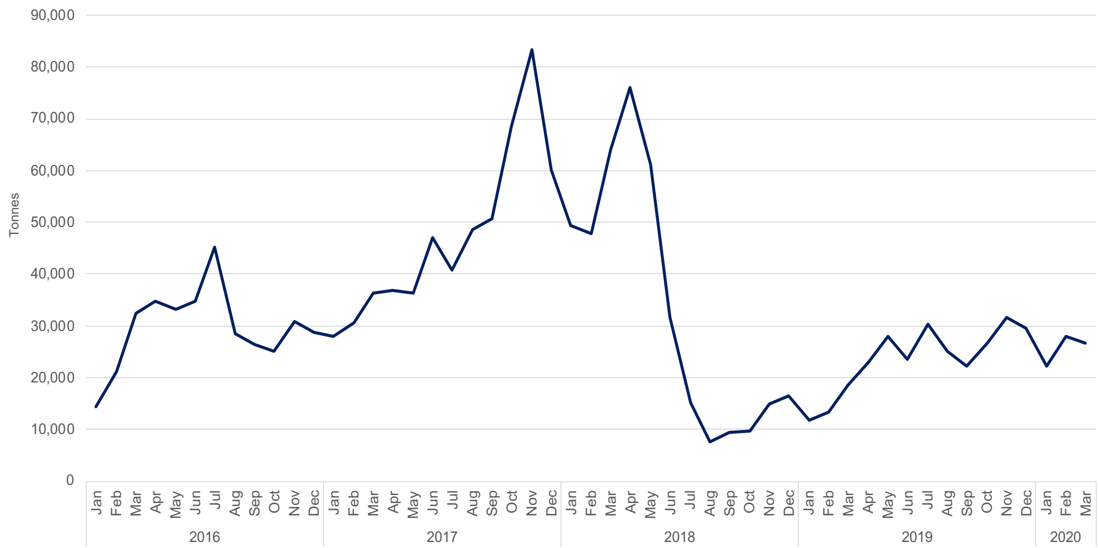


Figure 5.1. Total imports of plastic waste into Vietnam

(Data source: Comtrade-2020)

Driven by the environmental impacts of the plastic recycling industry, Vietnam implemented a range of new measures to restrict imports in 2018, including halting the issue of new licenses. Following this, the volume of imports sharply fell in the second half of 2018 before slightly rising again in early 2019. Imports have remained reasonably steady in 2019 and 2020 at approximately 25,000 tonnes per month. The breakdown of imports by major trading partner countries is displayed in Figure 5.2.

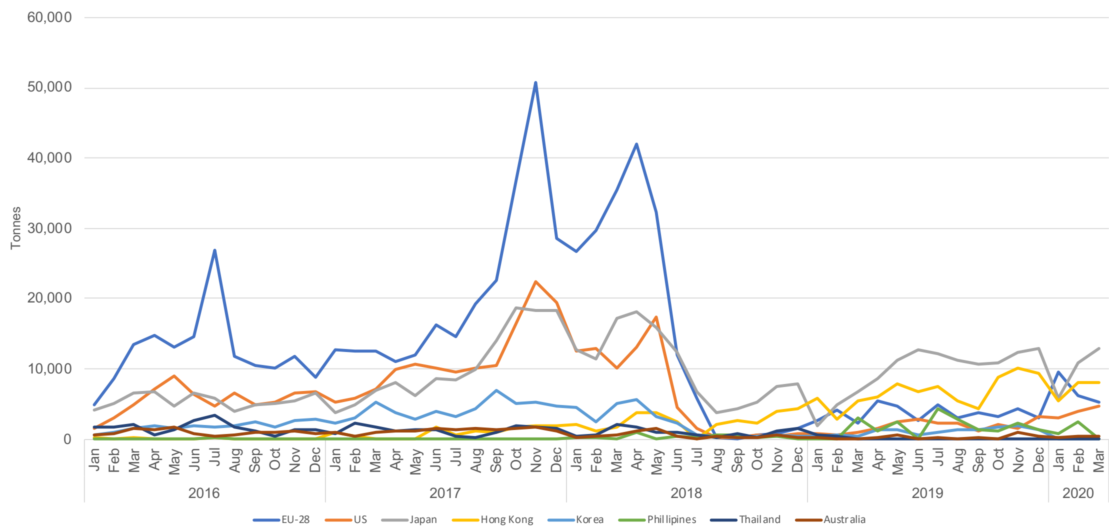


Figure 5.2. Imports of plastic waste into Vietnam from top 8 trading countries

(Data source: Comtrade-2020)

- ***The legal trade in plastic waste***

Enormous and ever-increasing quantities of plastic waste have overwhelmed domestic waste management infrastructures. In the face of this crisis, a key tactic for many high-income countries with high plastic consumption has been to export plastic waste overseas; for example, the 38 member countries of the Organisation of Economic Cooperation and Development (OECD) are responsible for 87 percent of all plastic waste exports since reporting began in 1988.

5.2.2. Recycled Plastics Standards and Standardization

5.2.2.1. Commercial guide to baled recycled plastic scrap

Standardization plays a central role in the sustainable introduction of the Circular Economy Model (CEM) and the establishment of a global supply chain for plastic recyclates. Due to differences in economic, political, and legal bases, at present, there are only a few international standards in the field of plastic recycling. The main prerequisites for developing an active market for recycled plastics are quality of materials, clear accountability for recycling properties, and assurance of supply.

In this document the resources on standards for recyclable materials, recycled plastic products are extracted and referenced from the Institute of Scrap (Waste) Industry, German Standard, EN - European standards, ISO – international.

To meet these prerequisites, traceability of recycled materials, standard sampling, and characterization methods for recycled products and products must be ensured. recycled ingredients, must be guaranteed. Also, application and product-specific requirements must be considered in technical and safety data sheets (TDS, SDS).

The standard specifications included in this Circular are intended to assist members in the buying and selling of their materials and products.

Parties to a transaction may specify particular variations or additions to these specifications as are suited for their specific transactions and for their individual convenience. Any deviation from the standard specifications, however, should be mutually agreed to and so stipulated in writing by the parties to the transactions. *(Source: Scrap Specifications Circular 2021 - Institute of Scrap Recycling Industries - ISR)*

5.2.2.2. Baled Recycled Plastic Scrap Commercial Guidelines

- ***General Information***

Commercial Guidelines for Baled Recycled Plastic Scrap were developed to provide industry-wide quality standards. These standards will facilitate the commodity trading of these materials. They will also focus suppliers of such material on the quality requirements of their customers.

Shipments should be essentially free of dirt, mud, stones, grease, glass, and paper. The plastic must not have been damaged by ultraviolet exposure. Every effort should be made to store the material above ground and under cover. A good faith effort on the part of the supplier will be made to include only rinsed bottles which have closures removed.

- ***Product***

These guidelines are designed with the potential for dealing with all recycled plastic in bale form. Initial specifications refer only to bottles. The code framework allows for genera- tion of guidelines for all types of plastic packaging materials (including rigids and flexibles) with room for expansion to other plastic products and resins including those which are used to produce durable goods. Guidelines for those prod- ucts may be added at a later date.

- ***Bale Density***

Bales shall be compressed to a minimum density of 10 pounds per cubic foot and a maximum density to be deter- mined by individual contract between Buyer and Seller.

Increased density may improve transportation efficiency, but over-compression may adversely affect the ability of a Buyer to separate, sort, and reprocess the material.

- ***Bale Tying Material***

Bale wires, ties, or straps shall be made of non-rusting or corroding material.

- ***Bale Integrity***

Bale integrity must be maintained through loading, shipping, handling, and storage. Distorted or broken bales are difficult to handle. They are unacceptable and may result in down- grading, rejection, or charge back.

- ***Allowable Contamination***

Unspecified materials must not exceed 2% of total bale weight. Bales which contain over 2% will be subjected to reduction in the contracted price of the material as well as charges for disposal of the contaminants. The reduced

Percentage will vary depending upon the amount and type of contamination. Quality of the baled plastic is the primary factor which determines the value.

- ***Prohibited Material***

Certain materials are understood to be specified as "prohib- ited." Such materials will render the bale "non-specification" and may cause some customers to reject the entire ship- ment. These may include plastic materials which have a deleterious effect on each other when reprocessed, and materials such as agricultural chemicals, hazardous materi- als, flammable liquids and/or their containers, and medical waste.

- ***Liquids***

Plastic containers/materials should be empty and dry when baled. The bale should be free of any free flowing liquid of any type.

5.2.2.3. Standards for recycled plastic scrap baled

Common issues for this category:

The following list applies to all materials listed in this category.

Standards for recycled plastic scrap baled

- Caps, enclosures, and labels are acceptable.
- Product need not be washed but preferred.

(1) PET Bottles

Description: Any whole Polyethylene Terephthalate (PET, #1) bottle with a screw-neck top that contains the ASTM D7611 "#1, PET or PETE" resin identification code and that is clear, transparent green, or transparent light blue. All bottles should be free of contents or free-flowing liquids and rinsed.

PET Bottle Bale Grade Chart

PET Bale Grade	Grade A	Grade B	Grade C	Grade F
Total PET Fraction by Weight	>94%	(93-83)%	(82-73)%	<72%
Total Amount of Contamination Allowed	6%	(7% -17)%	(18-27)%	>28%

"PET fraction" refers to the total weight of PET bottles in a PET bale, inclusive of caps and labels when still attached to PET containers, as a percentage of the total weight of that bale.

(2) HDPE Color Bottles

Description: Any whole, blow-molded, High-Density Polyethylene (HDPE, #2) bottle containing the ASTM D7611 "#2, HDPE" resin identification code that is pigmented and opaque, and was generated from a curbside, drop-off, or other public or private recycling collection program. All bottles should be free of contents or free-flowing liquids and rinsed.

HDPE Bale Grade Chart

HDPE Bale Grade	Grade A	Grade B	Grade C	Grade F
Total HDPE Fraction by Weight	>95%	(94-85)%	(84-80)%	<79%
Total amount of contamination allowed	5 %	(6-15)%	(16-20)%	21%

"*HDPE Fraction" refers to the total weight of HDPE bottles in a HDPE bale, inclusive of caps and labels when still attached to HDPE containers, as a percentage of the total weight of that bale.*

(3) HDPE Natural Bottles

Description: Any whole, blow-molded, High-Density Polyethylene (HDPE, #2) containing the ASTM D7611 "#2, HDPE" resin identification code that is unpigmented, and was generated from a curbside, drop-off, or public or private collection program. All bottles should be free of contents or free-flowing liquids and rinsed.

HDPE Natural Bale Grade Chart

The HDPE Natural Bale Chart is similar to the same HDPE Color Bottles (2)

(4) PET Thermoforms

Description: Any whole Polyethylene Terephthalate (PET, #1) package labeled with the ASTM D7611 "#1, PET or PETE" resin identification code including and not limited to egg cartons, baskets, clamshell containers, cups, lids, cake domes, covers, blister pack without paperboard backing, tubs, deli containers, trays and folded PET sheet containers. All packages should be free of contents or free flowing liquids and rinsed. This grade does not include bottles and jars.

- Product: PET Thermoform Plastic
- Source: Post-Consumer material
- Contamination: Including closures (caps, lids, and rings) on bottles is acceptable. Removal of closures is also acceptable.
- Total contaminants should not exceed 5% by weight.

No more than 2% by weight of any of the following individual contaminants will be allowed:

- Aluminum; Metal containers or cans
- Loose paper or cardboard

- Polystyrene, PLA, PVC, PETG
- Liquid residues, primarily water (2% maximum allowed)

(5) HDPE Injection Bulky Rigids

Description: Any injection grade #2 HDPE, typically found to be wide-mouthed containers and/or oversized items generated through a positive sort from curbside, drop-off, or other public or private recycling collection program. Examples include carts, crates, buckets, baskets, lawn furniture, etc. Metal such as axels and bolts should be removed. Buckets/pails with metal handles are acceptable.

- Product: Buckets, Pails, Oversized Rigid Plastics
- Source: Post-Consumer Material
- Contamination: The following levels of contamination are allowed
- 10% maximum acceptable: Polypropylene (PP, #5)
- 4% maximum acceptable: Polyethylene Terephthalate (PET, #1) plastics, Polyvinyl Chloride (PVC, #3) plastics, Low Density, Polyethylene (LDPE, #4) plastics, Polystyrene (PS, #6) plastics, Other (#7)
- 2% maximum acceptable: Metal, Liquid or other residues, Paper/cardboard

(6) PP SMALL Rigids Plastic

Description: Any Polypropylene (PP, #5) whole bottle, container product, generated through a positive sort from curbside, drop off, or other public or private recycling collection program. Examples include prescription bottles, yogurt cups, margarine tubs, ice cream tubs, cold drink cups, microwaveable trays, tofu tubs, dishwasher safe storage containers, hangers, bottle cap enclosures, etc.

Bulky Polypropylene (PP, #5) plastic items greater than 5 gallons, should be avoided (e.g., drums, crates, buckets, baskets, toys, totes, and lawn furniture).

- Product: Polypropylene Containers
- Source: Post-Consumer Material
- Contamination: Total contaminants should not exceed 8% by weight

The following levels of contamination are allowed

- 2% Maximum acceptable: Metal, Paper/Cardboard, Liquid or other residue, High-Density Polyethylene (HDPE, #2), Any plastic container or packaging containing Polyethylene Terephthalate (PET, #1), Polyvinyl Chloride (PVC, #3), Polystyrene (PS, #6), Other (#7).

(7) PP All Rigid Plastic

Description: Any Polypropylene (PP, #5) whole bottle, container product, generated through a positive sort from curbside, drop off or other public or private recycling collection program. Bulky Polypropylene (PP, #5) are items greater than 5 gallons, (e.g. buckets, crates, wastebaskets, toys, and storage bins).

Examples include prescription bottles, yogurt cups, margarine tubs, ice cream tubs, cold drink cups, microwaveable trays, tofu tubs, dishwasher safe storage containers, hangers, bottle cap enclosures, etc.

- Product: Polypropylene Containers
- Source: Post-Consumer Material
- Contamination: Total contaminants should not exceed 8% by weight

The following levels of contamination are allowed

- 2% Maximum acceptable: Metal; Paper/Cardboard; Liquid or another residue; High-Density Polyethylene (HDPE, #2); Any plastic container or packaging containing Polyethylene Terephthalate (PET, #1), Polyvinyl Chloride (PVC, #3), Polystyrene (PS, #6), Other (#7).

(8) PE Retail Mix Film

Description: Any polyethylene bag and overwrap accepted by retailers from their customers or polyethylene stretch wrap or other film generated back of the house may be included. Bags may be mixed color or printed and primarily High-Density Polyethylene (HDPE, #2) but are expected to include other polyethylene bags and LDPE/ LLDPE overwrap. Films may be coded with ASTM D7611 resin identification code “#2, HDPE” and #4, LDPE”. All bag bundles should be free of free-flowing liquids.

- Product: Mixed Film
- Source: Post-Consumer material
- Contamination: Total contaminants should not exceed 5% by weight: Non-polyethylene other plastics; Loose Paper; Strapping, twine, or tape; Liquid residue (2% maximum).

(9) PE Clear Film

Description: Any mix of natural polyethylene, High-Density Polyethylene (HDPE, #2), Low-Density Polyethylene (LDPE, #4), or Linear Low-Density Polyethylene (LLDPE, #4) film, PE Clear Film Description Variances

PE Clear Film Description Variances

Grade B	Grade C
80% clear, up to 20% color, clean and Natural LDPE and/or LDPE films.	50% clear, 50% color, dry, LDPE or LLDPE Films

Totaling at least 95% clear or natural polyethylene film is accepted. Films may be coded with ASTM D7611 resin identification code.

- Product: Polyethylene film
- Source: Post-Consumer or Post-Commercial material Contamination
- Total contaminants should not exceed 5% by weight: Pigmented polyethylene films; Non-polyethylene other plastics such as strapping; Labels; Liquid residue (2% maximum).

ANNEX

Table 5.4. Overview of the existing product-specific standards on plastic recyclates

Standard	Main points
DIN SPEC 91446 2021 -12	The DIN-SPEC 91446 defines a system for the classification of recycled plastics based on the quantity of data available for the material. It provides guidelines for the labeling of the recyclate type and content and also gives guidance for the characterization of plastic waste as feedstock material for recycling. The goal is to set standards for definitions of post-industrial recyclate (PIR), and post-consumer recyclate (PCR), quality grades, labels, and processes.
ISO 15270	Description of operations and terminology for development of infrastructure for various recycling approaches and a sustainable market for recyclates and recyclate-based plastic products.
ISO 14021	Requirements, terminology and general evaluation as well as a verification methodology for symbol and graphics for self-declared environmental claims, like “compostable”, “degradable” or “recyclable.
EN 15343	Description of a process required for the traceability of recycled plastics and calculation of recycled content in a given recyclate-based plastic product.
EN 15347	Schema for the characterization of plastic waste to be provided by supplier to a buyer:1. The mandatory data: mass of the batch, color (visual examination), form (chips, film, bottles, etc.), history of the waste (original use, art of collection and treatment after it became a waste), main and all of the secondary polymers present, packaging.2. Optional data: polymer properties, impact strength, mass flow index, Vicat softening temperature, additives, contaminations, humidity, volatile components, ash residues, elongation at break, yield stress, number of volatiles.
CEN/TR 15353 (DINTechnical report)	Description of a framework for the development ofbstandards for recycled plastic
CEN/TS 16011 (SPEC 91011)	Description of sampling, specimen preparation, testing methods and documentation for plastic recyclates.
CEN/TS 16010 (SPEC 91010)	Definition of sampling procedures for testing of plastic waste and recyclates during all stages of recycling process
DIN EN 13430	Specification of the requirements and scope of technologies for packaging, to be classified as recyclable. Description of material recovery criteria with regard to chemical composition, suitability for certain recycling approach and corresponding environmental impacts.
DIN EN 13437	Description of criteria for a recycling of diverse packaging materials, corresponding recycling process steps and material flow for various packaging materials including plastics.

Standard	Main points
DIN EN 17410 (Draft)	Description of the existing quality control, traceability and testing processes for recycled PVC for use in window and door profiles, including corresponding material requirements including origin, waste art, ash residues, bulk density, color (visual examination), foreign substances, grain size distribution, form, Vicat temperature, e-modulus, strength of the welded corners. Definition of guidelines for recyclability with regard to contaminations, which would affect the recycling after the use stage.
ISO 12418-1	Description of a designation system for all postconsumer PET bottle recyclate forms including powder, flakes or pellets on appropriate levels of the designatory properties including intrinsic viscosity, level of contaminations, water content, bulk density, recycling process used, form of the product, mesh size used in the case of pellet extrusion, filler, intended application and / or processing method, information regarding food packaging, color, etc.
ISO 12418-2	Definition of testing methods to be used for the determination of the properties of PET bottle recyclates, for example, presence of various impurities and contaminations
DIN CEN/TS 14541(DIN SPEC 16498)	Representation of characteristics for utilization of non- virgin PVC-U, PP, PP and PE materials
DIN CEN/TS 16861 (DIN SPEC 91009)	Definition of markers and analysis processes verifying purity of PET recyclates for food industry (merely as an additional guideline for Challenge Test of European Food Safety Authority (EFSA)

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