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Master of Science in Energy Engineering for an Environmentally Sustainable World

BIO-ENERGY AND WASTE-TO-ENERGY TECHNOLOGIES

Waste Recycling

A.Y. 2017/2018

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OUTLINE

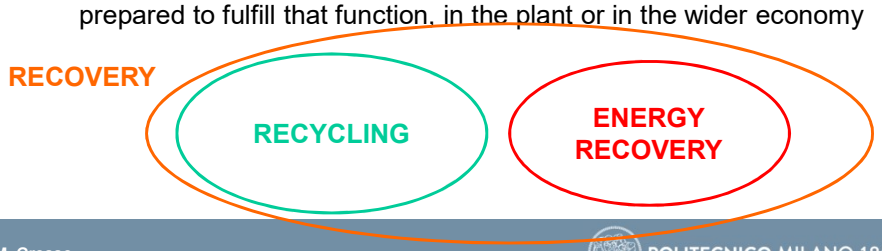
- *Recycling and recovery*
- *Packaging waste: current management*
- *Plastic recycling*
- *Glass recycling*
- *Paper recycling*
- *Aluminium recycling*
- *Energy and environmental considerations on material recycling*

RECYCLING AND RECOVERY

Definitions (Directive 2008/98/EC)

Recycling: any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations

Recovery: any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfill a particular function, or waste being prepared to fulfill that function, in the plant or in the wider economy



EU PACKAGING DIRECTIVE

Directive 2004/12/EC on packaging and packaging waste

Targets for recovery and recycling set for year 2008:

Overall recovery target: minimum 60%

Overall recycling targets: minimum 55%, maximum 80%

Minimum recycling targets for each material:

- ✓ 60% paper and glass
- ✓ 50% steel and aluminium
- ✓ 22.5% plastic (counting exclusively material that is recycled back into plastics) (*26% in Italy*)
- ✓ 15% wood (*35% in Italy*)

Percentages are calculated on the amount of packaging put in the market (and not on the packaging waste collected!)

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THE SITUATION IN ITALY: THE CONAI CONSORTIUM

National Packaging Consortium, established in 1997

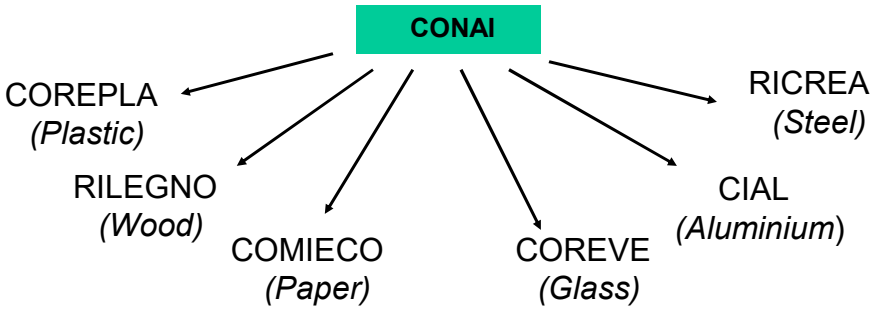
Entity aimed at:

- ensuring the achievement of recovery and recycling targets for packaging waste
- ensuring the necessary connection between the packaging waste collection system (managed by the local authorities) and the economic operators involved in all steps of the management of packaging materials

Annex E D.Lgs. 22/97

CONAI charges packaging producers and users a cost for subsequent separated collection, recovery and recycling through the so-called "environmental contribution" (*contributo ambientale CONAI*)

THE SITUATION IN ITALY: THE SIX CONSORTIA



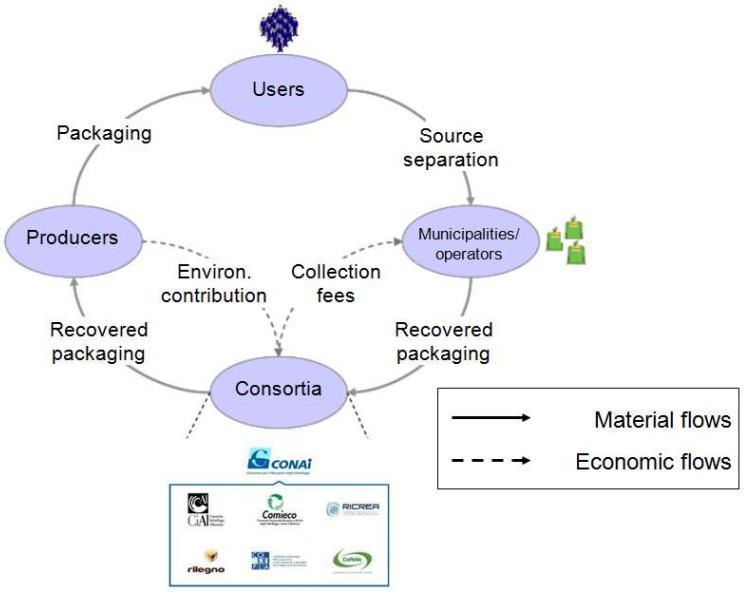
The Consortia gather all the companies involved in the **life cycle** of each material

CONAI directs and coordinates the activities of the consortia, in charge of the recovery and recycling, providing the necessary connection between them and the Public Administration

ANCI-CONAI agreement (started in 1999, renewed every 5 years)

→ defines the collection fees which are paid to the municipalities or to the managers of waste collection services

MATERIAL AND ECONOMIC FLOWS



MATERIAL AND ECONOMIC FLOWS

CONAI environmental contribution (CAC), in € per tonne

Material	Year 1998	Year 2018
Steel	15.49	8
Aluminium	51.64	45
Paper	15.49	4
Wood	2.58	7
Plastic	72.30	188 !!
Glass	2.58	13.3

MATERIAL AND ECONOMIC FLOWS

Collection fees depend on the **quality of the collected materials**

Also the **residues management** obligations are affected by the material quality

An example for plastic:

Type of collection	% impurities	Collection fee (euro/t)	Disposal of the sorting residues in charge to
Mono-material	≤ 5%	278	Consortium (Corepla)
	> 5%-16%	196	
	>16%	0	Local authority
Multi-material	≤ 10%	278	Consortium (Corepla)
	> 10%-20%	196	
	>20%	0	Local authority

PACKAGING MATERIALS RECOVERY

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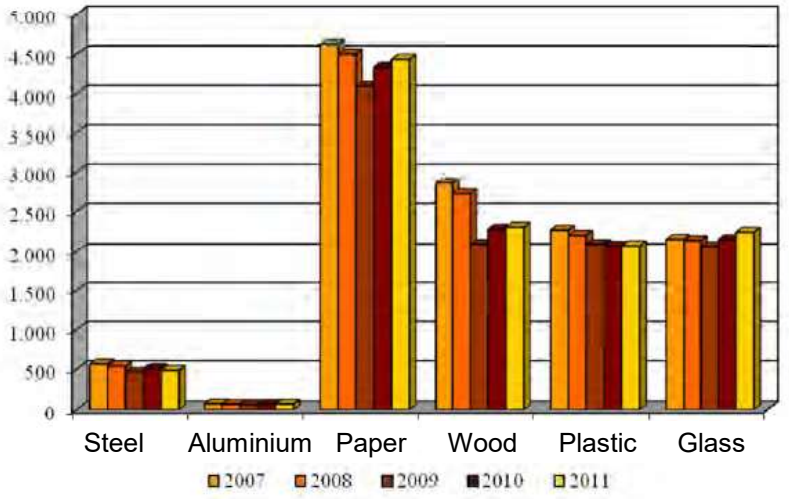
Amount of packaging put in the market (t * 1000)



Source: ISPRA, 2013

PACKAGING MATERIALS RECOVERY

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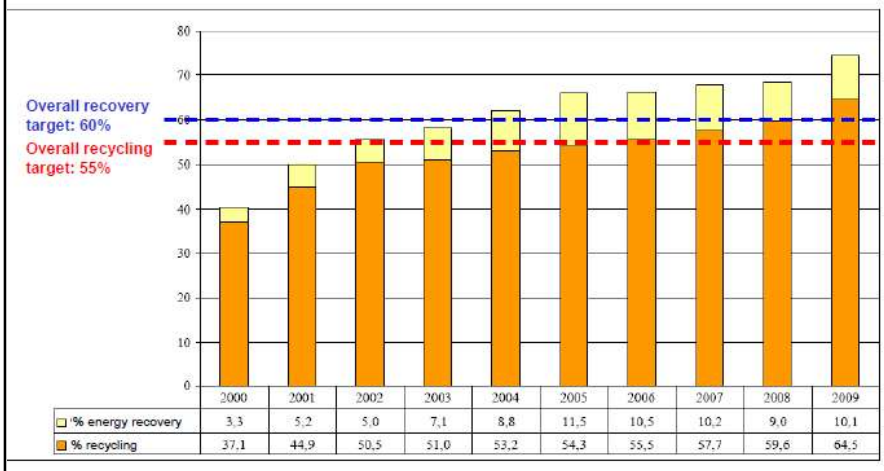
Recovery and recycling vs. EU targets



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
% energy recovery	3,3	5,2	5,0	7,1	8,8	11,5	10,5	10,2	9,0	10,1
% recycling	37,1	44,9	50,5	51,0	53,2	54,3	55,5	57,7	59,6	64,5

Source: ISPRA, 2011

PACKAGING MATERIALS RECOVERY

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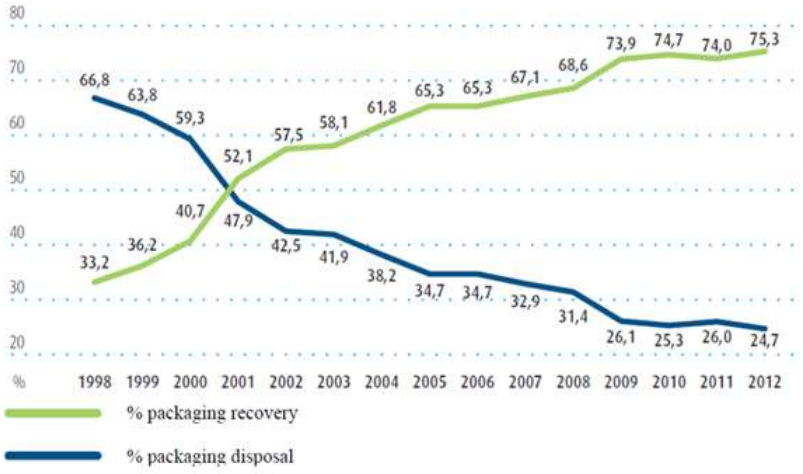
Evolution of waste packaging management in Italy



Source: CONAI

PACKAGING MATERIALS RECOVERY

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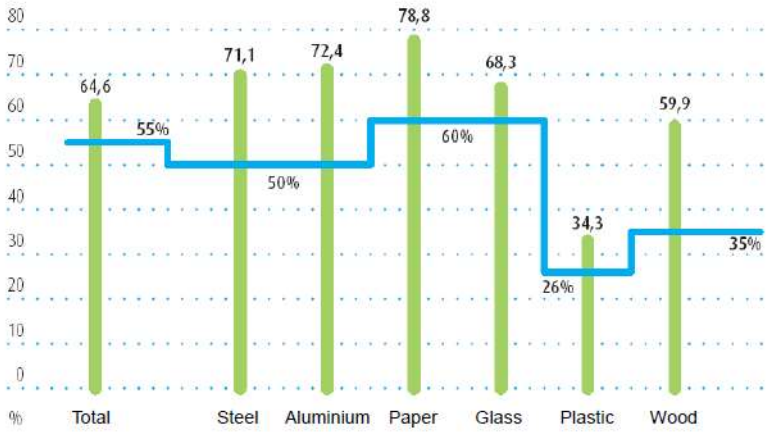
Recycling results in 2010, compared with the EU targets (in blue)



Source: CONAI, 2011

PACKAGING MATERIALS RECOVERY

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Recycling and recovery in Italy in 2010 compared with the 2008 targets set for Italy

Material	Packaging waste put in the market (kton)	Recycling (kton)	Energy recovery (kton)	Total recovery (kton)	Total recycling rate (%)	Total recovery rate (%)	Recycling targets 2008 (%)
Steel	504	358	-	358	71.1	71.1	**50**
Aluminium	64.2	46.5	3.5	50	72.4	77.9	**50**
Paper	4338	3416	361	3777	78.8	87.1	**60**
Wood	2233	1338	64	1402	59.9	62.8	**35**
Plastic	2073	711	744	1455	34.3	70.2	**26**
Glass	2153	1471	-	1471	68.3	68.3	**60**
TOTAL	**11366**	**7341**	**1172**	**8513**	**64.6**	**74.9**	**55**

Source: CONAI

GENERAL SORTING AND RECYCLING SCHEME

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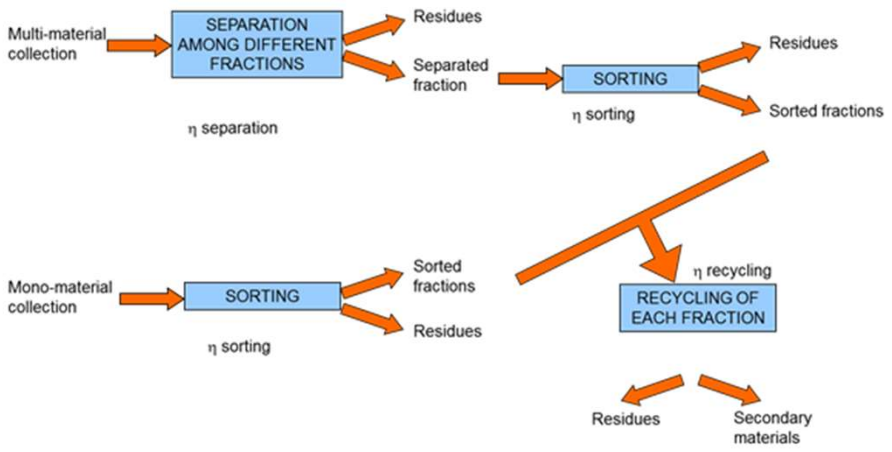

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PLASTIC RECOVERY

Polymers → large molecules composed of repeating structural units (monomers) made of C, H, O, Cl, derived from oil

2 TYPOLOGIES OF PLASTIC POLYMERS:

- thermoplastic: weak chemical bonds, do not undergo chemical change in their composition when heated and can be moulded again and again
- thermosetting: strong chemical bonds, they irreversibly cure, i.e. cannot be melted and re-shaped after they are cured

THERMOPLASTIC → easily recyclable into new plastic products

THERMOSETS → cannot be recycled, except as a filler material

PLASTIC RECOVERY

MAJOR TYPES OF THERMOPLASTIC POLYMERS:

- ✓ *HDPE – High-density polyethylene (Bottles, grocery bags, milk jugs, recycling bins, agricultural pipe, playground equipment)*
- ✓ *LDPE – Low density polyethylene (Plastic bags, various containers, dispensing bottles, various moulded laboratory equipment)*
- ✓ *PET – Polyethylene terephthalate (Polyester fibres, thermoformed sheet, strapping, and soft drink bottles)*
- ✓ *PP – Polypropylene (Auto parts, industrial fibres, food containers, and dishware)*
- ✓ *PS – Polystyrene (Desk accessories, cafeteria trays, plastic utensils, toys, video cassettes and cases, clamshell containers, and insulation board and other expanded polystyrene products - e.g., Styrofoam)*
- ✓ *PVC – Polyvinyl chloride (Pipe, fencing, shower curtains, lawn chairs, non-food bottles and children's toys)*

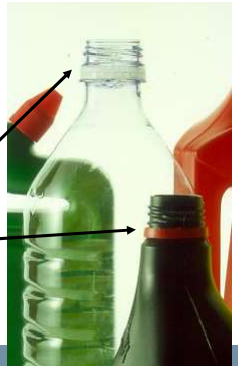
PLASTIC SORTING

Source separated plastic from household has to be firstly sorted in order to:

1. Remove any extraneous fraction (glass, paper, aluminium)
2. Separate the plastic packaging according to the type of polymer and possibly to the colour

→ Manual sorting

→ Automatic sorting (NIR* sensors)



PROBLEMS

- ➢ Bottles and caps made of different materials
- ➢ PVC gaskets within the caps of PET bottles

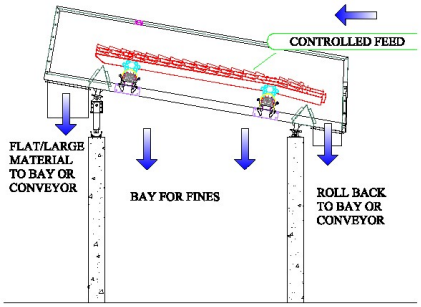
**** Near infra-red***

Sieving for size selection

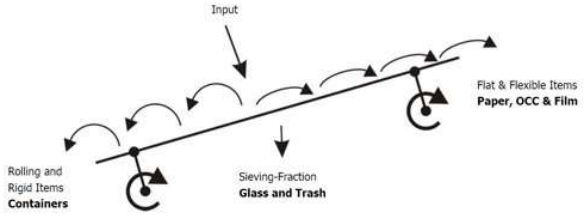
A single sieve can separate up to three streams:

- Large size: usually including plastic film (primarily LDPE). Other objects can be separated together with the film, in which they remain trapped
- Medium size: mainly bottles (PET and HDPE), that are the most interesting fractions for recycling. Impurities (pieces of film, plastic or non plastic objects of similar size) are contained in this stream
- Small size: stream of heterogeneous material: it can contain bottle caps, fragments of film, several impurities (metals, textile, paper etc.)

Ballistic separators



«2D vs. 3D» separation



PLASTIC SORTING

Ballistic separators

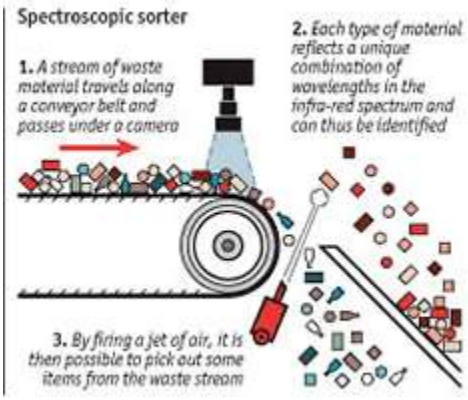
From min. 0:45

PLASTIC SORTING

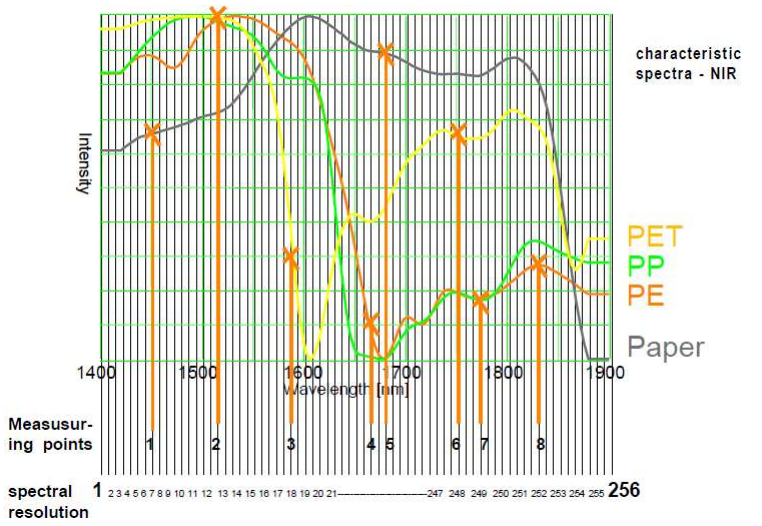
NIR sensor for polymer and colour separation

The sensor recognizes different polymers thanks to the reflection of infrared, which is typical for each plastic polymer: the sensor analyzes the reflected light and identifies the polymer

Air nozzles pneumatically shoot at the detected items to separate them



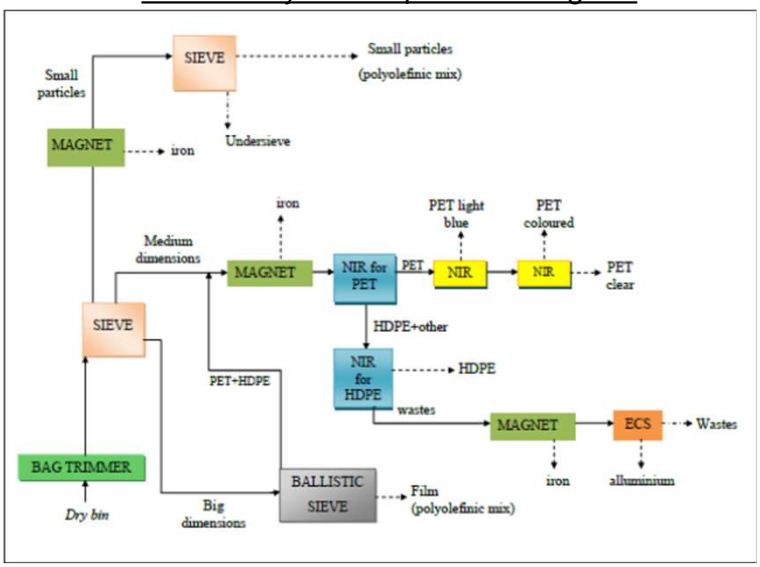
PLASTIC SORTING



"Black" plastic (mainly composed of PP) is the limit

PLASTIC SORTING

Possible layout of a plastic sorting line



PLASTIC SORTING

Sieves

NIR sensor

Courtesy of Montello SpA

PLASTIC RECYCLING

For each selected polymer, ex. PET:

1. Sorting: both manual and automatic (Metal and PVC detector)

2. Shredding: aimed at having a more homogeneous size distribution of the material, but still irregular in shape. An important volume reduction is obtained (1:5)

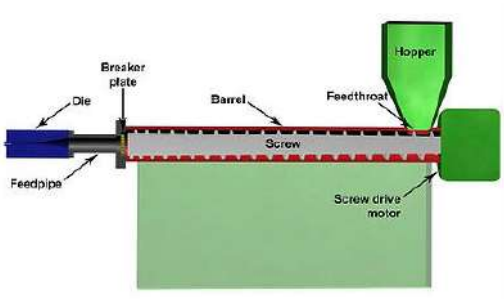
PLASTIC RECYCLING

3. Washing: with steam and caustic soda at 95°C in order to eliminate substances like glue, small metal parts, labels, fragments of HDPE caps (floating)
4. Grinding: for a further size reduction of the material (around 20 mm)
5. Drying: at 110°C by centrifugation and with the use of fans, down to a moisture content of 2-3%. PET dust is also separated by air filtration

Recycled PET flakes are obtained at this stage

PLASTIC RECYCLING

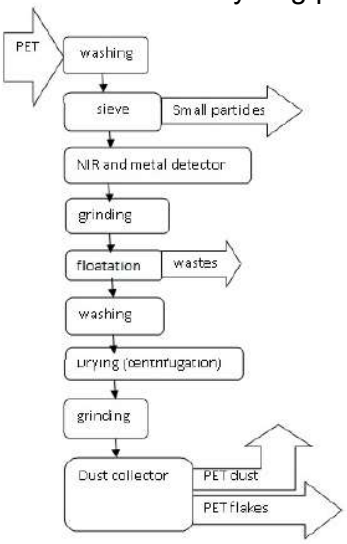
6. Granulation: material is sent to an extruder, where it is heated to the desired melting temperature of selected plastic polymer. The exiting molten polymer is then sliced in the form of 2-4 mm granules

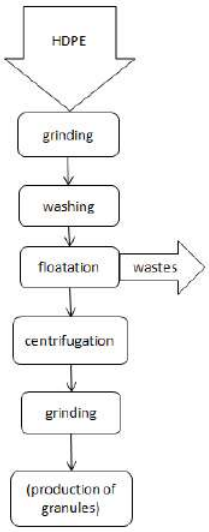


Granules are obtained at this stage

PLASTIC RECYCLING

Scheme of the recycling process for PET





Scheme of the recycling process for HDPE

PLASTIC RECYCLING

Example of a final product: dimpled sheet produced from granules of recycled HDPE

Courtesy of Montello SpA

PLASTIC RECYCLING

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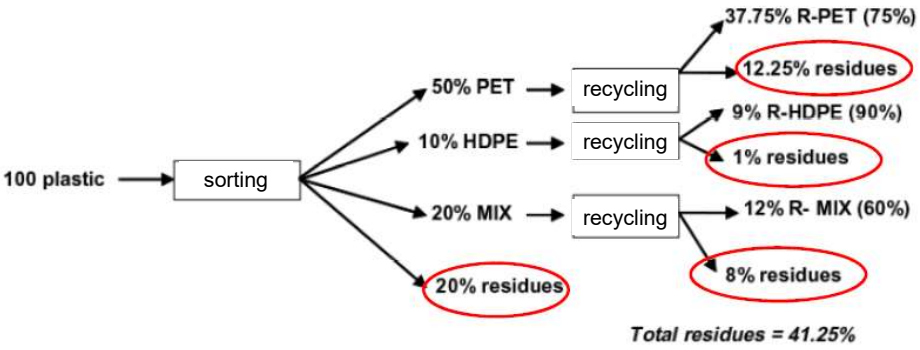

Typical mass balance of plastic recycling

L. Rigamonti, M. Grosso and M. Giugliano (2009). Waste Management, 29, 934-944

PLASTIC RECYCLING

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Sorting residues: composition of "Plasmix"

Plastic (%)	57
Paper and cardboard (%)	10
Wood (%)	3
Textiles (%)	3
Inerts and others, incl. metals (%)	27
TOTAL	**100**
LHV (kJ/kg)	20100
Ash (%)	20.5
Moisture (%)	9
C (%)	47.3
H (%)	7.1
Cl (%)	0.8
S (%)	0.2

Source: COREPLA, 2010

Uses for the recycled polymers

PET	Fibres for mats and textile materials (filters, absorbent material, camping equipment, filling for anoraks, sleeping bags, pillows)
PE	Bottles, waste bins, pipes, garden furniture
PVC	Pipes for sewage discharge, electric material
Mixed polymers	Low quality products

Recycled plastic and food contact

- **PET** (DM 134/2013)
  - ✓ Bottles shall be made of virgin PET for at least 50% of their weight and can be used with all types of beverages for prolonged storage at room temperature or below
  - ✓ Food trays made of recycled PET can be used with all types of food for prolonged storage at room temperature or below, but should not be used in a conventional or in a microwave oven
  - ✓ The recycled PET must come from a mechanical process approved by the EFSA (European Food Safety Authority)

PLASTIC RECYCLING

Recycled plastic and food contact

- **HDPE**
  - ✓ Removing volatiles from food bottles for their safe reuse is harder for HDPE than for PET (HDPE absorbs more volatiles and is processed at lower temperatures than PET)
  - ✓ HDPE bottles include a fraction of copolymer bottles for detergent and dishwashing liquids, which are loaded with perfumes and oils. These aren't allowed in food-grade HDPE (milk and water bottles are HDPE homopolymer)
  - ✓ homo- and copolymer bottles can't be mechanically separated by density, and are mainly separated by hand

According to a precautionary approach, use of recycled HDPE for the production of food containers should be carried out via multilayer packaging, with a layer of virgin HDPE in direct contact with food and an external layer in recycled material

PLASTIC RECOVERY

ENERGY RECOVERY

LHV of plastic: 30-35 MJ/kg

Low moisture and ash content

Co-combustion in

- *dedicated plants (grate or fluidised bed incineration plants)*
- *existing industrial plants (cement kilns)*

Combustion in

- *dedicated fluidised bed incinerators (not widespread)*

→ PROBLEM WITH CHLORINE (PVC)

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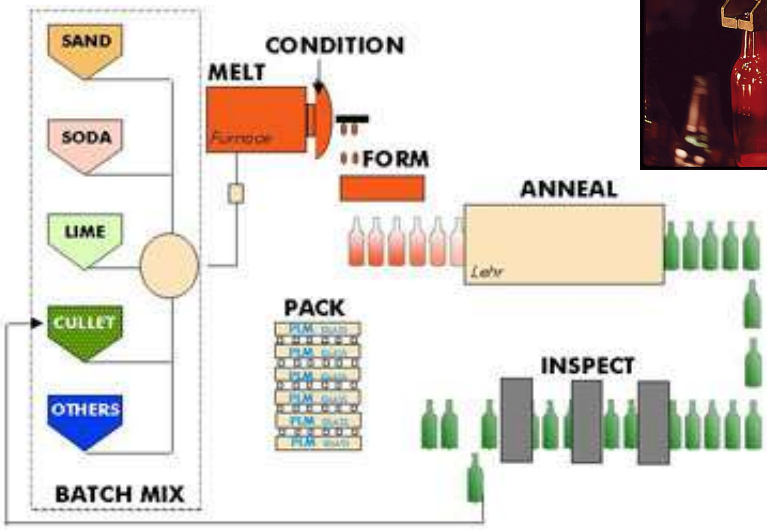
GLASS RECYCLING

Glass production process:

- sand (silica) is mixed with limestone (stabilizing), soda (melting), additives + glass cullet (up to 90% in weight)
- the mixture is fed into the furnace operated at temperatures up to 1575°C and natural gas- or fuel oil-fired
- molten glass is cast to obtain a product with the desired shape (i.e. a bottle)

GLASS CULLET → recycled crushed glass

GLASS RECYCLING



www.tynant.com

GLASS RECYCLING

ADVANTAGES OF GLASS RECYCLING

<u>Energy-intensive process</u>

→ Glass cullet has a lower melting temperature compared to raw materials:

- *lower fuel and electric energy consumptions (roughly 2.5% of fuel is saved in the furnace for each 10% of glass cullet utilised in the feeding mixture)*
- *reduced atmospheric emissions*
- *extended lifespan of the furnace*

<u>Reduced use of raw materials</u> (100 kg of glass are obtained starting from 100 kg of glass cullet, while 120 kg of raw materials would be required)

GLASS RECYCLING

PROBLEMS OF GLASS RECYCLING

Colour separation

- *green*
- *white*
- *brown*

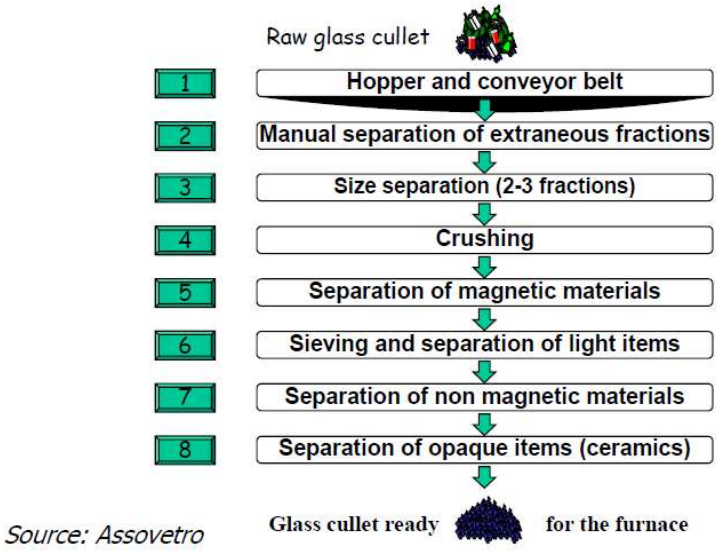
Historically adopted in Germany and Switzerland → three compartments bins

Green glass tolerates more contamination from other colors

The vast majority of recycled glass in Italy joins in the production of green hollow glass

GLASS RECYCLING

Scheme of a waste glass selection plant



Source: Assovetro

SECONDARY MATERIALS FROM GLASS RECYCLING

High quality glass cullet

- *90% new glass containers (bottles)*
- *10% secondary uses (abrasives, glass fiber,…)*

Low quality glass cullet

- *secondary uses*

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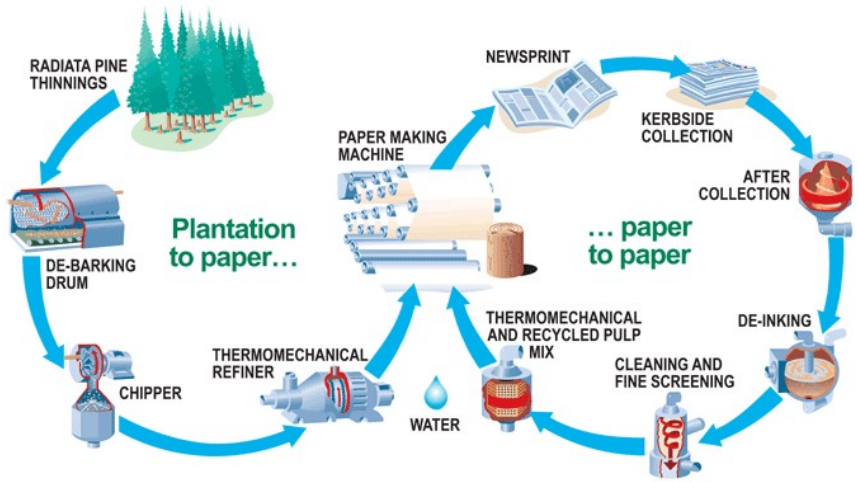
PAPER RECYCLING

WASTE PAPER SORTING

Waste paper is sorted (generally manually) among its major components:

- *cardboard packaging*
- *mixed paper*
- *residues*

PAPER RECYCLING



PAPER RECYCLING

Selected waste paper is:

- pulped
- sieved (to remove the contaminants)
- washed (to remove the glue)
- de-inked (if necessary)
- whitened (if necessary)

It is then mixed with primary raw material and sent to the paper machine, where pulp is progressively dehydrated and dried to originate the final sheet of paper

PAPER PRODUCTION

1. Pulp production
2. The pulp is feed to a paper machine where it is formed as a paper web and the water is removed from it by pressing and drying
3. Finishing (sizing, coating…)

Primary pulp production:
- Chemical processes (sulfate process, sulfite process)

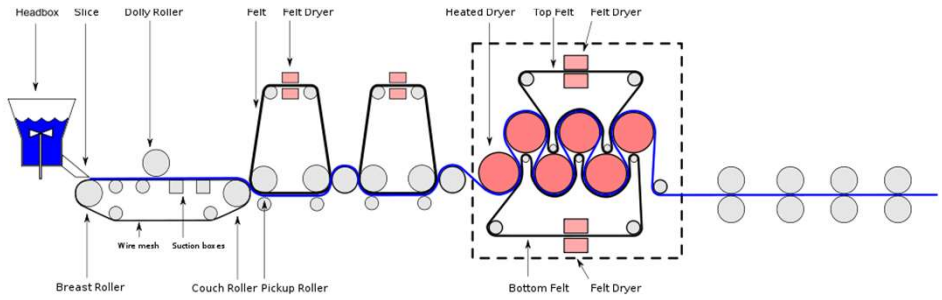
or

- Mechanical processes (thermo mechanical pulp and groundwood pulp)

Secondary pulp production:
- Selection of waste paper
- Maceration process in a pulper
- Eventually de-inking

PAPER PRODUCTION

Scheme of the Fourdrinier paper machine



PAPER RECYCLING

PROBLEMS AND LIMITATIONS

Characteristics of the fibres:

- virgin paper → long fibres
- recycled paper → short fibres

Fibres are degraded at each recycling step → progressive deterioration of the quality of recycled paper

<u>MAXIMUM AVERAGE NUMBER OF RECYCLING STEPS IS 4 TO 6</u>

Paper for books: up to 25% of waste paper

Newsprint: up to 35% of waste paper

Paper and cardboard for packaging: up to 90% of waste paper

ENERGY AND MATERIAL CONSUMPTION

Raw materials → pulp → paper

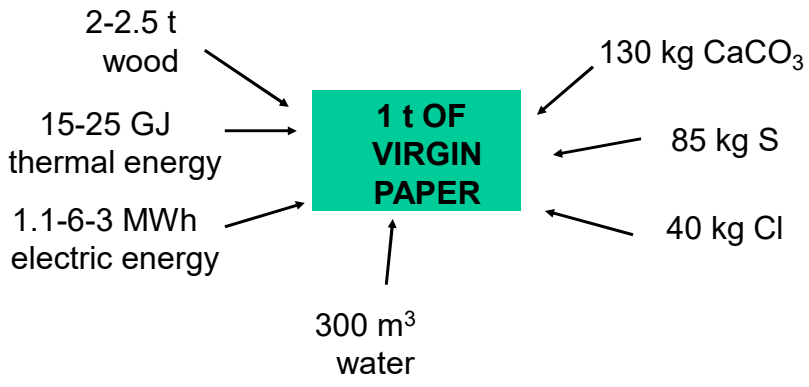
10-14 GJ/t
0.6-4.3 MWh/t

5-11 GJ/t
0,5-2 MWh/t

Waste paper

Raw material → pulp → paper

ENERGY AND MATERIAL CONSUMPTION



Recycled paper: savings of energy (40%), raw materials, water (60%)

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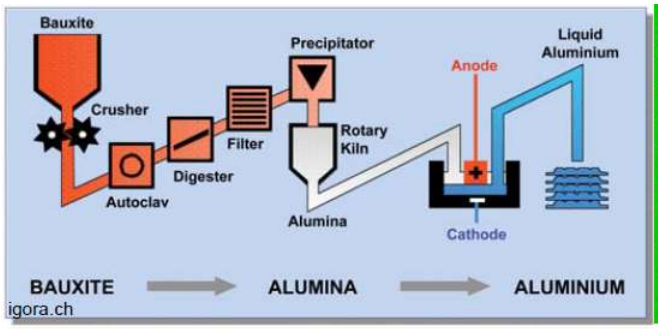
ALUMINIUM RECYCLING

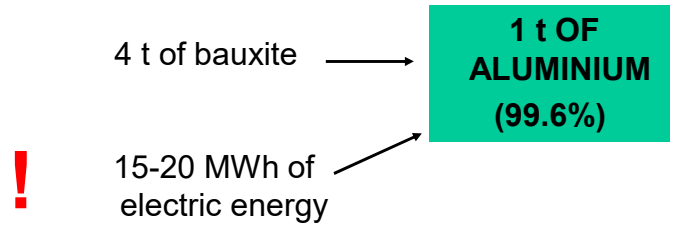


Primary production:
- bauxite mining
- production of alumina in the Bayer process
- production of aluminium dissolving alumina in an electrolytic bath (Hall-Héroult Process)

Secondary production: once sorted, scrap aluminium is then loaded into a furnace (rotary kiln under a salt cover), which melts the aluminium completely

ALLUMINIUM PRODUCTION

1. Bauxite mining
2. Refining to alumina, Al_2O_3 (Bayer chemical process)
3. Production of metallic aluminium (electrolytic process)



RECYCLING PROCESS

Waste aluminium from separated collection is:

- sorted from other materials (iron, glass)
- crushed (2.5 – 7.5 cm)
- treated at 500°C in pyrolytic kilns to remove paint and other adhering substances
- compacted into disks
- sent to a preheating kiln (T = 315°C)
- melted (at 800°C) in a saline rotary furnace and cast in the form of ingots (sodium chloride is fed in the furnace, which forms a "crust" that surrounds the molten aluminium by preventing its oxidation to Al_2O_3 due to the contact with air)

BENEFITS OF RECYCLING

- As for glass, it can be recycled a number of times without quality deterioration
- Huge energy savings are obtained by using secondary instead of primary aluminium

→ *Electricity saving up to 95%*
Savings in raw materials (bauxite)

ENERGY RECOVERY FROM ALUMINIUM

The aluminium powder is combustible

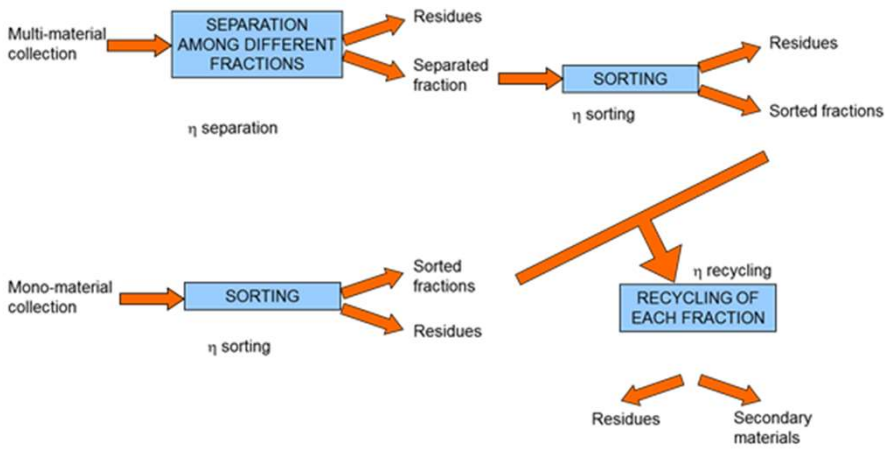
The aluminium into thin sheets thickness (< 50 μm) behaves similarly to the powder

→ Above 850°C thin aluminium yields energy: 1 kg of aluminium results in an energy release of 31 MJ, comparable to the energy produced by the combustion of 1 kg of coal or 0.8 kg of oil

OUTLINE

- *Recycling and recovery*
- *Packaging waste: current management*
- *Plastic recycling*
- *Glass recycling*
- *Paper recycling*
- *Aluminium recycling*
- *Energy and environmental considerations on material recycling*

ENERGY AND ENVIRONMENTAL CONSIDERATIONS ON MATERIAL RECYCLING



ENERGY AND ENVIRONMENTAL CONSIDERATIONS ON MATERIAL RECYCLING

Mass balance of sorting and recycling

MATERIAL	SORTING EFFICIENCY (weight %) (A)	RECYCLING EFFICIENCY (weight %) (B)	RECOVERY EFFICIENCY (weight %) (A × B)
Steel	92	90	82.8
Aluminium	90	83	74.7
Glass	94	100	94
Paper	95	90	85.5
Wood	86	95	81.7 (44.5 after drying)
Plastic	80	73.5	58.75

ENERGY AND ENVIRONMENTAL CONSIDERATIONS ON MATERIAL RECYCLING

Recycling vs. “downcycling”

Steel, **aluminium** and **glass** are not degraded with recycling

→ “permanent” materials

→ 1 to 1 substitution with corresponding primary materials

Plastic, **paper** and **wood** are progressively degraded during recycling

→ possible “downcycling”

→ 1 to <1 substitution of primary materials

ENERGY AND ENVIRONMENTAL CONSIDERATIONS ON MATERIAL RECYCLING

Primary energy saving of recycling compared to the primary production