Workshop: Lifecycle of Plastics

# Sorting and pretreatment of plastic waste

*Steven De Meester, Laboratory for Circular Process Engineering, Ghent University*

08/09/2020, Network-Wide Training Event 1

C-PlaNeT
CIRCULAR PLASTICS NETWORK FOR TRAINING

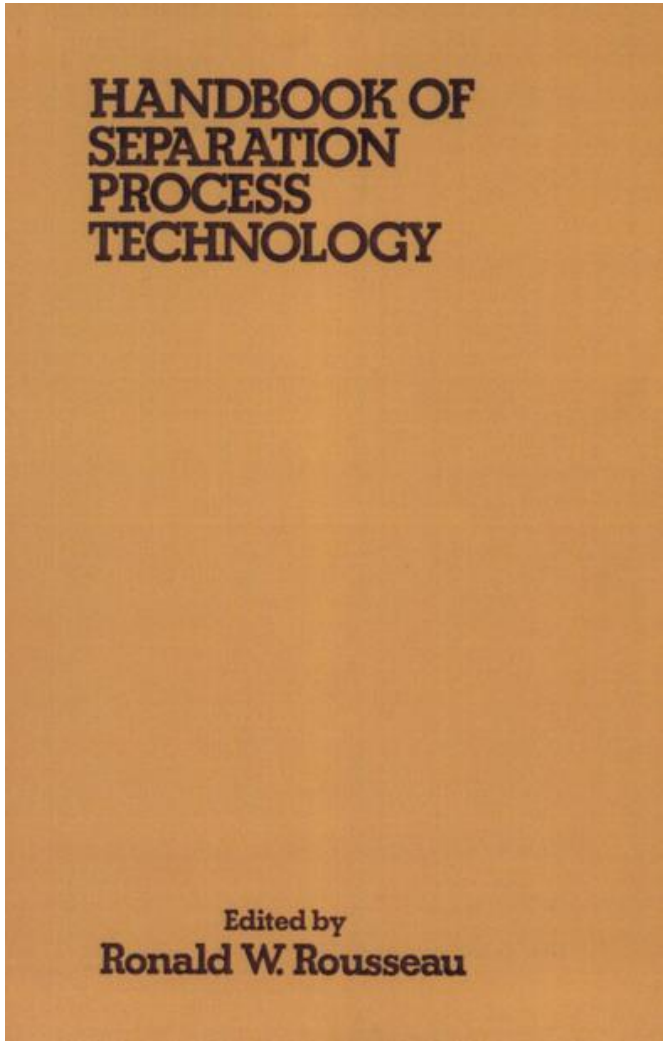
This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No. 859885.

# Waste pretreatment

?

?

# Let’s separate!

# Let’s follow the guidelines!

**TABLE 4.2-1 Summary of General Heuristics**

1. Select the separation methods first.
2. Always attempt to reduce the separation load.
3. Remove corrosive and unstable materials early.
4. Separate the most plentiful components early.
5. Save the most difficult separations for last.
6. Separations with high recovery fractions should be done last.
7. Move toward sequences with the smallest number of products.
8. Avoid adding foreign species to the separation sequence.
9. If used, immediately recover a mass separating agent.
10. Do not use another mass separating agent to recover the original one.
11. Avoid extreme operating conditions.

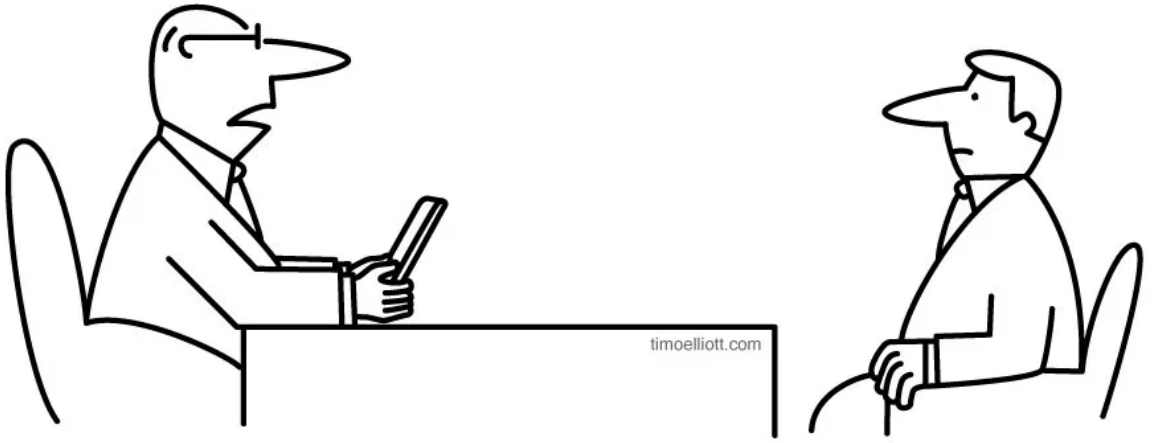
# 1. Select the separation methods

1. *Select the Separation Methods First.* Rudd et al.[5] point out that for a given process the most difficult task involves separating components from a mixture. In the section on selection of separation techniques, many of the factors that must be taken into account during the separation task selection were pointed out. The most important consideration involves evaluating the basis for separation which requires examining data on physical and chemical properties. Ranked lists are generated that are then used to evaluate possible separation methods. For instance, if components A, B, C, D, and E are to be separated, their relative volatilities and solubilities in a particular solvent may be pertinent. The following ranked lists, in descending order, might result:

**So what are the physicochemical properties of this heap?**

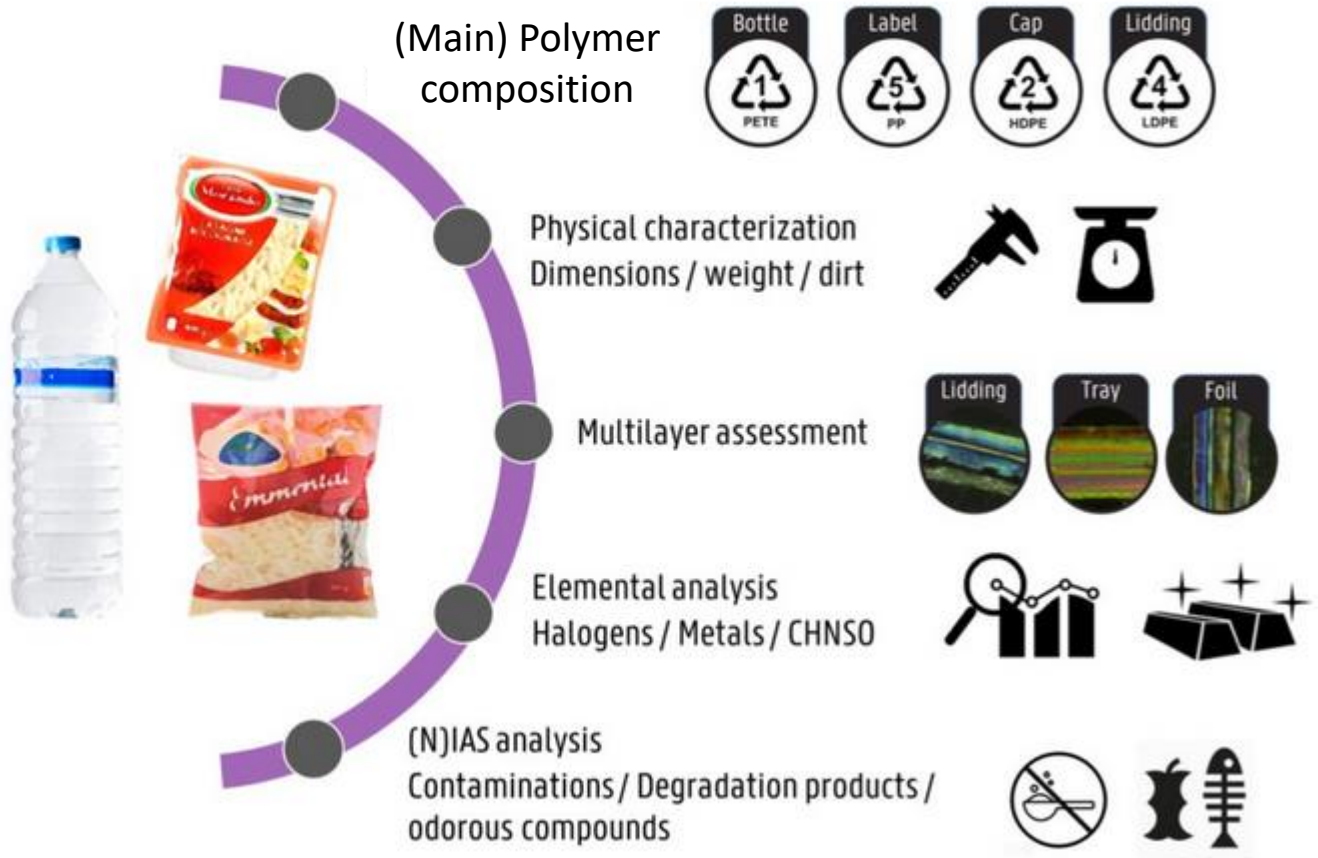
# Nothing to display

There are no data by this time

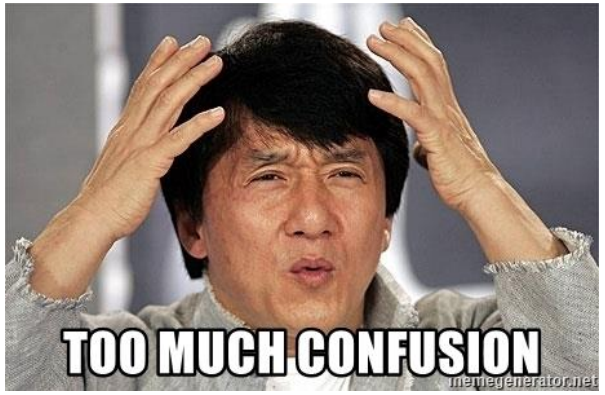



*"No, I'm afraid we can't 'just make the data up'*
*—this is business, not politics..."*

# Levels of physicochemical properties




➔ Does anyone have a detailed sampling and characterisation protocol by the way?



# But, there is something…

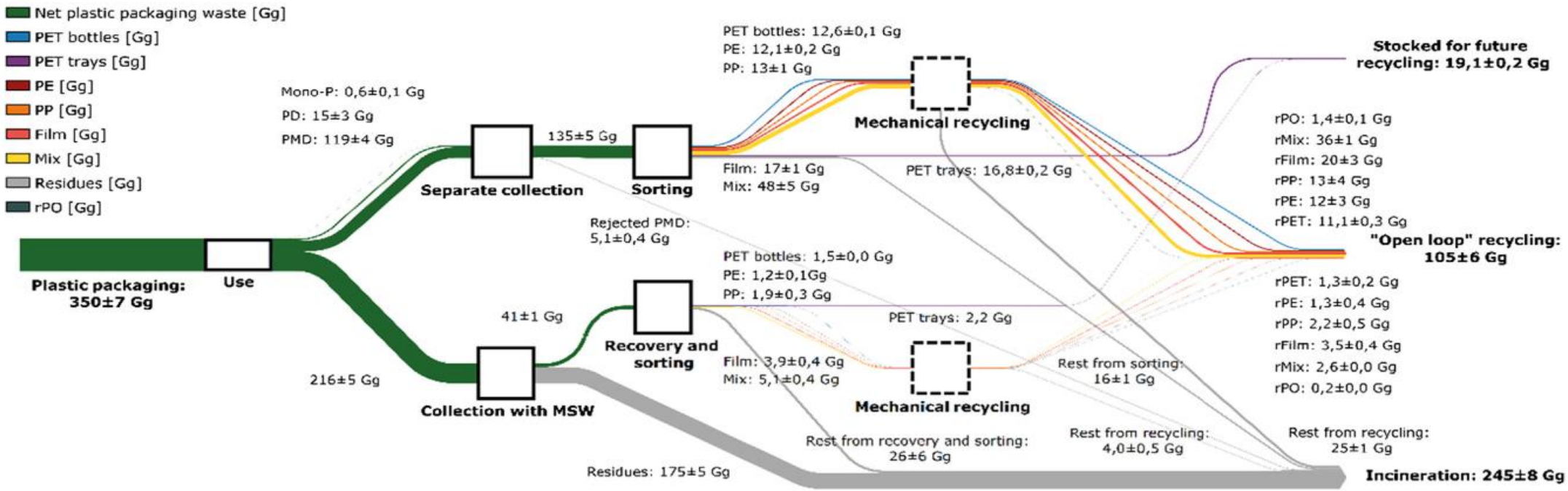



**Table 5**
The material composition of the washed milled goods of 2014 and 2017 [%].

| | | PET | PE | PP | PS | PVC | Paper | Metal | Glass | Other | Rest |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PET SC | **2014** | 98.6 ± 22.3 | 0.1 ± 0.0 | 0.1 ± 0.2 | 0.5 ± 0.2 | 0.1 ± 0.1 | 0.1 | 0.2 | 0.0 | 0.2 | 0.1 |
| | **2017** | 98.8 ± 3.4 | 0.1 ± 0.0 | 0.1 ± 0.1 | 0.3 ± 0.0 | 0.0 ± 0.1 | 0.1 | 0.1 | 0.0 | 0.1 | 0.4 |
| PE SC | **2014** | 0.0 ± 0.0 | 89.4 ± 11.1 | 9.8 ± 1.8 | 0.1 ± 0.0 | 0.1 ± 0.1 | 0.0 | 0.0 | 0.0 | 0.6 | 0.0 |
| | **2017** | 0.0 ± 0.0 | 92.6 ± 38.9 | 7.1 ± 2.0 | 0.0 ± 0.0 | 0.0 ± 0.0 | 0.0 | 0.0 | 0.0 | 0.3 | 0.0 |
| PP SC | **2014** | 0.1 ± 0.1 | 3.8 ± 1.3 | 93.1 ± 19.9 | 0.2 ± 0.1 | 0.4 ± 1.6 | 0.0 | 0.0 | 0.0 | 2.4 | 0.0 |
| | **2017** | 0.0 ± 0.1 | 5.4 ± 1.8 | 92.0 ± 46.2 | 0.1 ± 0.0 | 0.3 ± 0.4 | 0.0 | 0.0 | 0.0 | 2.3 | 0.0 |
| Film SC | **2014** | 0.0 ± 0.1 | 81.7 ± 26.0 | 14.7 ± 4.8 | 0.3 ± 0.2 | 0.2 ± 0.3 | 0.0 | 0.0 | 0.0 | 3.1 | 0.0 |
| | **2017** | 0.0 ± 0.0 | 82.8 ± 20.6 | 13.0 ± 2.1 | 0.1 ± 0.0 | 0.1 ± 0.2 | 0.0 | 0.0 | 0.0 | 4.0 | 0.0 |
| MIX SC | **2014** | 0.6 ± 0.9 | 47.5 ± 20.3 | 39.6 ± 14.7 | 3.9 ± 2.0 | 1.0 ± 1.4 | 0.0 | 0.0 | 0.0 | 7.4 | 0.0 |
| | **2017** | 0.2 ± 0.3 | 51.2 ± 2.3 | 36.4 ± 1.6 | 1.7 ± 0.3 | 0.8 ± 1.1 | 0.0 | 0.0 | 0.0 | 9.7 | 0.0 |

Contents lists available at ScienceDirect
Waste Management
journal homepage: www.elsevier.com/locate/wasman

The impact of collection portfolio expansion on key performance indicators of the Dutch recycling system for Post-Consumer Plastic Packaging Waste, a comparison between 2014 and 2017

Marieke Brouwer [a,b,1,*], Caterina Picuno [c], Eggo U. Thoden van Velzen [a,b,*], Kerstin Kuchta [c], Steven De Meester [d], Kim Ragaert [e]

## B.2 Composition of rigid plastic waste - polymer, product type and product design

Table B2: Detailed composition of source separated rigid plastic waste from the municipality of Copenhagen, 2017, divided into product types, polymer groups and product purity. TT: Trays and tubs, SP: Single polymer, MP-S: Multi polymer – separable, MP-NS: Multi polymer – *non*-separable.

| Polymer | PET | | | PE | | | PP | | | Other polymers | | | Sum |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Product design | SP | MP-S | MP-NS | SP | MP-S | MP-NS | SP | MP-S | MP-NS | SP | MP-S | MP-NS | |
| ***Food packaging*** | ***12-13*** | ***7-8*** | ***4-5*** | ***3*** | ***2*** | ***0*** | ***12-15*** | ***0*** | ***6-7*** | ***1-2*** | ***0*** | ***1*** | ***51-52*** |
| Bottles for beverages | 0 | 5-6 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7-8 |
| Bottles and cans for food | 0 | 2 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4-5 |
| TT-fruit and vegetable | 2 | 0 | 0 | 0 | 0 | 0 | 0-1 | 0 | 0 | 0-1 | 0 | 0 | 3-4 |
| TT-dairy | 0 | 0 | 0 | 0 | 0 | 0 | 4-5 | 0 | 0 | 0-1 | 0 | 0 | 5 |
| TT-meat | 1 | 0 | 3 | 0 | 0 | 0 | 0-1 | 0 | 6 | 0 | 0 | 0 | 10-11 |
| TT-other/unidentified food | 8-9 | 0 | 1 | 0 | 0 | 0 | 7-8 | 0 | 1 | 0 | 0 | 1 | 18-19 |
| Other rigid food packaging | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 |
| ***Non-food packaging*** | ***2-3*** | ***3-4*** | ***0*** | ***4-5*** | ***14-15*** | ***0*** | ***3*** | ***0*** | ***0*** | ***1-3*** | ***0*** | ***0*** | ***29-31*** |
| Bottles for hygiene and cleaning | 0 | 3-4 | 0 | 2 | 11-12 | 0 | 1-2 | 0 | 0 | 0 | 0 | 0 | 19-20 |
| Bottles with hazardous labelling | 0 | 0 | 0 | 3-2 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4-5 |
| Other rigid non-food packaging | 2 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 1-3 | 0 | 0 | 5-7 |
| ***Non-packaging*** | ***0*** | ***0*** | ***0*** | ***2-3*** | ***0*** | ***0*** | ***7-8*** | ***1-2*** | ***0-1*** | ***4-5*** | ***0-1*** | ***0-1*** | ***18-19*** |
| Toys | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| Flower pots | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 2-3 |
| Others | 0 | 0 | 0 | 2 | 0 | 0 | 5-6 | 1-2 | 1 | 3-4 | 0 | 0-1 | 14-16 |
| ***Sum*** | ***15*** | ***10-12*** | ***4-5*** | ***9-10*** | ***16-17*** | ***0*** | ***22-26*** | ***1-3*** | ***8*** | ***6-8*** | ***1*** | ***1-2*** | ***100*** |

Contents lists available at ScienceDirect

Waste Management

journal homepage: www.elsevier.com/locate/wasman

# Characterisation of source-separated, rigid plastic waste and evaluation of recycling initiatives: Effects of product design and source-separation system

M.K. Eriksen *, T.F. Astrup

*Department of Environmental Engineering, Technical University of Denmark, DK-2800 Kgs. Lyngby, Denmark*

# REFLEX PROJECT

## A summary report on the results and findings from the REFLEX project

Figure 2 Ordered composition of post-consumer film by application (percentage by weight)

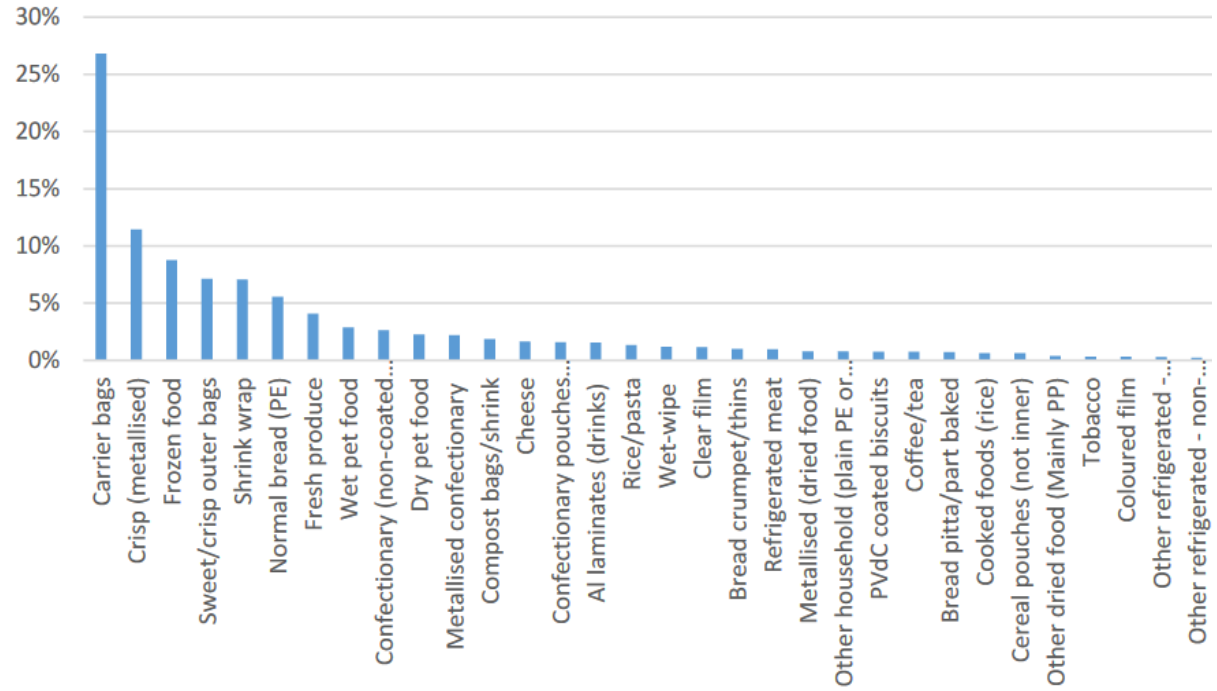
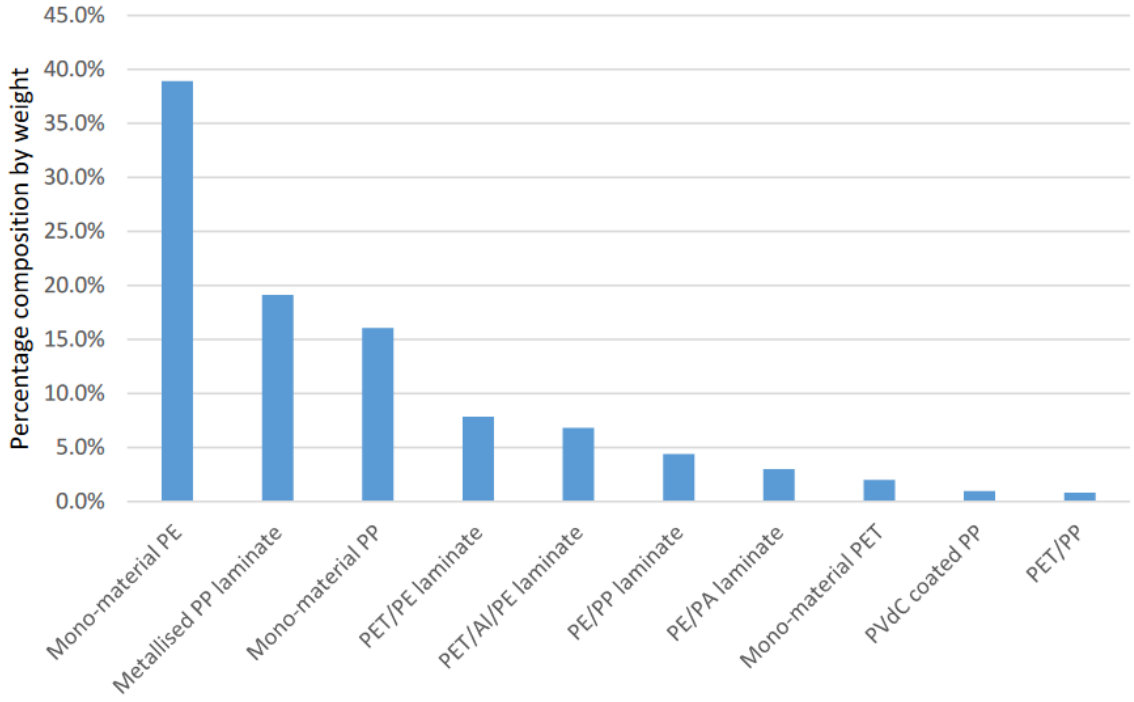
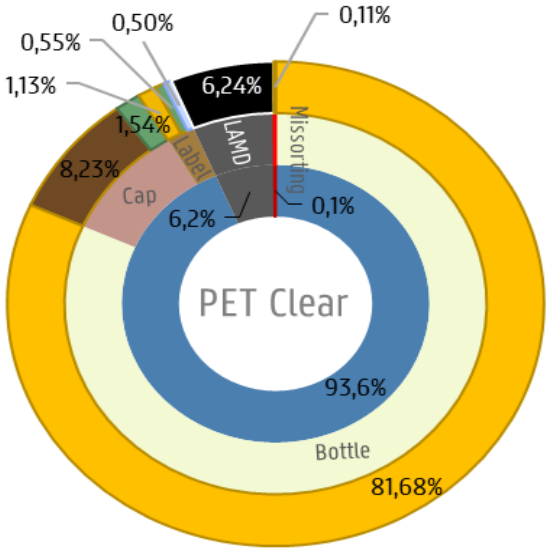
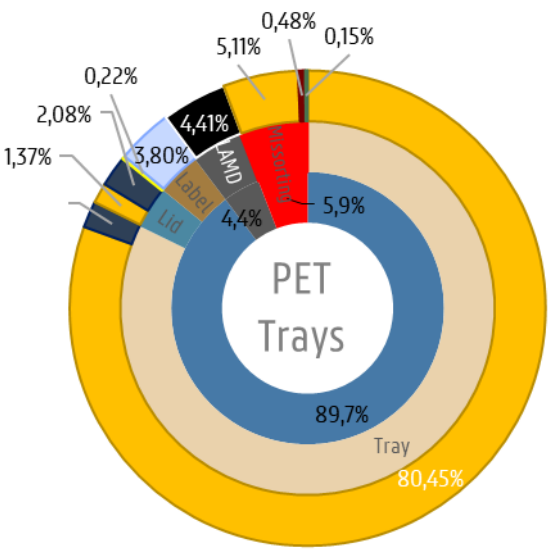


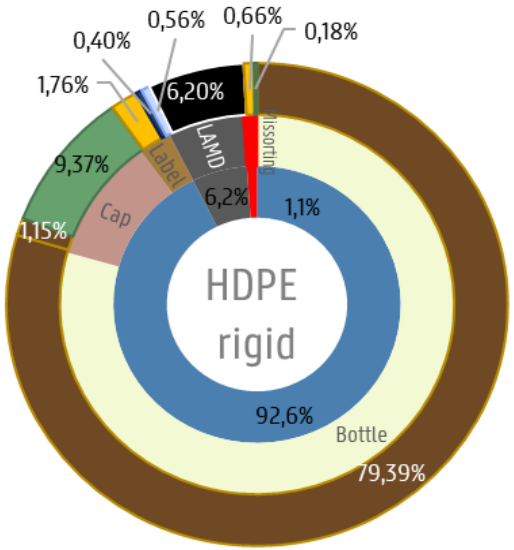

Figure 4 Composition of flexible packaging in residual waste by polymer structure

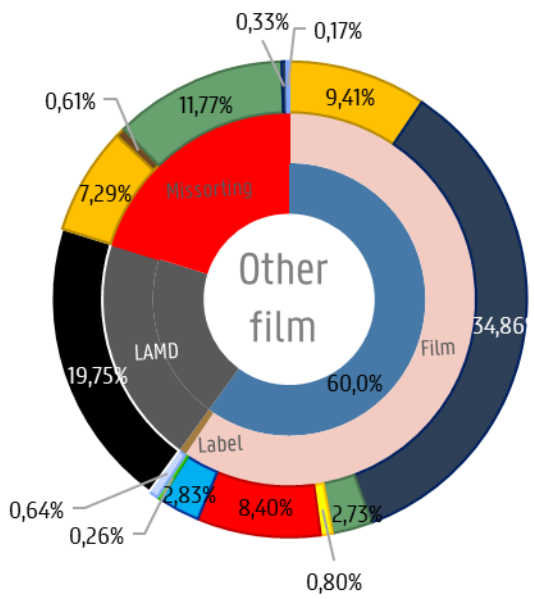


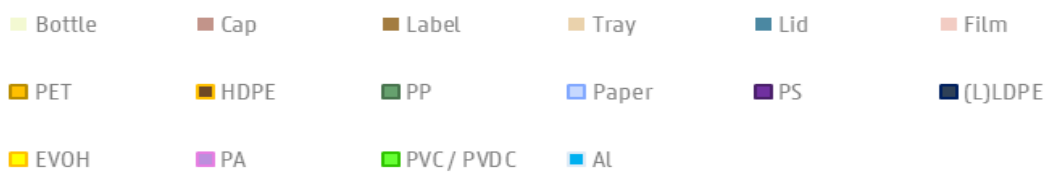

https://ceflex.eu/public_downloads/REFLEX-Summary-report-Final-report-November2016.pdf



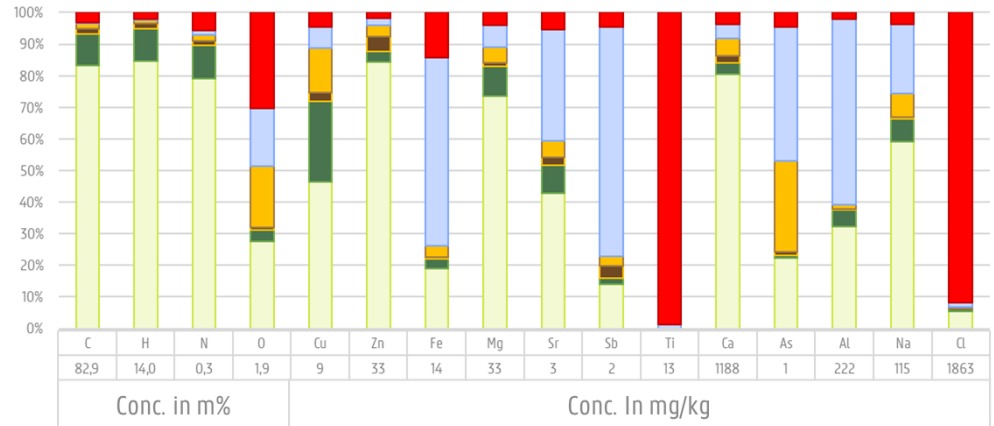



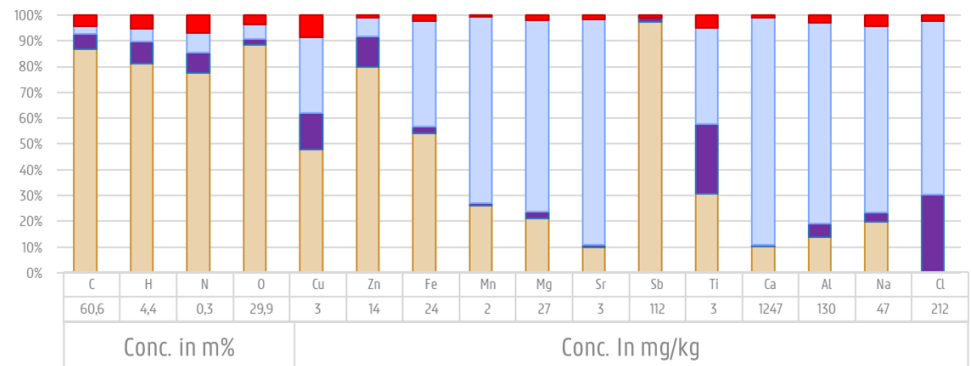

MATTER
Mechanical and Thermochemical Recycling of mixed plastic waste

CATALISTI
WE MEAN BUSINESS

HDPE




PET trays




Bottle Tray Film Cap – PE Cap – PP Lid Label – plastic Label – paper Missorting

# Ok, let us start from those compositions

# Compaction

| Name | kg/m3 | source |
|---|---|---|
| LDPE films, loose | 17 | Average from http://www.tellus.org & http://www.federalinternational.com/ |
| Rigid plastics big pieces & mixed rigid | 49 | N State |
| PP film | 14 | Tellus |
| PVC, loose | 202 | Tellus |
| EPS | 6 | U.S. EPA |
| PET soda bottles, whole, loose | 21 | MN STATE |
| PET film | 14 | Tellus |
| SipWell 10L | 55 | SipWell e-mail contact |
| LDPE, compacted | 89 | http://www.federalinternational.com/ |

Waste often < 100kg/m³
If you push hard on your bin, maybe <150kg/m³
During transport < 300kg/m³

# Compaction: baling

# Compaction: Pelletising

- Create friction/heat to ‘melt it together’
- High density

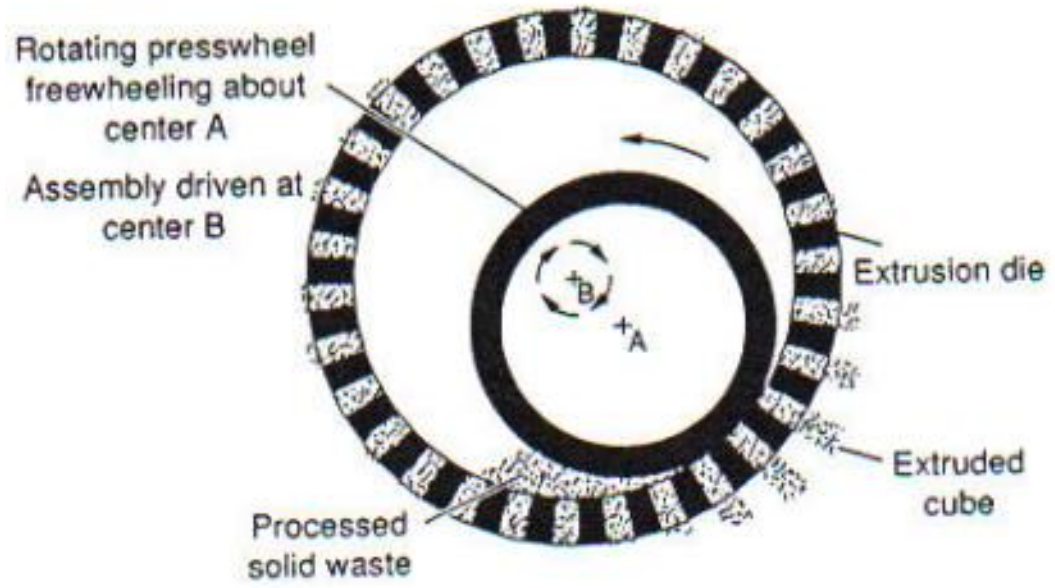
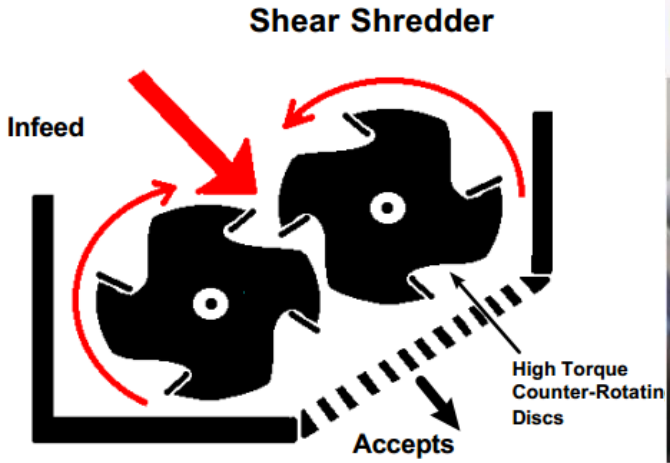



**FIGURE 12-18**
Cross section of extrusion dies used in a typical cubing machine for processed MSW. Note: Pelleting machines work on a similar principle, but the diameter of the dies is smaller.

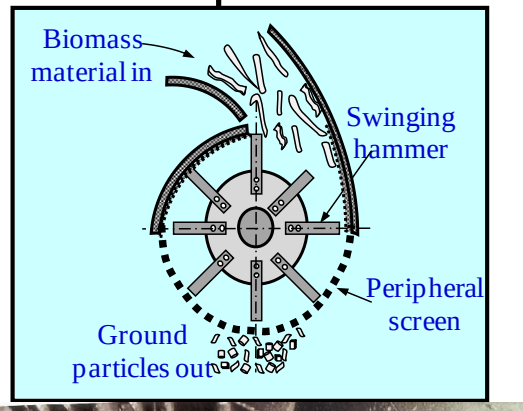
# Size reduction

- Why?
  - Homogenisation
  - Better handling
  - Increase surface to volume area
- 3 options: shear, impact, cut

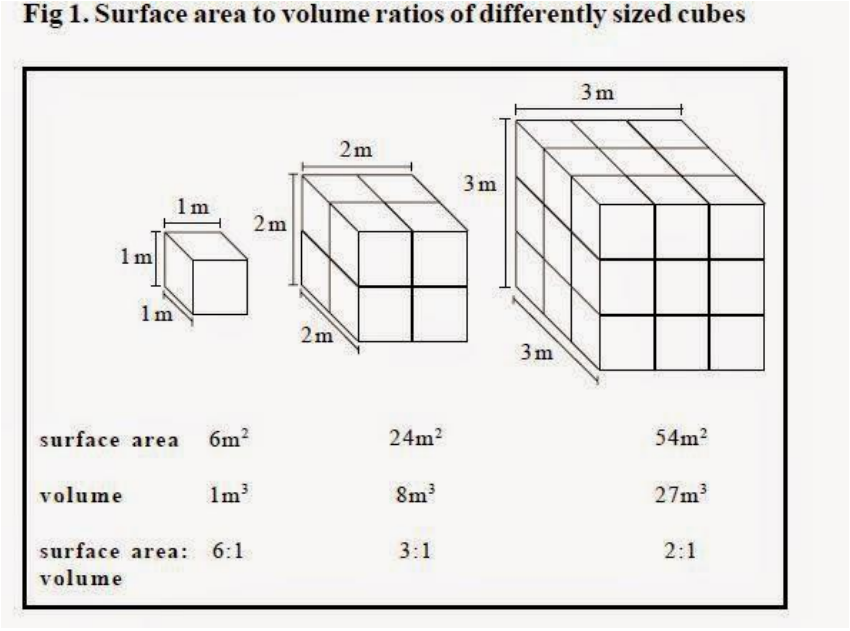




Impact




Cut

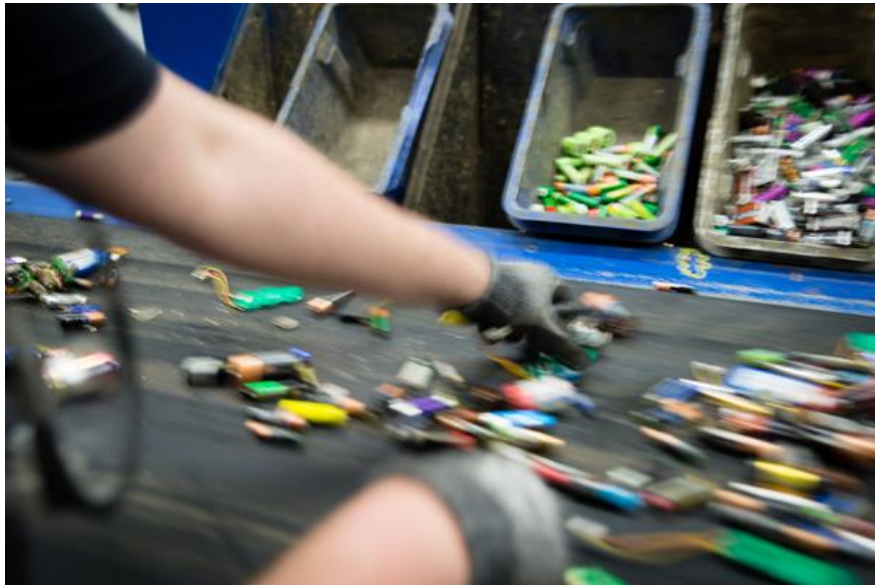


Wait a minute!

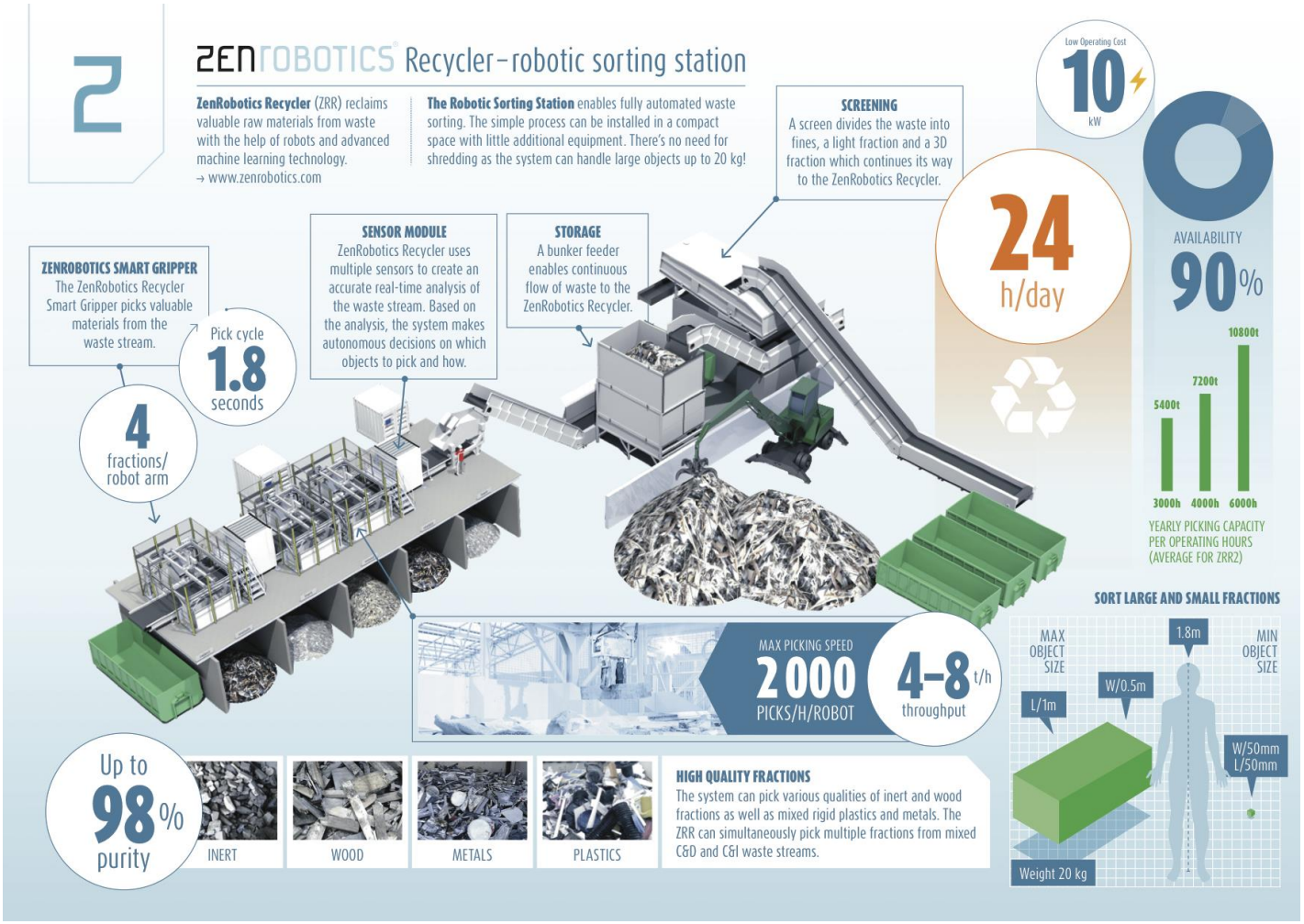
Separation before shredding and compaction


PHOTO COURTESY OF TOTAL RECLAIM

Manual dismantling plays a large role on the production line at Total Reclaim in Seattle, Washington.



# That’s a bit old school?



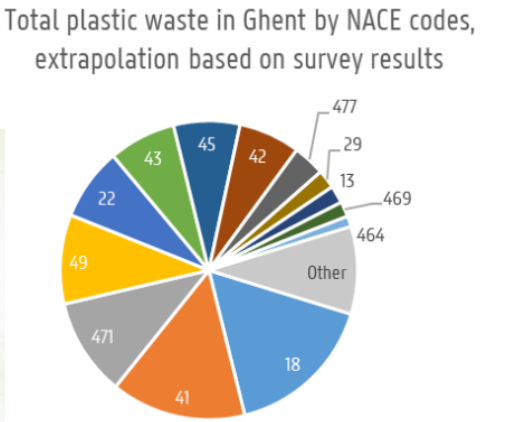



https://www.youtube.com/watch?time_continue=97&v=X_1sOPqM_VA&feature=emb_logo

# Post-commercial waste

Interreg 2 Seas Mers Zeeën PlastiCity
EUROPEAN UNION
European Regional Development Fund

‘perskraakwagen’



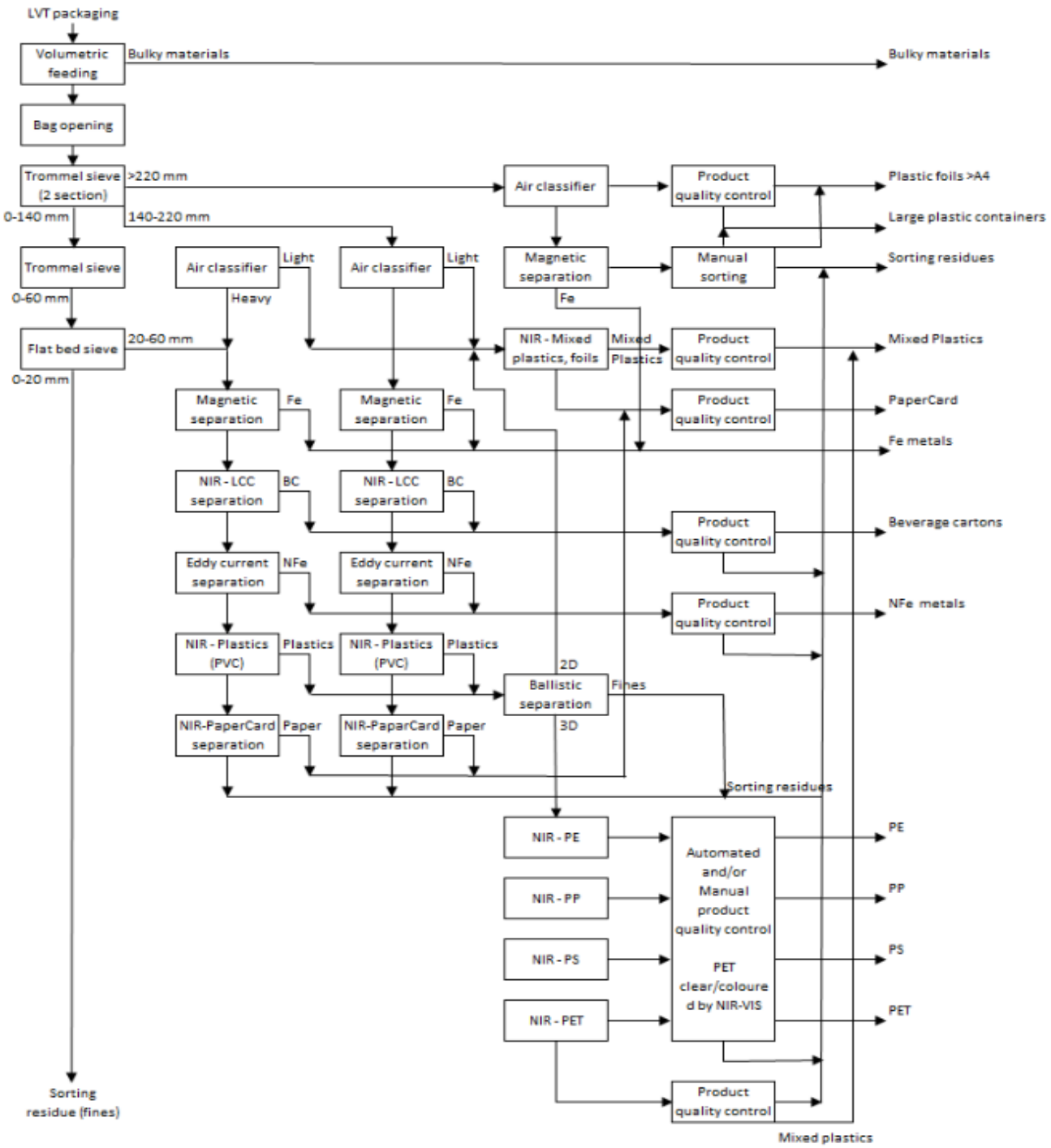

| all compositions all end destinations | | |
|---|---|---|
| NACE | description | t/year |
| 18 | Printing and reproduction of recorded media | 5,446.66 |
| 41 | Construction of buildings | 4,883.38 |
| 471 | Retail sale in non-specialised stores | 3,518.19 |
| 49 | Land transport and transport via pipelines | 3,213.80 |
| 22 | Manufacture of rubber and plastic products | 2,607.06 |
| 43 | Specialised construction activities | 2,426.13 |
| 45 | Wholesale and retail trade and repair of motor vehicles and motorcycles | 2,397.85 |
| 42 | Civil engineering | 2,229.03 |
| 477 | Retail sale of other goods in specialised stores | 1,147.86 |
| 29 | Manufacture of motor vehicles, trailers and semi-trailers | 673.08 |
| 13 | Manufacture of textiles | 635.78 |
| 469 | Non-specialised wholesale trade | 543.20 |
| 464 | Wholesale of household goods | 385.75 |
| Other | NACE codes accumulated <10% | 3,145.69 |
| | sum | 33,253.47 |

Loose track, homogenized, compacted, mixed

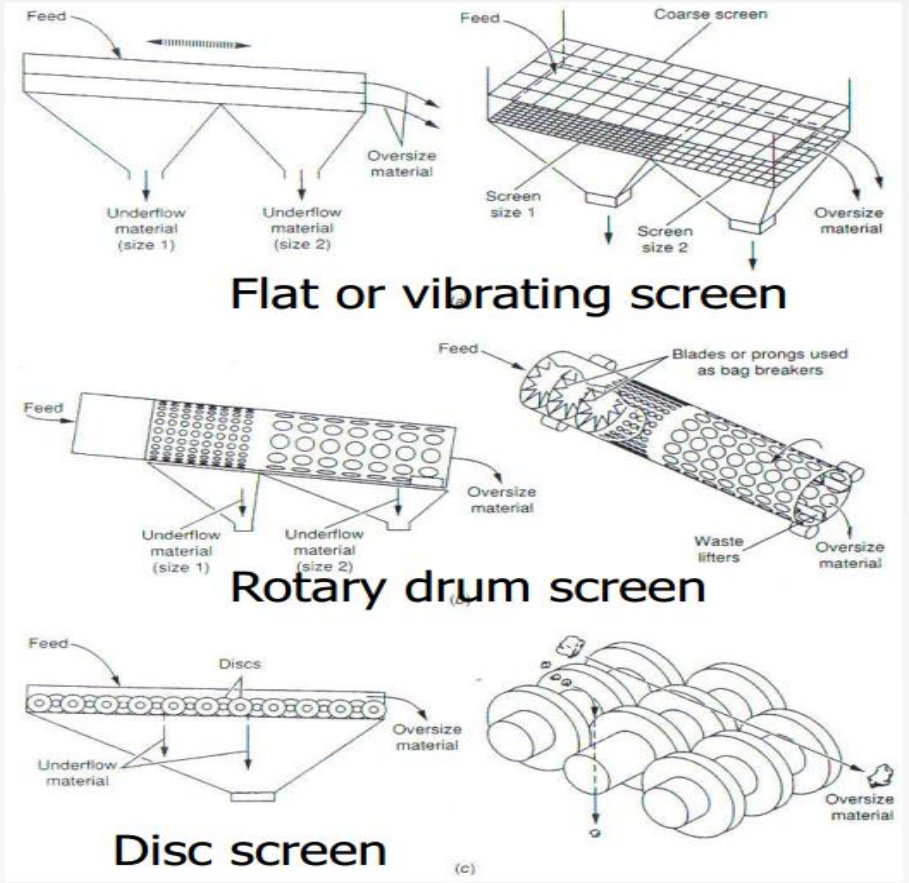
Traceability, compacted, unmixed

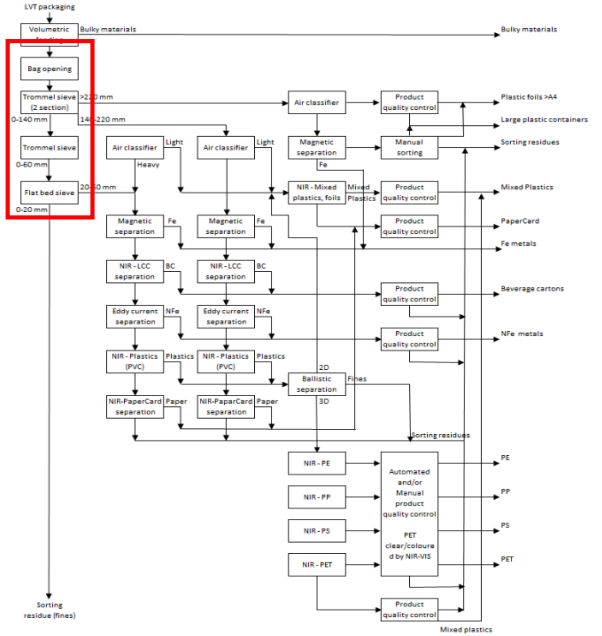
# Sorting

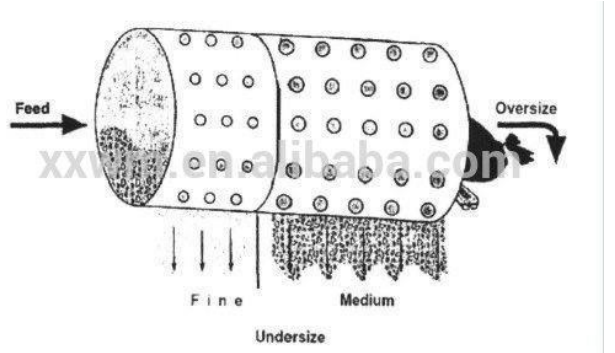
# Typically plastic (packaging) waste goes to a sorting plant before shredding



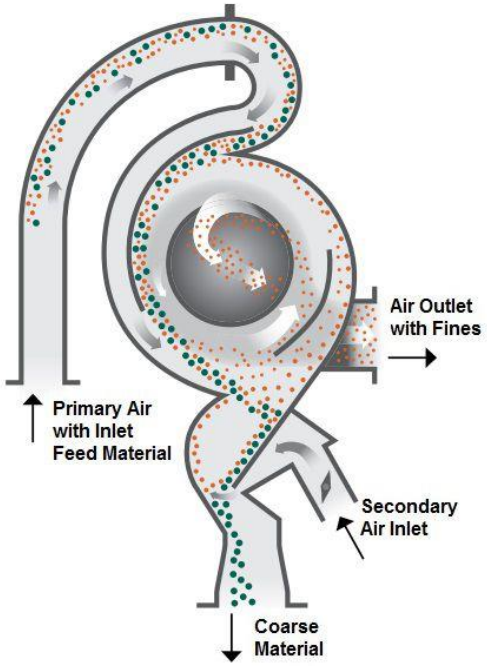
# Sieving

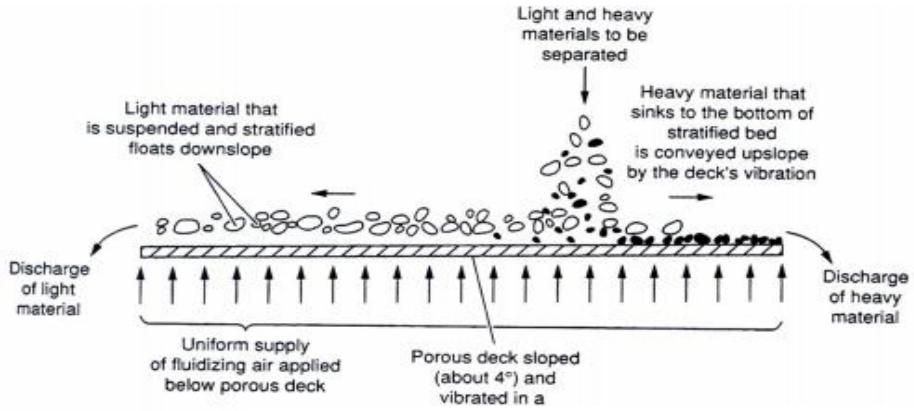

Feed
Oversize material
Underflow material (size 1)
Underflow material (size 2)
Flat or vibrating screen
Feed
Coarse screen
Screen size 1
Screen size 2
Oversize material
Feed
Blades or prongs used as bag breakers
Oversize material
Underflow material (size 1)
Underflow material (size 2)
Waste lifters
Rotary drum screen
Feed
Discs
Oversize material
Underflow material
Oversize material
Disc screen
(c)

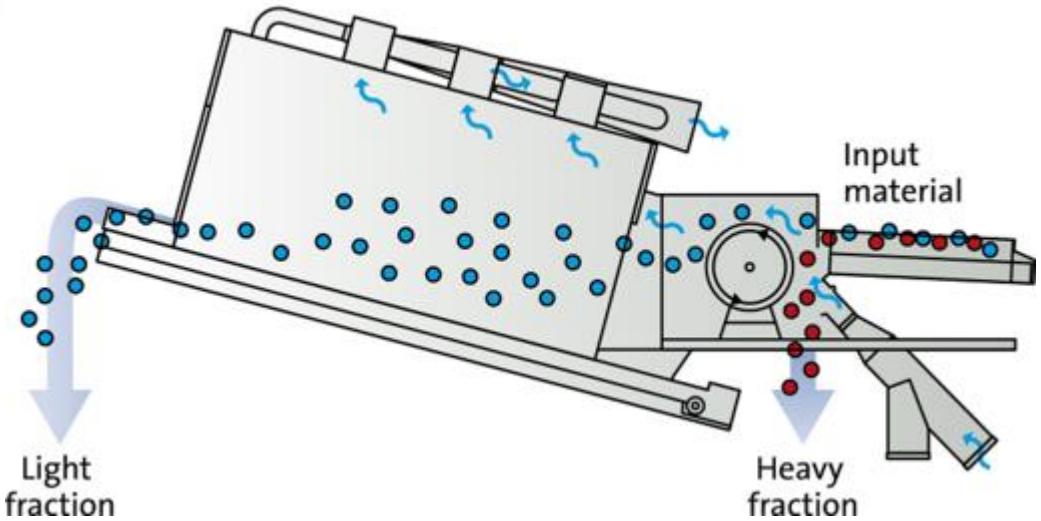

LVT packaging
Bulky materials
Bag opening
Trommel sieve (2 section)
0-140 mm
140-220 mm
Trommel sieve
0-60 mm
Flat bed sieve
20-200 mm
0-20 mm
Air classifier
Light
Heavy
Magnetic separation
Fe
NIR - Mixed plastics, foils
Mixed Plastics
NIR - LCC separation
BC
Eddy current separation
NFe
NIR - Plastics (PVC)
Plastics
NIR-PaperCard separation
Paper
Ballistic separation
2D
3D
Fines
Product quality control
Manual sorting
Sorting residues
Automated and/or Manual product quality control
NIR - PE
NIR - PP
NIR - PS
NIR - PET
PET clear/coloured by NIR-VIS
Plastic foils >A4
Large plastic containers
Mixed Plastics
PaperCard
Fe metals
Beverage cartons
NFe metals
PE
PP
PS
PET
Sorting residue (fines)
Mixed plastics

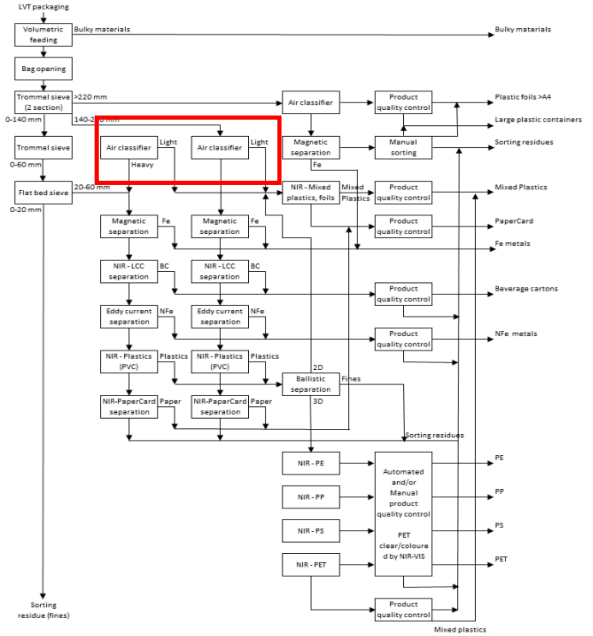

Feed
Oversize
Fine
Medium
Undersize

# Air classification / windshifting



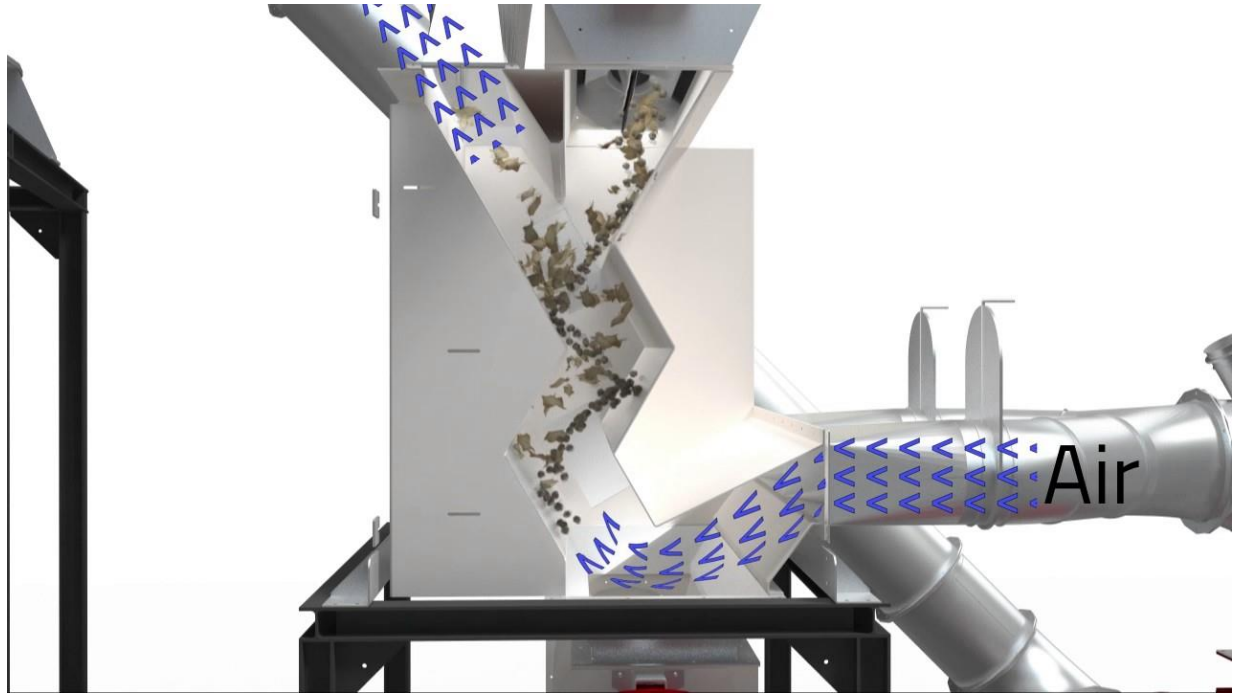



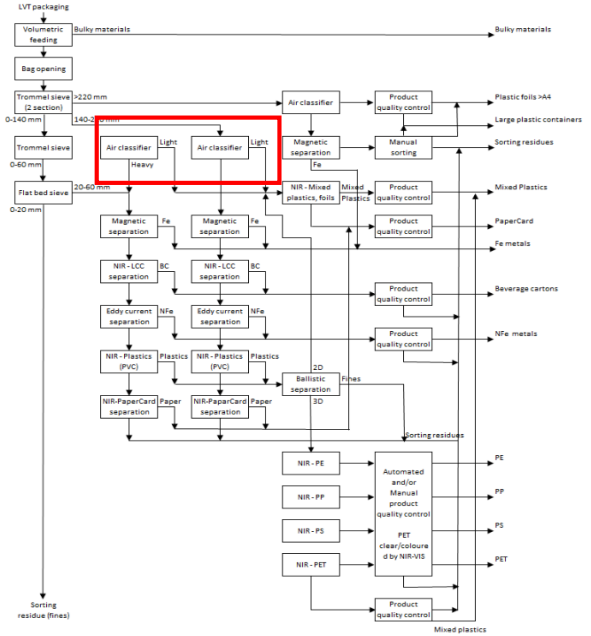



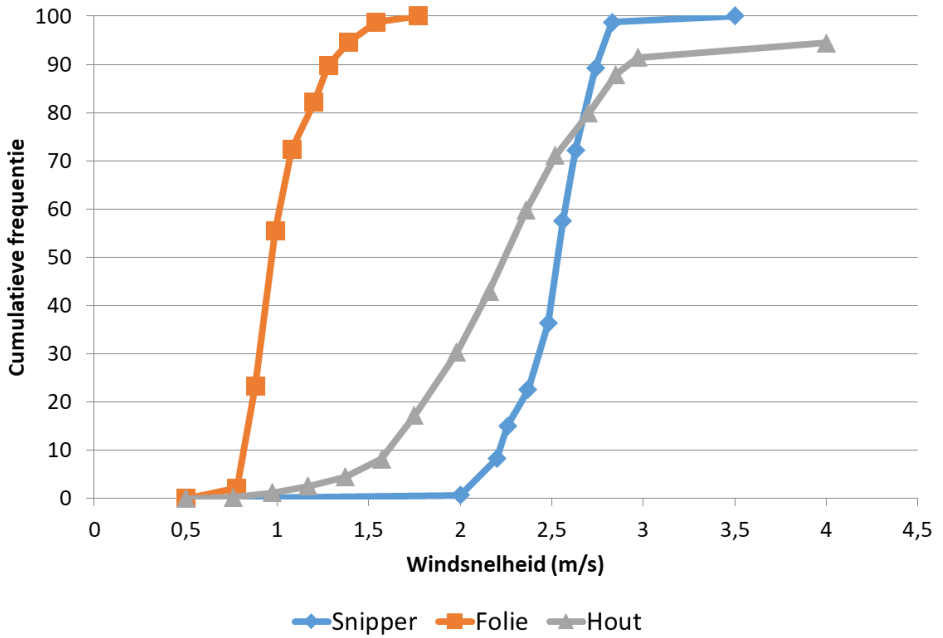



# Air classification / windshifting

- Windshifting

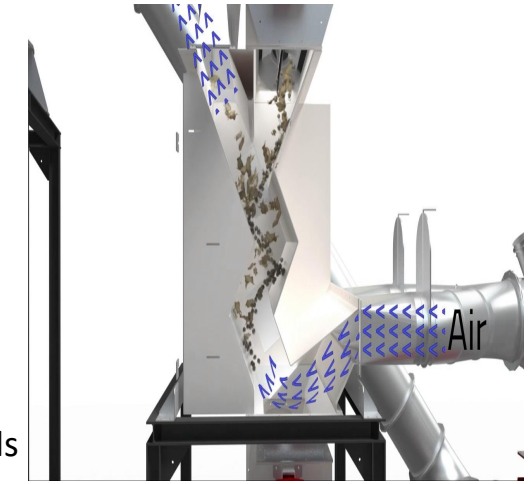


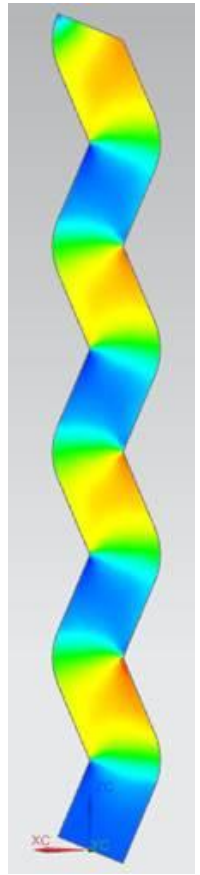

Adhesive removal

Separation of plastics and labels

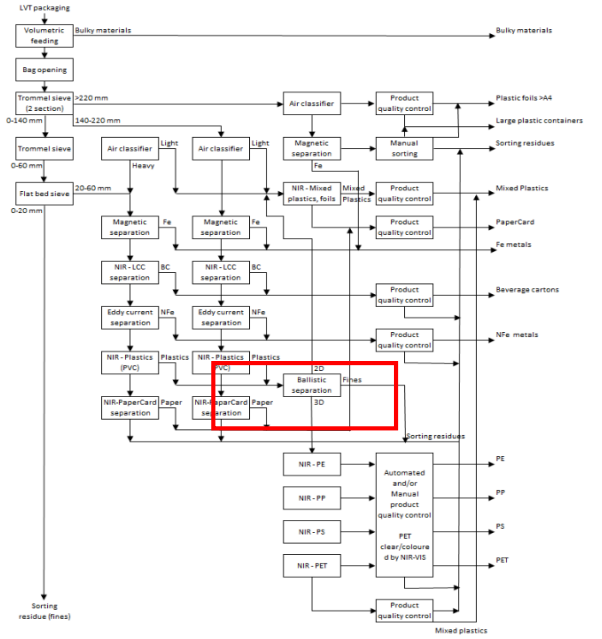


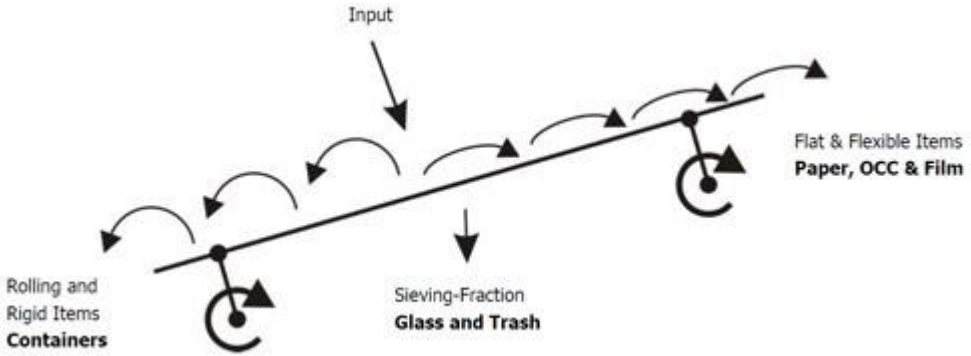

Air classification

Flotation



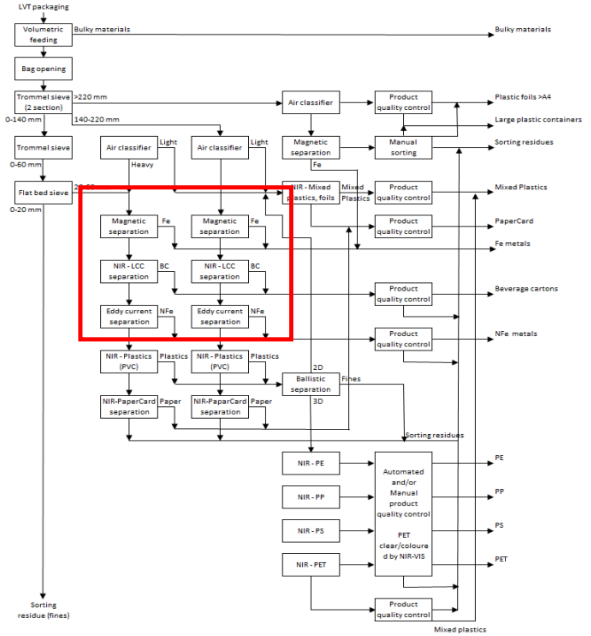
# Ballistic separation

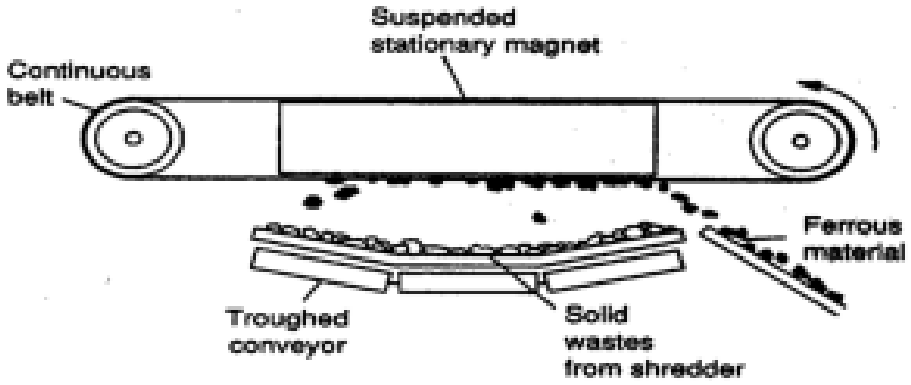


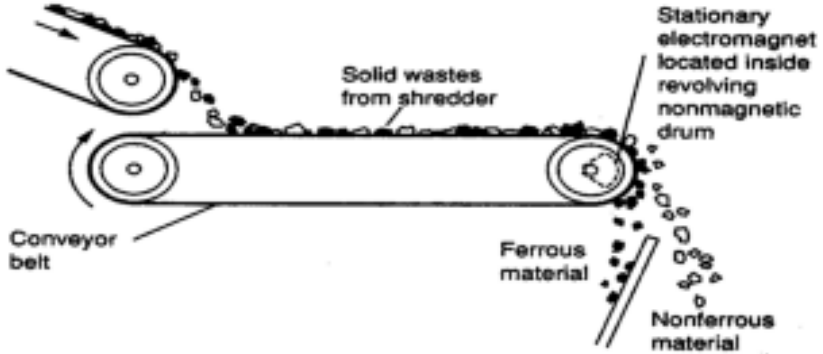



# Magnetic separation

- Iron and derivates
- Easy separation, valuable output
- Metals can damage pumps and reactors
- So everyone has a magnet!

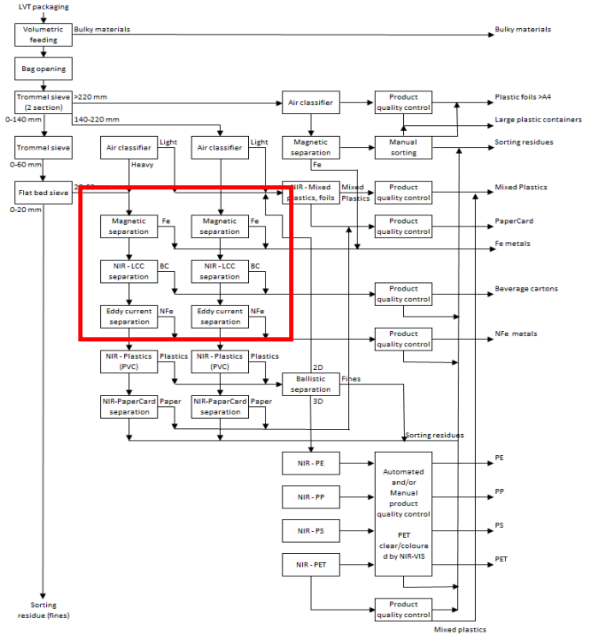


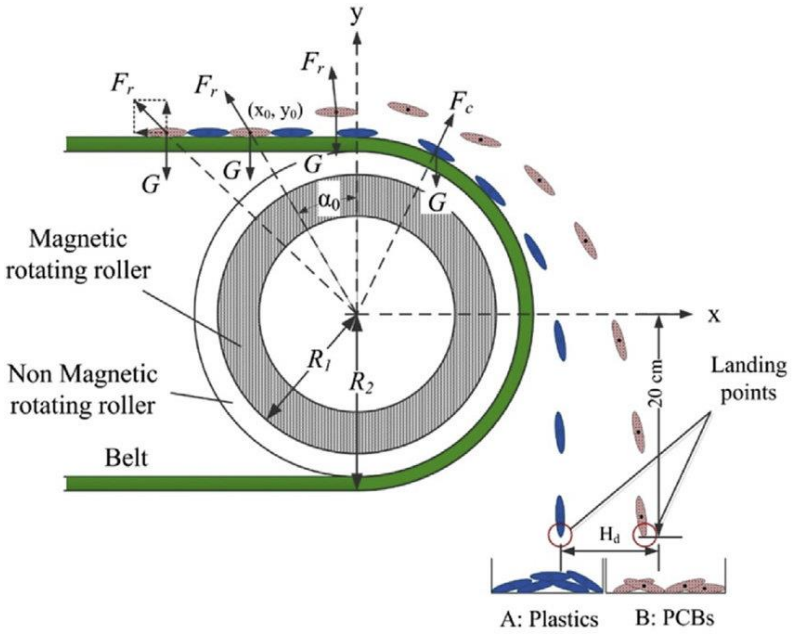



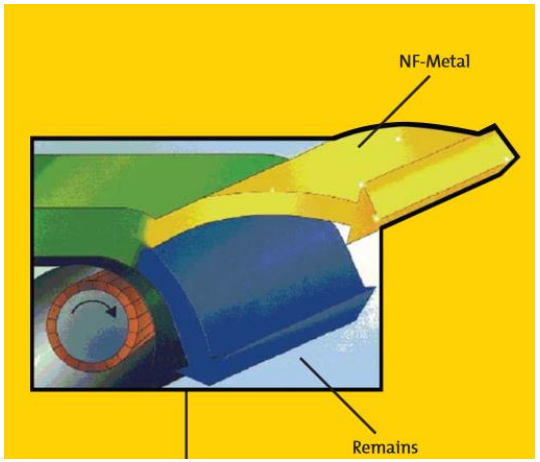



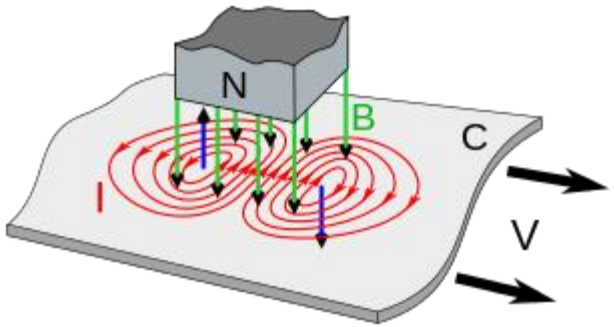
# Eddy current

- NFe metals separated by ‘Foucault currents’
- Rotating magnet creates $F_r$ = repulsive forces
- It is basically how your induction cooking plate works
- Cans, but also some Tetra Pack. Al layer of crisps too thin



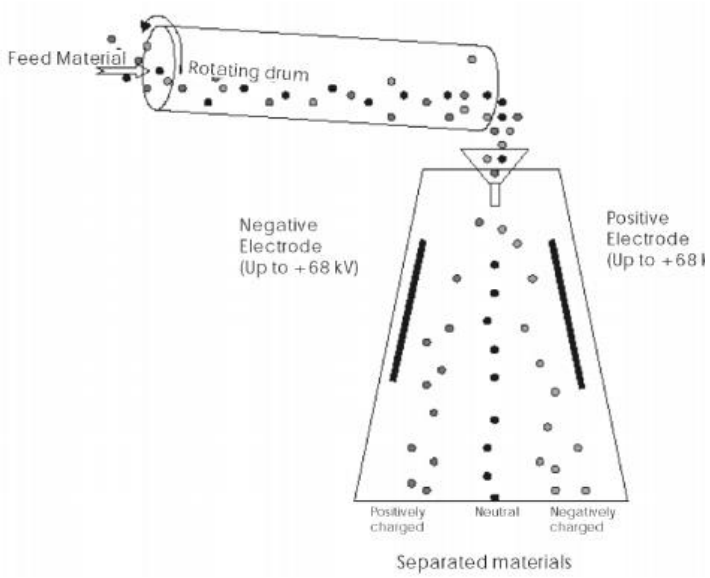



# Triboelectric separation

- Not usual at sorting plants, but related
- (Packaging) Plastic goes more negative, E.g. wood is neutral
- Material needs to be dry!



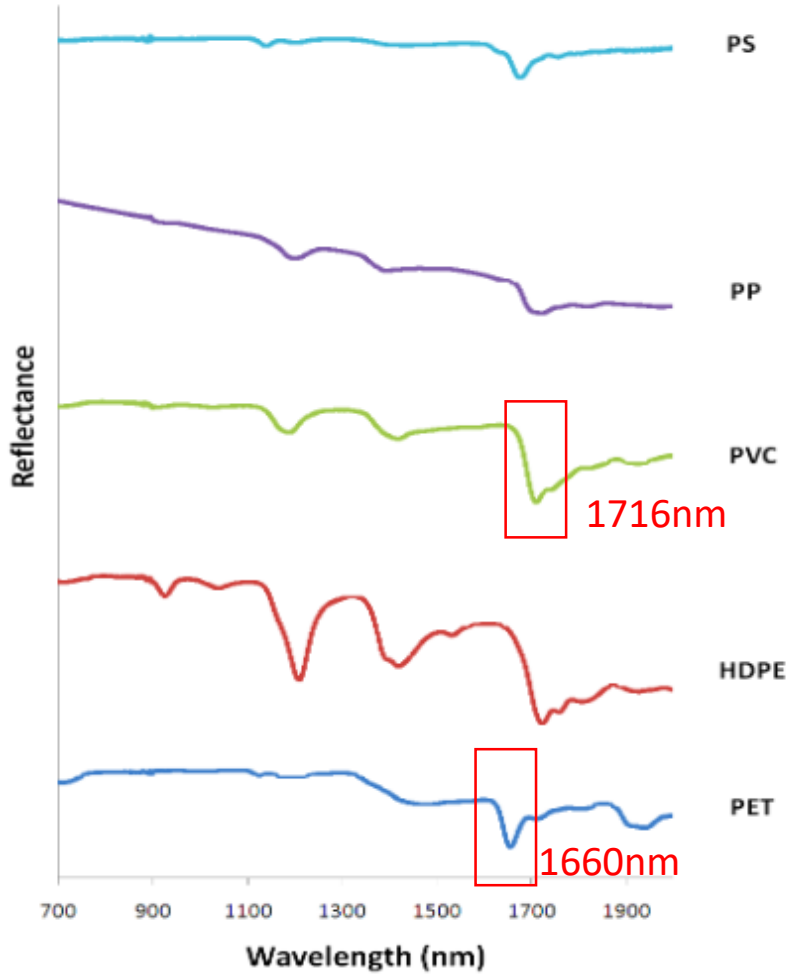

Positive (+)

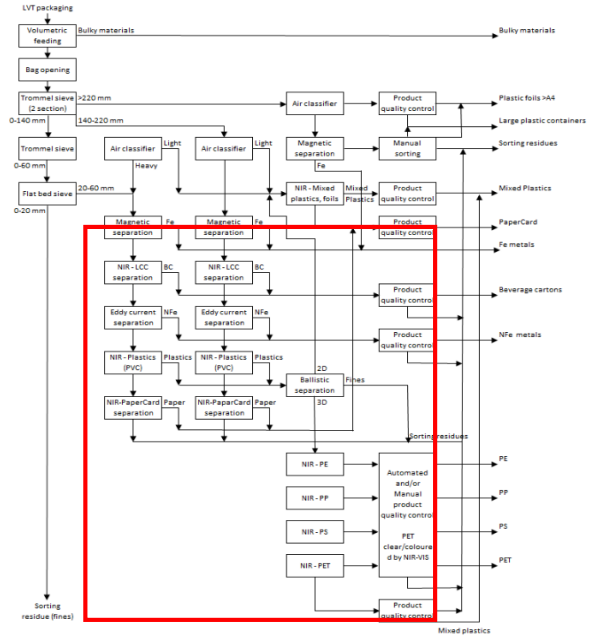
Glass
Mica
Polyamide (Nylon 6, 6)
Rock salt (NaCl)
Wool
Fur
Silica
Silk
Aluminum
Poly (vinyl alcohol) (PVA)
Poly (vinyl acetate) (PVAc)
Paper
Cotton
Steel
Wood
Amber
Poly (methyl methacrylate) (PMMA)
Copper
Silver
Gold
Poly (ethylene terephthalate) (Mylar)
Epoxy resin
Natural rubber
Polyacrylonitrile (PAN)
Poly (bisphenol Acarbonate) (Lexan, PC)
Poly (vinylidene chloride) (Saran)
Polystyrene (PS)
Polyethylene (PE)
Polypropylene (PP)
Poly (vinyl chloride) (PVC)
Polytetra fluoroethylene (Teflon, PTFE)

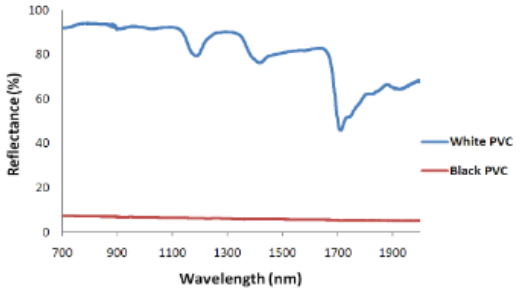
Negative (-)

# NIR: Near InfraRed separation

- Optical separation
- Based on infrared spectrum ➔ absorbance of light
- Separation of different types of materials (minerals, plastics, etc.)
- Very powerful technique
- Blacks are currently a bit difficult
- Only surface scanned (<20µm)

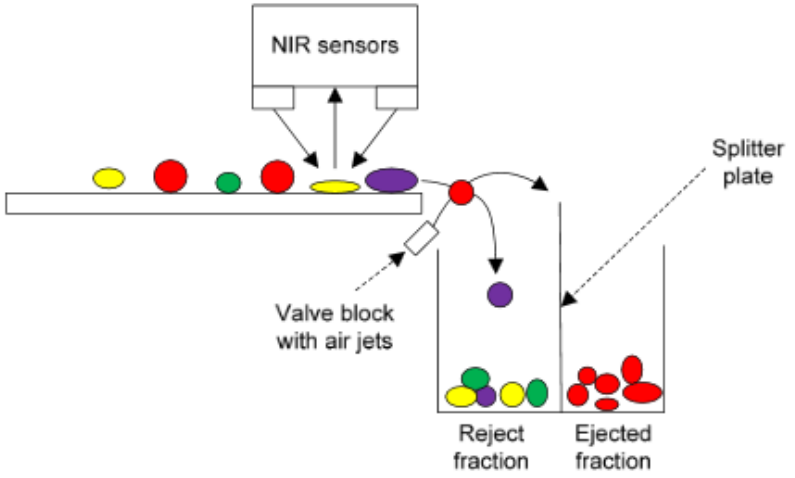


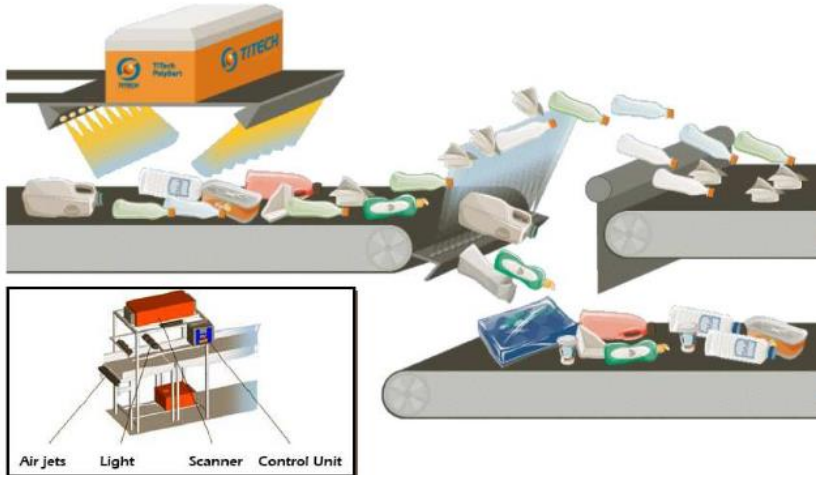





# NIR: Near InfraRed separation

- NIR has high belt speeds (3m/s)
- Because it is so good, companies tend to overload it
- Efficiencies are typically around 90%
- Best not as ‘first’ separation to get a 10% material out of a mix
- Usually done ‘positive’ (e.g. all PE) and then ‘negative’ (e.g. all non PE)

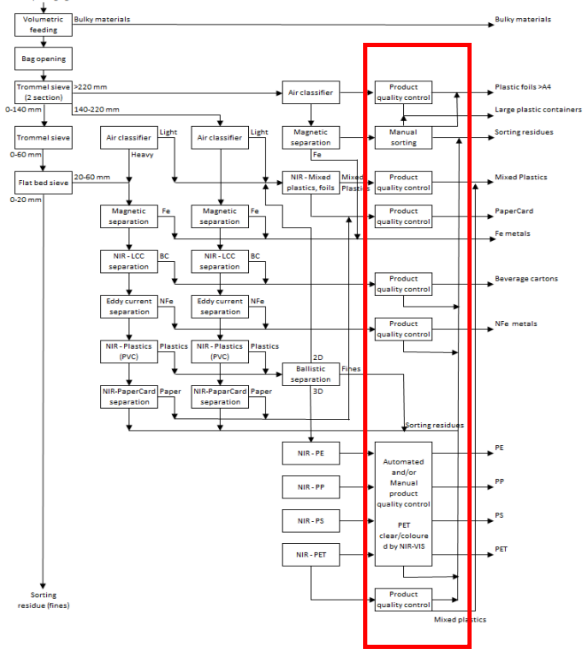




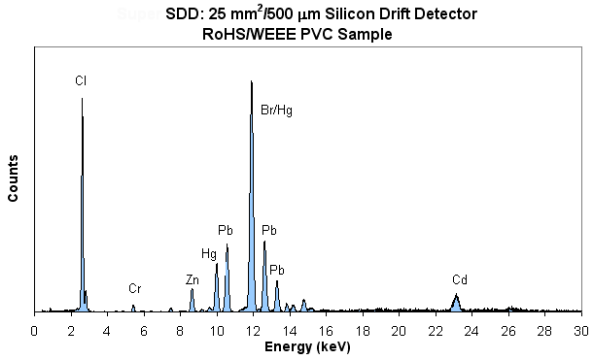
4. *Separate the Most Plentiful Components Early.* Components comprising a large fraction of the feed should be removed first. Clearly, the separation load will depend on the amount of material to be processed. By reducing the amount of this material early in the sequence, processing costs can be cut.

# Manual depollution

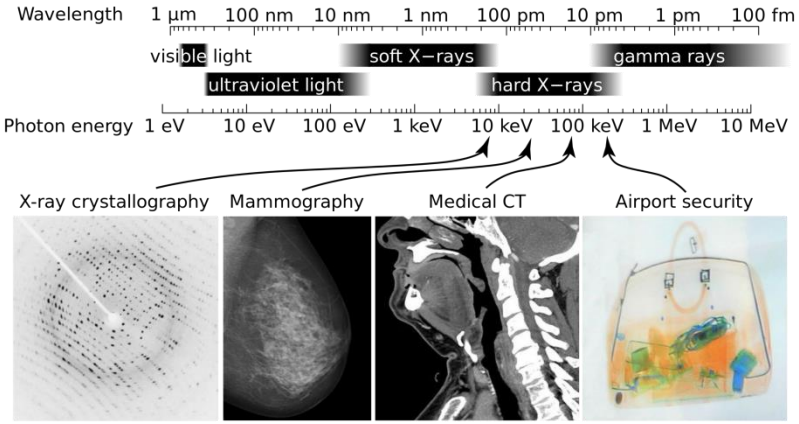


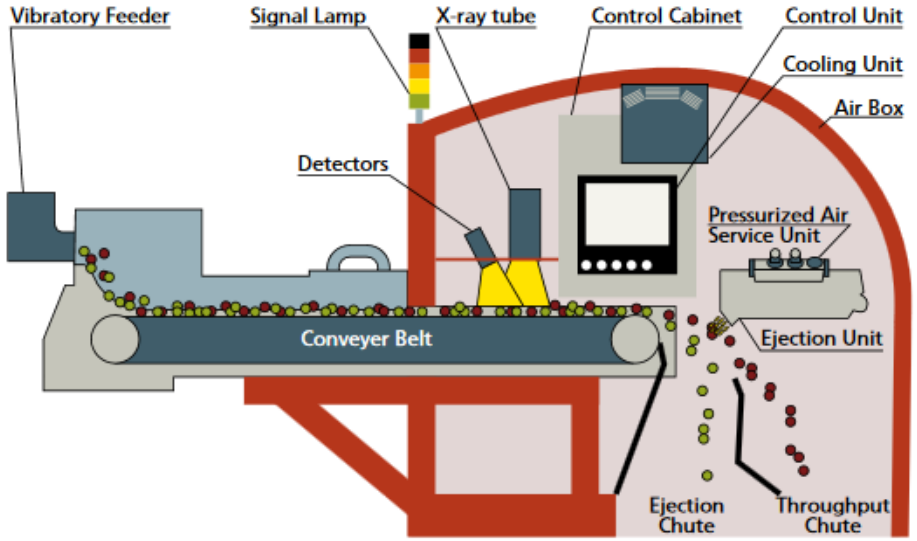

5. *Save the Most Difficult Separations for Last.* When the differences in properties (boiling point, density, etc.) of the components to be separated are not far apart, separation of those components is done best in the absence of other nonkey components. In the case of gas absorption, as the solubility of a particular component in a solvent decreases, the number of trays or height of packing required for the separation increases. Also, as the liquid and gas inventories in the column go up, the diameter of the column goes up. Thus, as the amount of material to be processed is reduced, so too is the cost of the separation. The same argument is equally valid when a particularly difficult separation requires specialized equipment.

# Optical separation

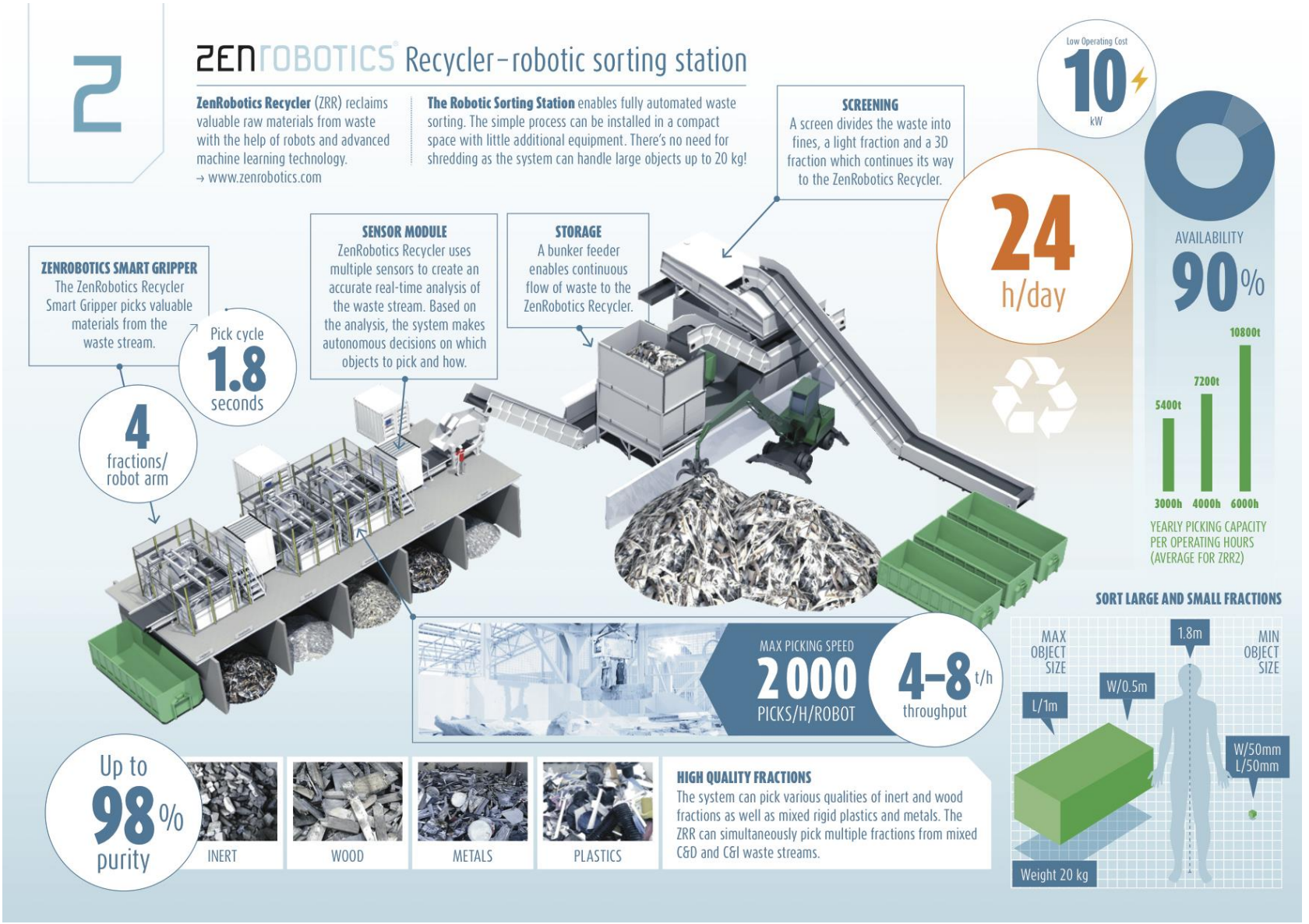



- X-ray: ‘radiation’ between 1pm en 10nm
- Can scan molecular structure ‘into’ the material
- Example; separate PVC with lead out of mix when recycling windows
- Radiation in a waste company



# Example Robotics / AI

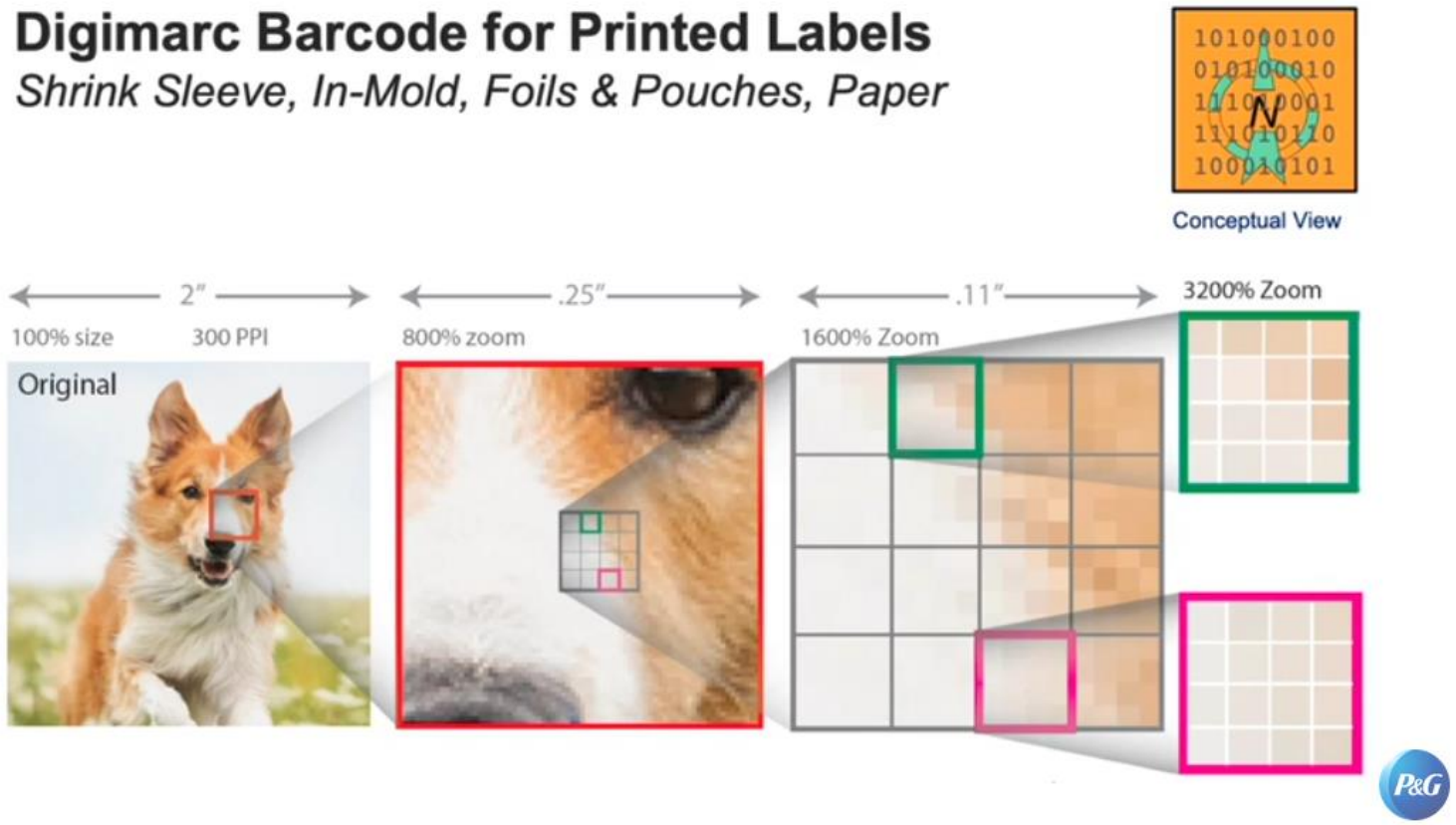



https://www.youtube.com/watch?time_continue=97&v=X_1sOPqM_VA&feature=emb_logo

# Example tracers

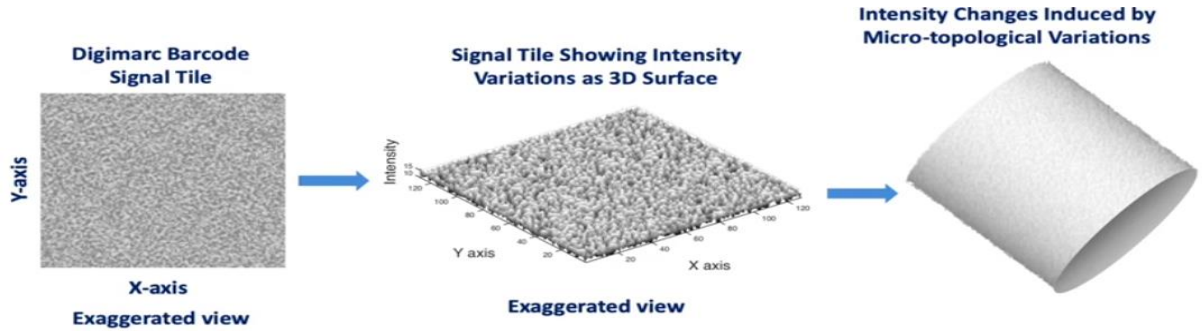

https://www.youtube.com/watch?v=nvPcSV2OHXU

# Example watermarks





https://www.youtube.com/watch?v=anTLAySG-18



# HolyGrail project

## Pioneer Project HolyGrail

**3-year initiative and collaborative project led by Procter & Gamble**

**Find a *harmonized* approach to improve detection and sorting of plastic**

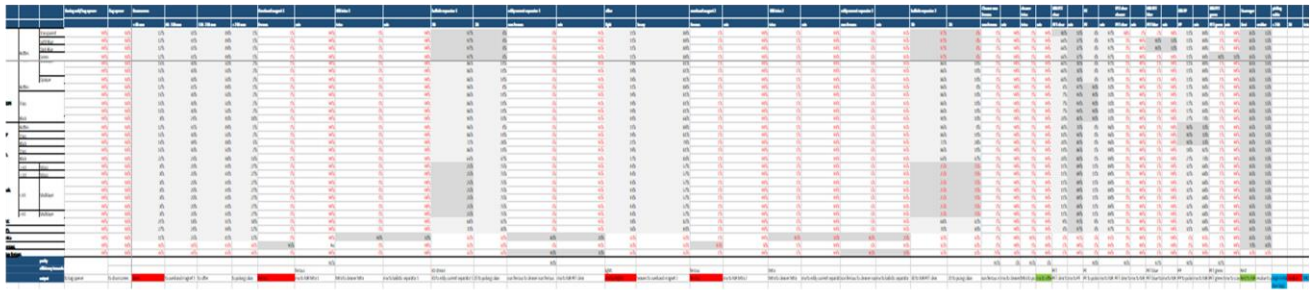
- **Digital watermarking** vs. chemical tracers

**Top 5 identification priorities:**

- Food vs. non-food grade plastics
- Recyclable vs compostable packaging
- Shrink-sleeved plastic identification
- New materials introductions
- Mono vs multi material thermoform and film


# Ghent University sorting model

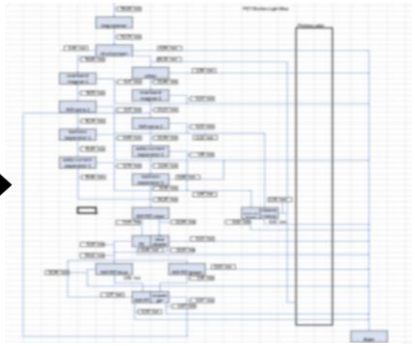
Sorting efficiencies for plastics in separation processes

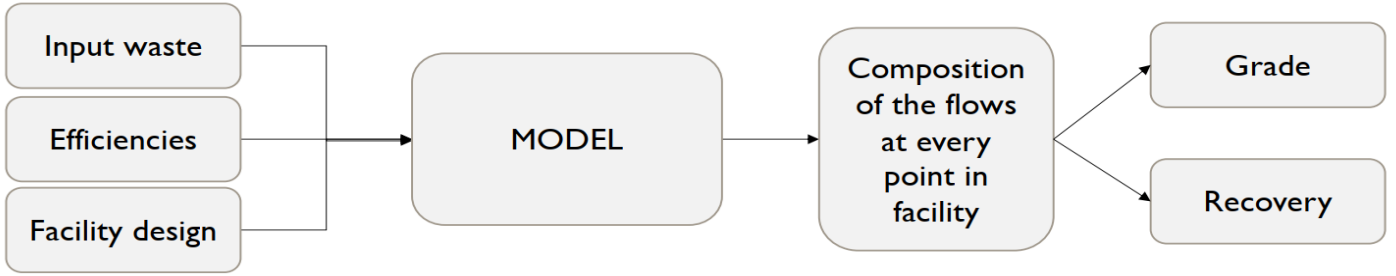


- Puzzle the flowsheet together based on sorting efficiencies
- Input-Output calculations

$$f^m = (I - (Q^m)^T) * \mu^m$$

- Cross contamination matrix

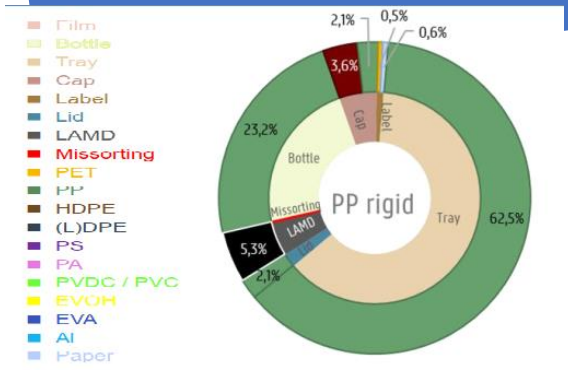


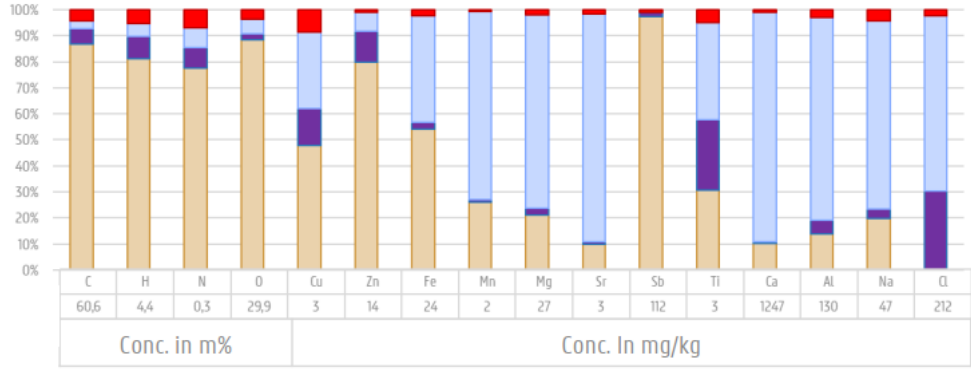


| Examples of representative waste items (m) (brand names anonymized) | waste item category | Ballistic separator | | | Drum screen | | | | Wind sifter | Magnet | Eddy current | NIR PET | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ballistic: 3D | ballistic: 2D | ballistic: fines | drum screen: 0 - 40mm | drum screen: 40 - 120mm | drum screen: 120 - 220mm | drum screen: >220 | windsifter: | | | | IR PET: on-PET |
| **Carbonated soft drink 1,5L** | PET - Bottles and flasks - transparent | 97.0% | 3.0% | 0.0% | 0.0% | | | | | | | | 10.0% |
| **PET tray pastry** | PET - Trays - transperant - Monolayer | 80.0% | 20.0% | | | | | | | | | | 0.0% |
| **Multilayer PET, cheese slices - 1** | PET - Trays - transperant - Multilayer | | | | | | | | | | | | 0.0% |
| **Laundry detergent 2L** | HDPE - Bottels and flasks | | | | | | | | | | | | 0.0% |
| **Laundry detergent, black laundry 1,5L** | HDPE - black | | | | | | | | | | | | 0% |
| **Hot water food tray: noodles, 360g** | PP - Pots, tubes and trays | | | | | | | | | | | | 0% |
| **Mushroom trays 500g** | PS - Pots, tubes and trays | | | | | | | | | | | | 0% |
| **Soda can shrink wrap** | Film - > A4 - Mono- and Multilayer | | | | | | | | | | | | % |
| **Candy bag 250g** | Film - < A4 - Multilayer | | | | | | | | | | | | % |
| **Frozen French fries bag 2500g** | Film - > A4 - Mono- and Multilayer | | | | | | | | | | | | % |
| **Juice box drink carton 1L** | Drinking carton | | | | | | | | | | | | |
| **Soft drink aluminium can** | non-ferrous metals | | | | | | | | | | | | |
| **Canned Tomatoes 400g** | ferrous metals | | | | | | | | | | | | |
| **Medicine blister pack** | PVC | | | | | | | | | | | | |
| **white processed meats foamed tray** | EPS | | | | | | | | | | | 0.1% | 99.9% |

SPLIT FACTORS

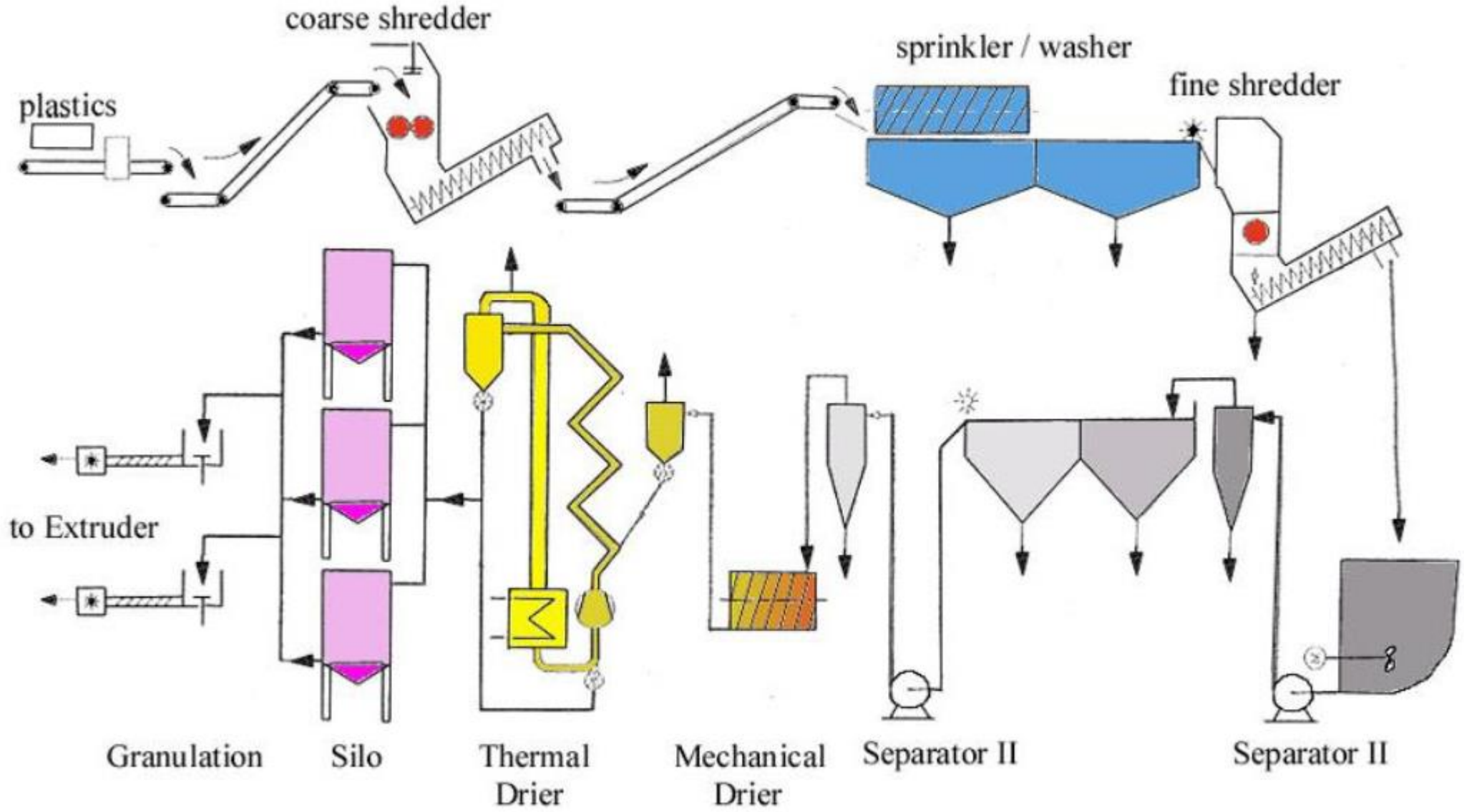
Currently ±120 representative products at brand level with composition



# Recycling

# Processing Plant of Recycled Plastic



# SPW is dumped in a big heap

1st shredder step (grinding):

Mixed SPW reduces to fist-sized particles

1st grinding

Transporter:
take shredded
SPW to silo

Pre-wash installation:

Removal of glass, metal and rocks by water stream

1st wash

Friction washers:

Wash off contaminations (organic)

2nd wash

Cutting mill:

Further grinding of SPW
+ another friction wash

2nd grinding + 3rd
washing

Sink-float separation in $H_2O$

PP, PE float

PS, PET, PVC sink

1st separation

4th wash

Heavy fraction:

To mechanical dryer via screws. Mixed polymer waste is dried and stored.

1st secondary polymer material: PET-PS-PVC

Floating fraction (PP-PE) to wind-shifter → separate films from bulky polymers

# Density separation

- ‘Easy’
- Usually water is used
- Separating the polyolefins
- This creates:
  - PP/PE
  - PVC/PET(/PS)

| Plastic type | Materials used in the 1960s-80s | Materials used at present | Range in densities (g $cc^{-1}$) | Typical density (g $cc^{-1}$) |
|---|---|---|---|---|
| Polyethylene foam | X | X | 0.03-0.30 | 0.2 |
| Ethylene propylene diene M-class rubber | | X | 0.86-0.95 | 0.88 |
| Paper | X | X | 0.69-0.83 | 0.80 |
| Very low density polyethylene | | X | 0.880-0.916 | 0.905 |
| Cross linked polyethylene | | X | 0.920-0.945 | 0.935 |
| Low density polyethylene | X | X | 0.918-0.93 | 0.932 |
| Medium density polyethylene | X | X | 0.926-0.940 | 0.935 |
| High density polyethylene | X | X | 0.941-0.965 | 0.94 |
| Polystyrene | X | X | 1.03-1.07 | 1.06 |
| Polyamide (6, 66 & 11) | | X | 1.06-1.16 | 1.14 |
| Cross-linked polyethylene | | X | 1.15-1.28 | 1.15 |
| Chlorinated polyethylene | | X | 1.09-1.25 | 1.16 |
| Polyurethane | X | X | 0.4-1.2 | 1.20 |
| Polychloroprene rubber | | X | 1.23-1.5 | 1.32 |
| Silicone rubber | | X | 1.25-1.50 | 1.30 |
| Polyvinyl chloride | X | X | 1.37-1.42 | 1.39 |
| Polyethylene terephthalate | | X | 1.35-1.40 | 1.37 |
| Ethylene-vinyl-acetate | | X | 0.927-1.97 | 1.40 |
| Ethylene-propylene rubber | | X | 1.2-1.47 | 1.4 |
| Polyoxymethylene | | X | 1.41-1.42 | 1.42 |
| Chloroprene rubber | | X | ≈1.47 | ≈1.47 |
| Ethylene vinyl-acetate | | X | ≈1.49 | ≈1.49 |
| Mica tape | X | X | ≈1.5 | ≈1.5 |
| Nitrile butane/Acrylonitrile-butadiene rubber | | X | ≈1.5 | ≈1.5 |
| Polychloroprene | | X | ≈1.55 | 1.55 |
| Styrene-butadiene rubber | | X | 1.45-1.70 | 1.6 |
| Rubber | X | X | 1.52-≈1.6 | 1.6 |
| Chlorosulfonated polyethylene | | X | 1.64 | 1.64 |
| Ethylene tetrafluoroethylene | | X | ≈1.74 | 1.70 |
| Fluorine-ethylene-propylene | | X | ≈2.15 | ≈2.15 |
| Polytetrafluoroethylene | | X | 2.07-2.20 | 2.17 |

# WEEE

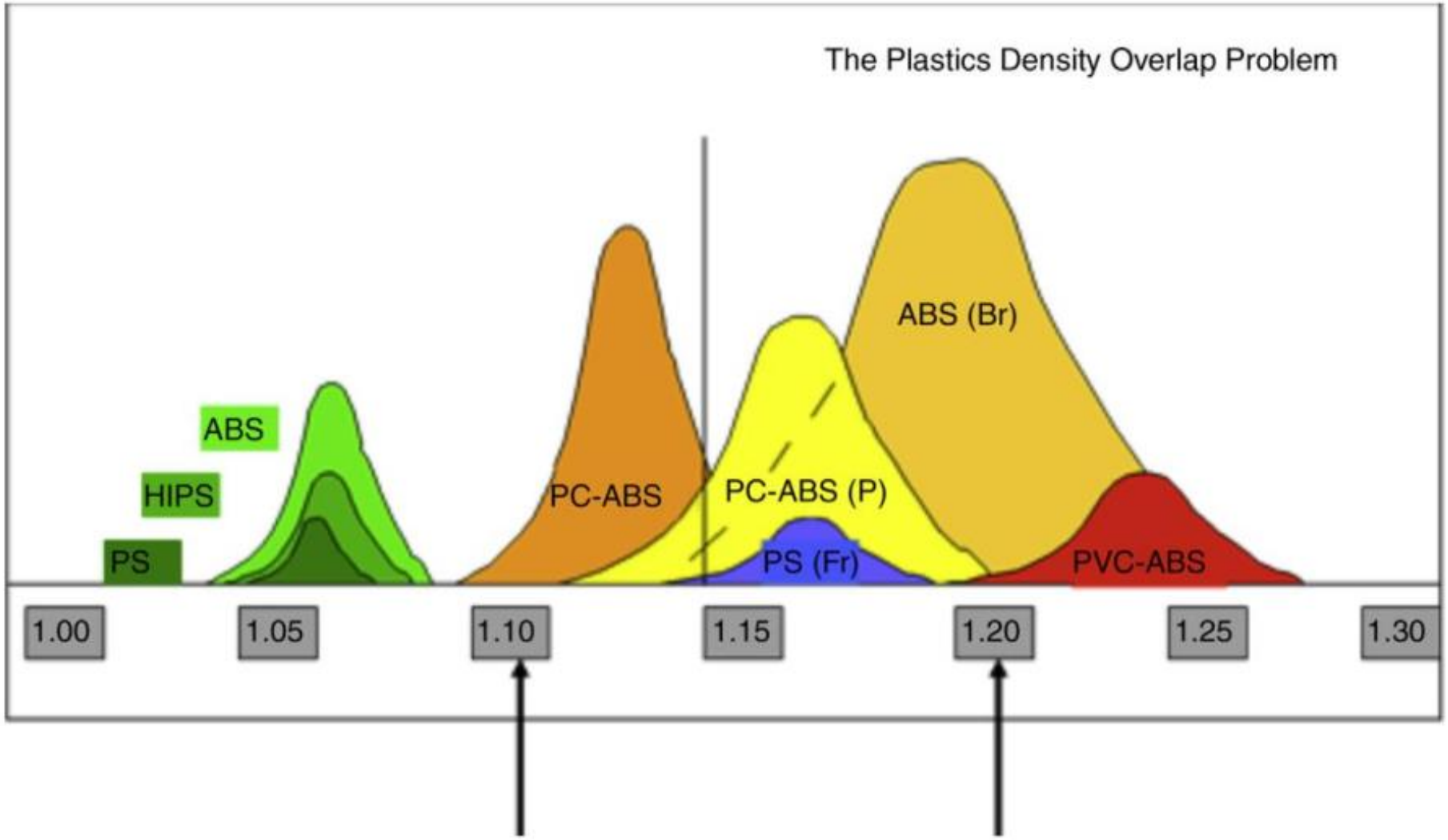


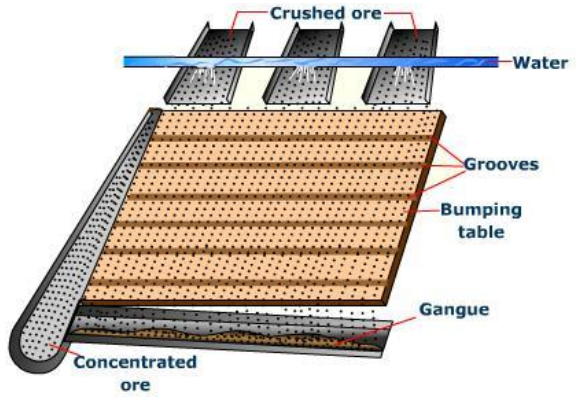

Figure 3.14 *Overlapping plastic density [19].*

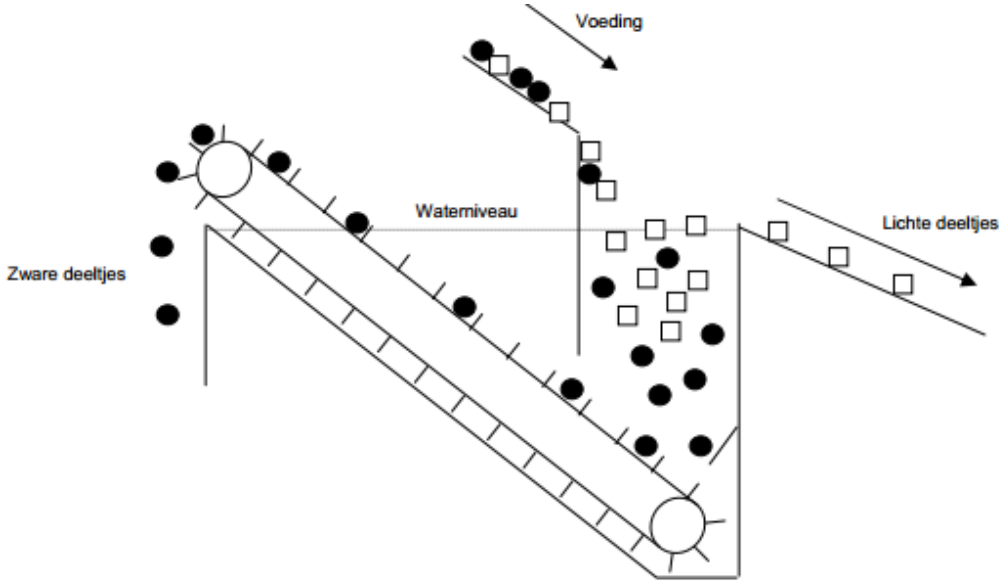
# Density separation: easy?

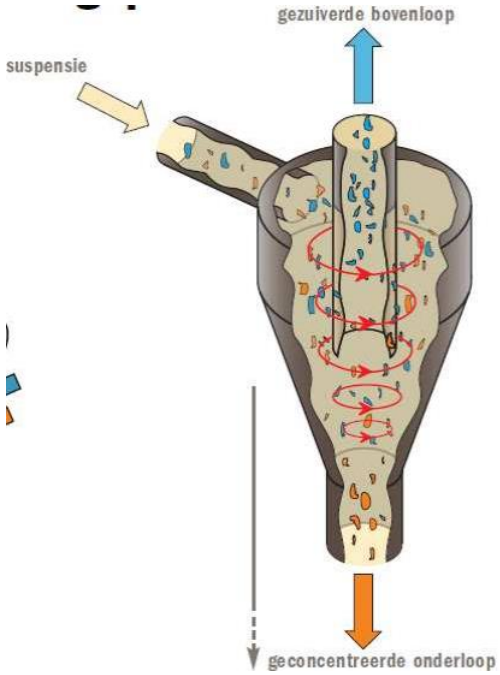
8. *Avoid Adding Foreign Species to the Separation Sequence.* It is best to avoid adding mass separating agents, such as in azeotropic distillation and leaching, because these agents subsequently must be recovered, often creating a separation problem. This is one reason why energy separating agents often are preferred.

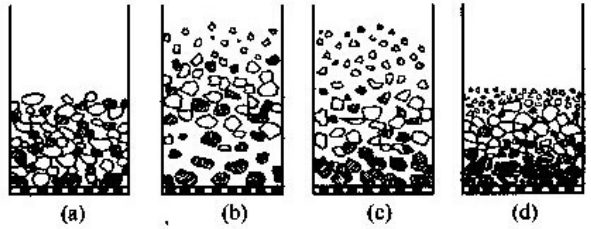
- Simple?
  - Medium
  - Process setup
  - Particle size and shape

| Dense liquid | Density ($g/cm^3$) |
|---|---|
| $H_2O$ | 1.0 |
| $NaCl + H_2O$ | 1.2 |
| $ZnCl_2$ | 1.75 |
| $CaCl_2 + H_2O$ | 1.5 |
| Bromoform | 2.89 |
| Acetone: TBE = 0.27:1 | 2.5 |
| TBE | 2.96 |
| Clerici solution | 4.28 |



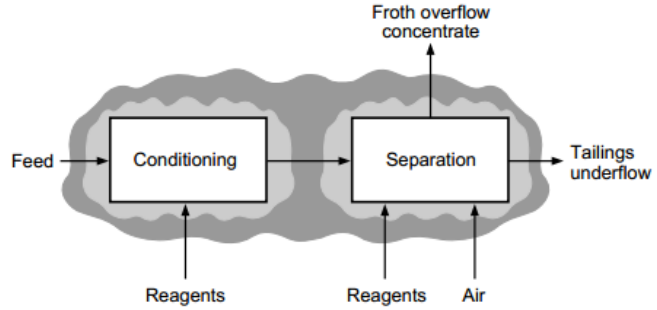



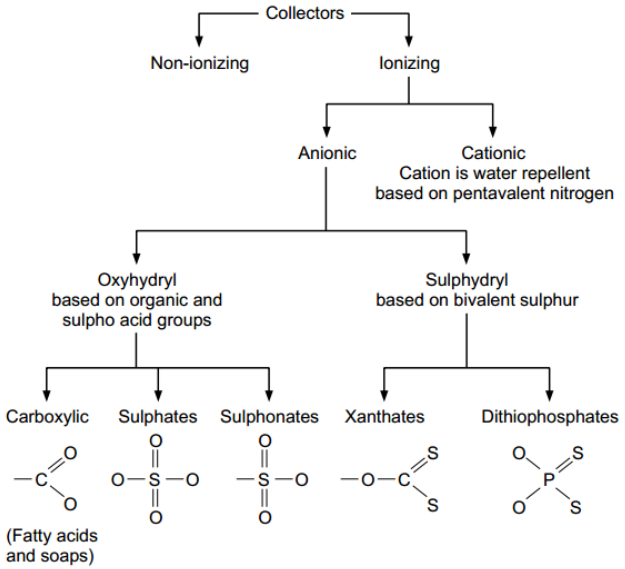



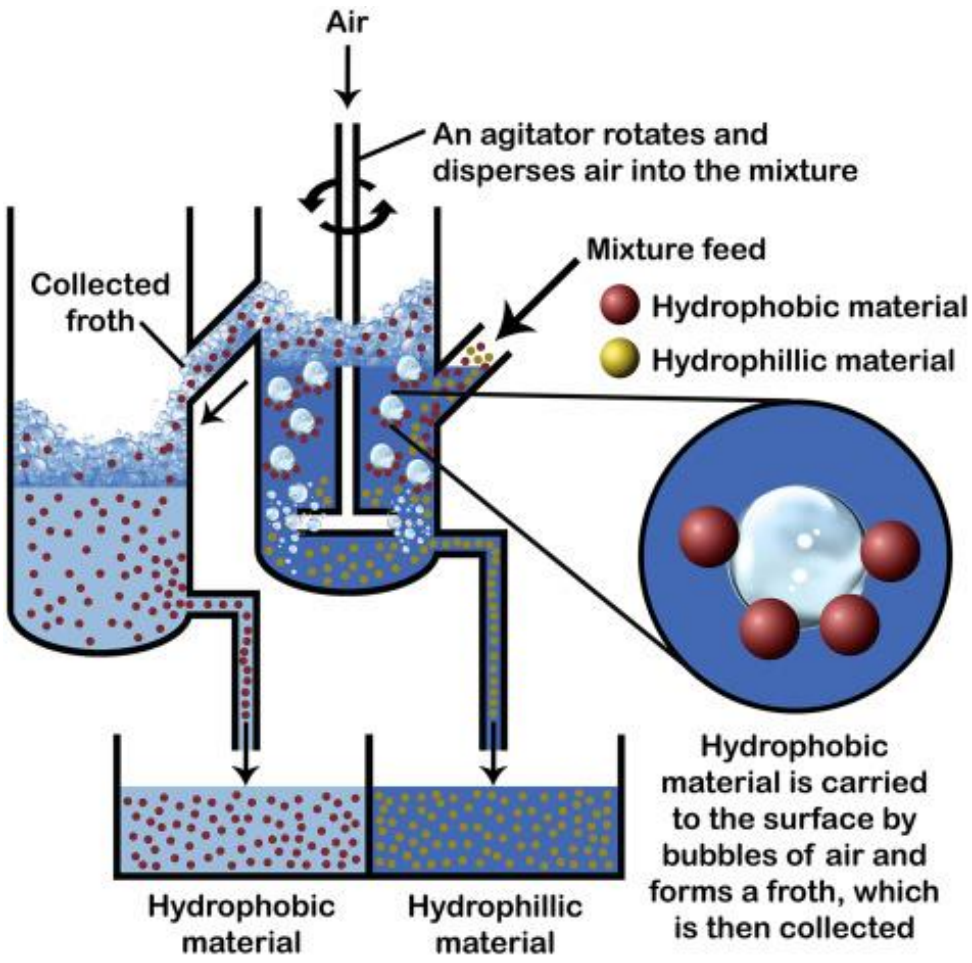

(a) Particles mixed pile before laying;
(b) Rising water lift the bed layer;
(c) Particle sedimentation stratification in the water;
(d) Water drops, bed layer is dense, heavy mineral into the bottom.

# Froth flotation

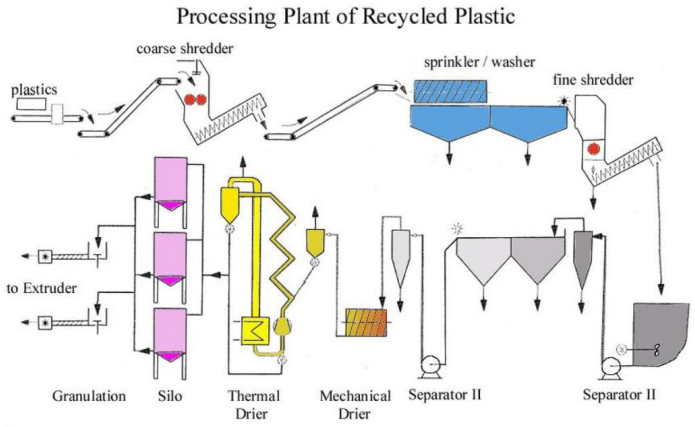
- Introduce air bubbles
- Density + hydrofobicity
- Surface chemistry adjusted by collectors
- Frothers stabilise foam layer

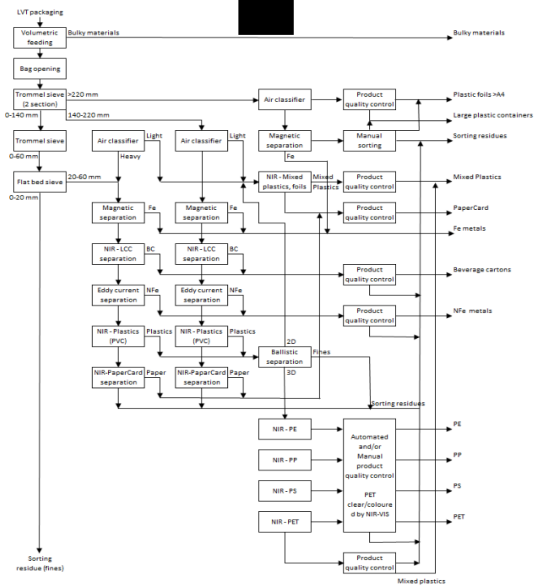


# And if we do all that..



We can do this!

Or in best case maybe this!

Which is great by the way!

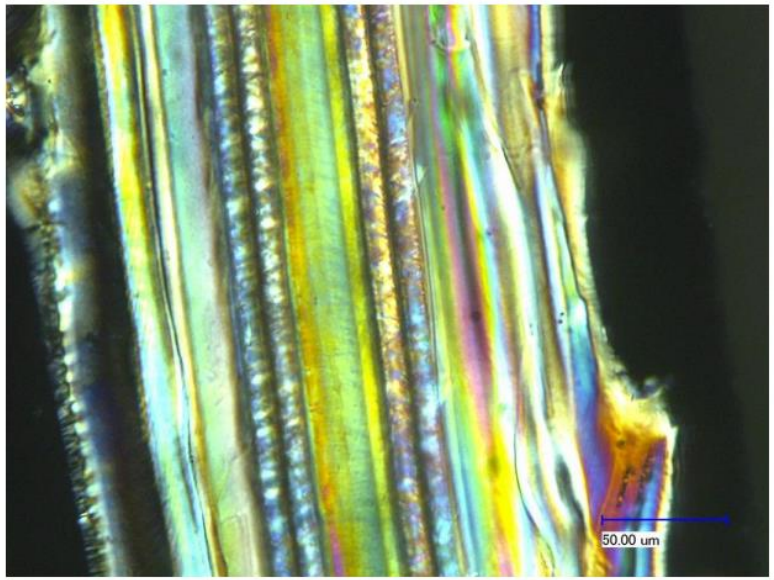
And there are a few exceptions!

But more advanced pretreatment and recycling techniques should be developed!

(or miracles should happen at design side)  (or both)

# Advanced precleaning


- Chemical wash to remove
  - Odour
  - Inks
  - Layers

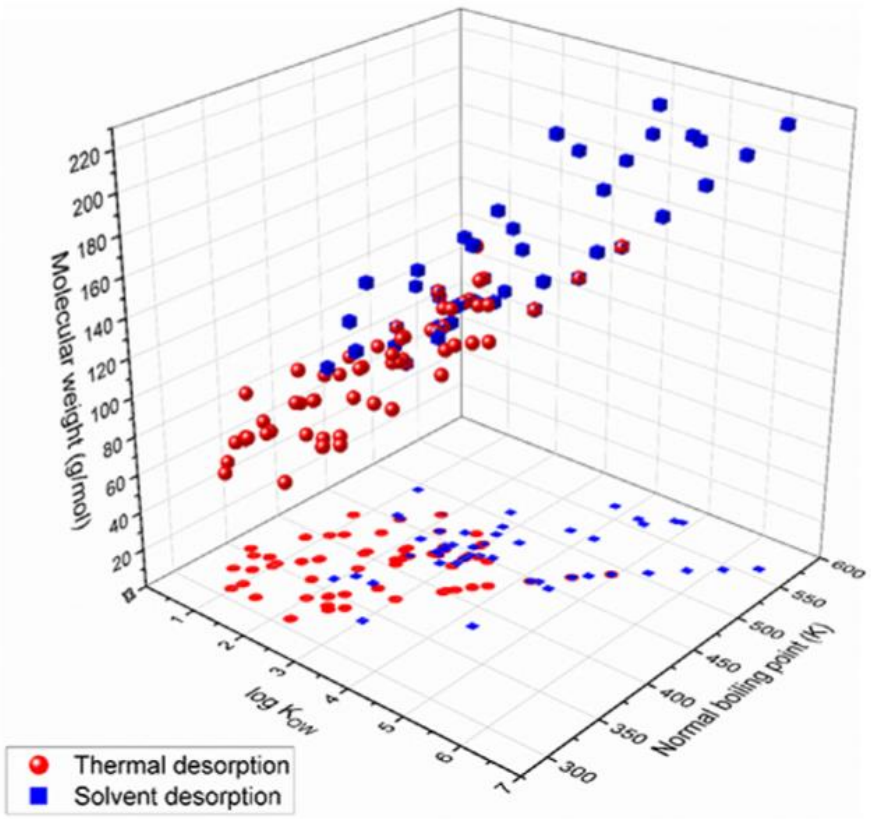



Prebaked bread

Thickness: (right to left)

| | | | | | |
|---|---|---|---|---|---|
| PE | | 62,8 | ± | 9,8 | µm |
| PE | | 9,6 | ± | 0,7 | µm |
| EVOH | | 1,6 | ± | 0,4 | µm |
| PE | | 9,5 | ± | 0,7 | µm |
| Tie | | | | | |
| PA | | 26,8 | ± | 0,9 | µm |
| tie | | | | | |
| PE | | 10,8 | ± | 0,6 | µm |
| EVOH | | 2,0 | ± | 0,7 | µm |
| PE | | 8,1 | ± | 0,3 | µm |
| BOPA | | 16,7 | ± | 1,6 | µm |
| Ink/ tie layer? | | 8,8 | ± | 0,9 | µm |
| PE | | 13,6 | ± | 0,9 | µm |
| PE | | 26,9 | ± | 1,8 | µm |

# Deodorisation



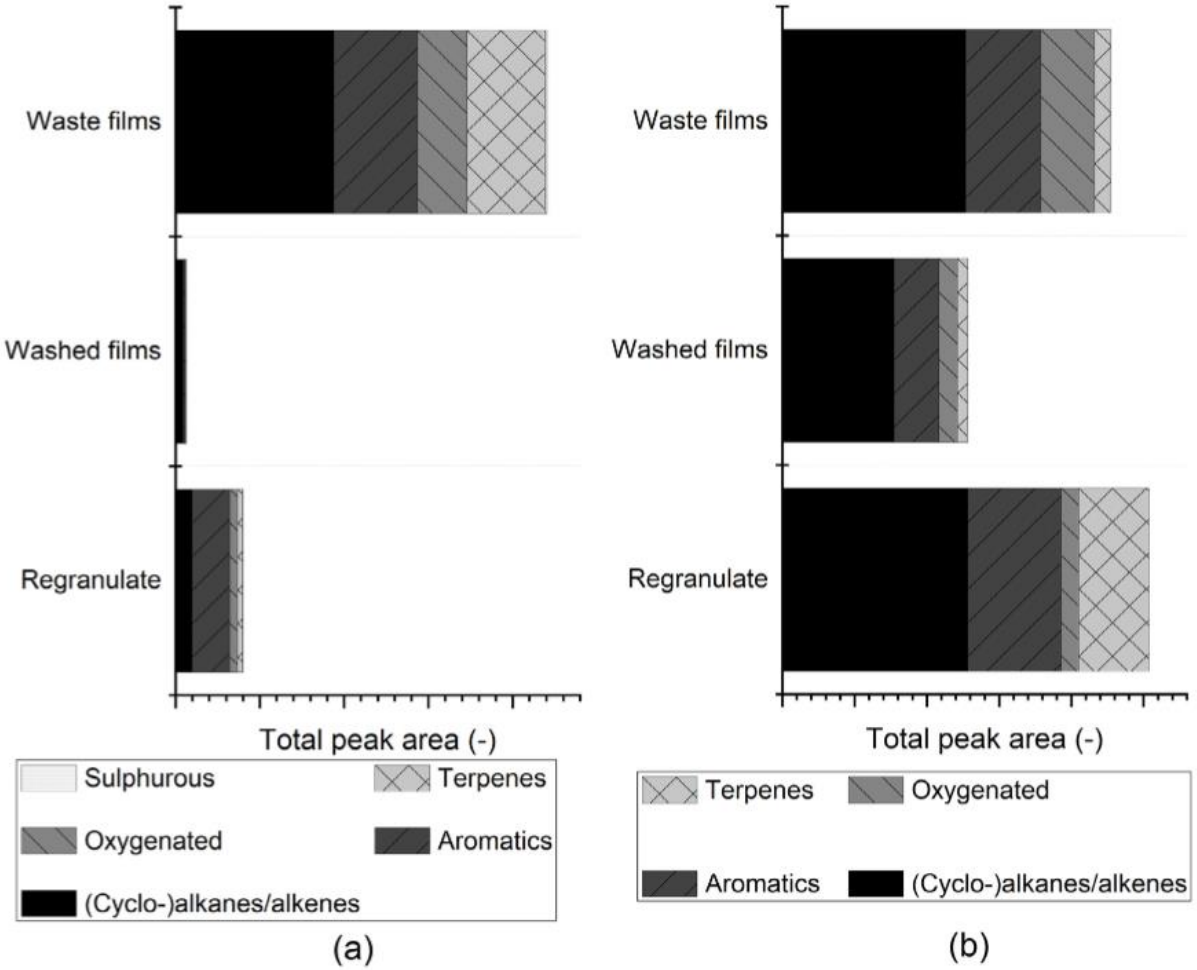
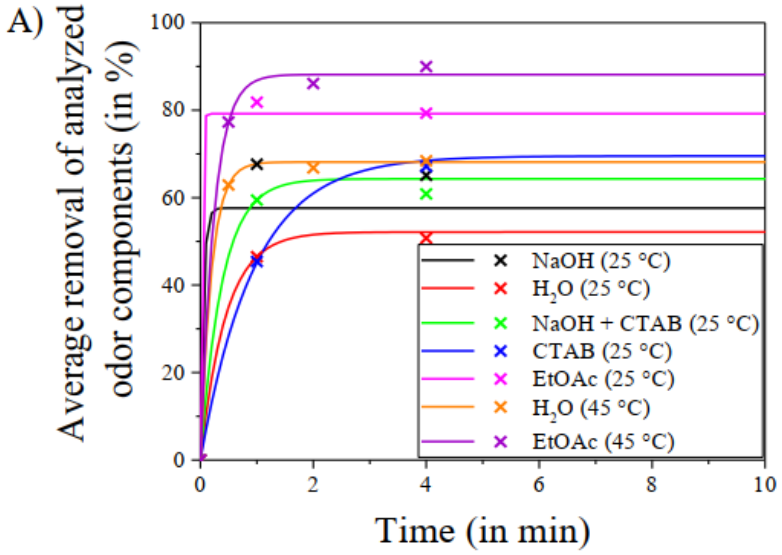
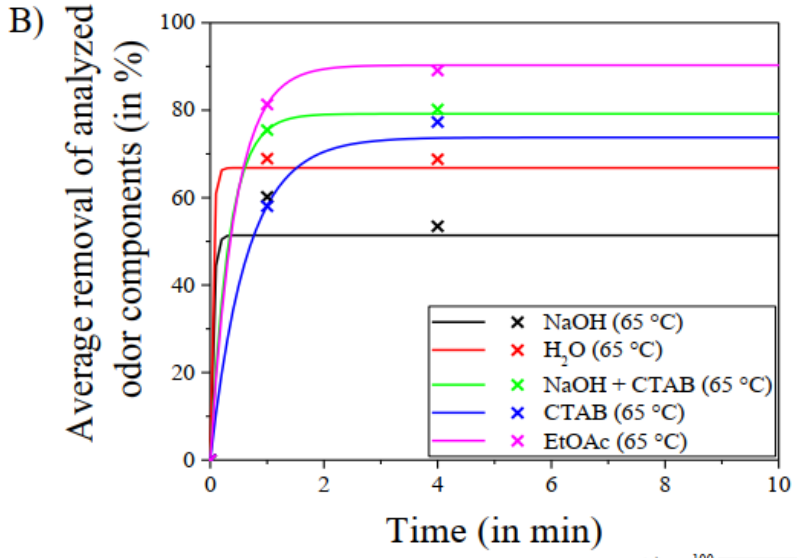
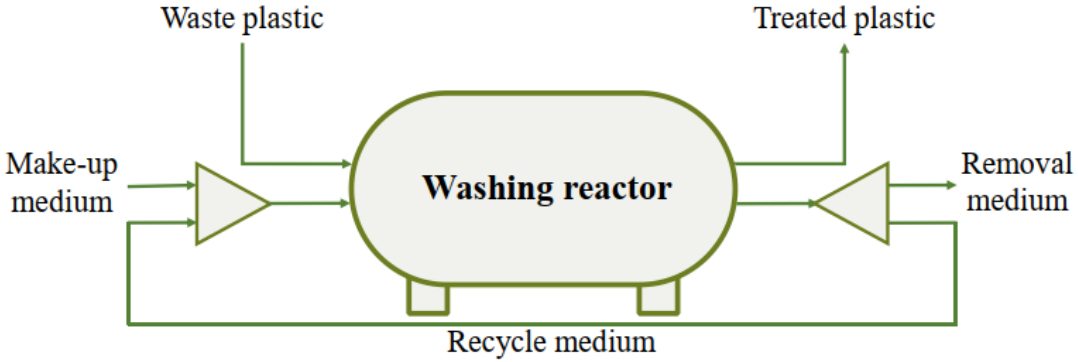



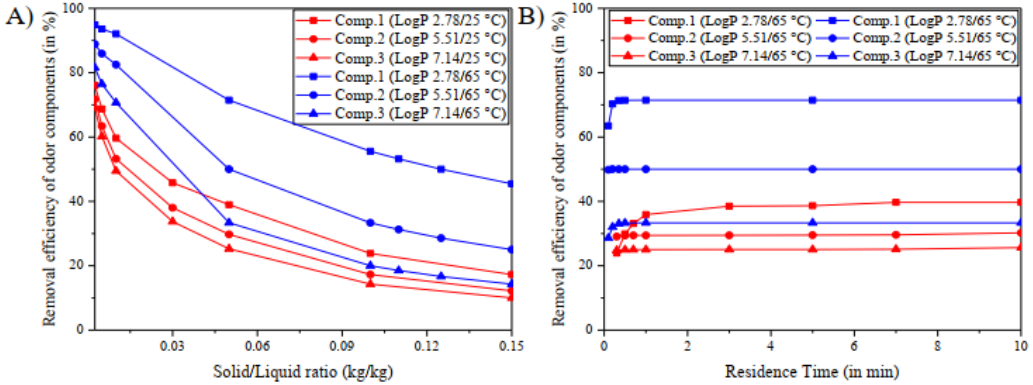

**Fig. 6..** Headspace composition of Waste films, Washed films and Regranulated material: (a) Thermal desorption sampling (b) Solvent desorption sampling.

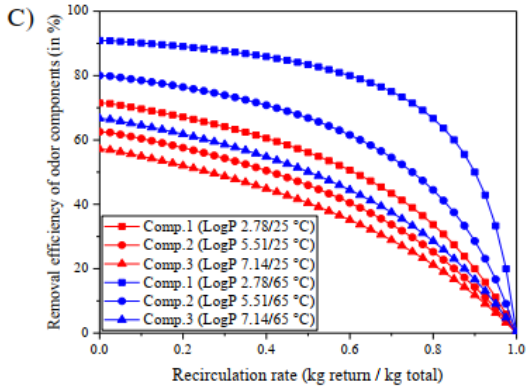
# Deodorisation



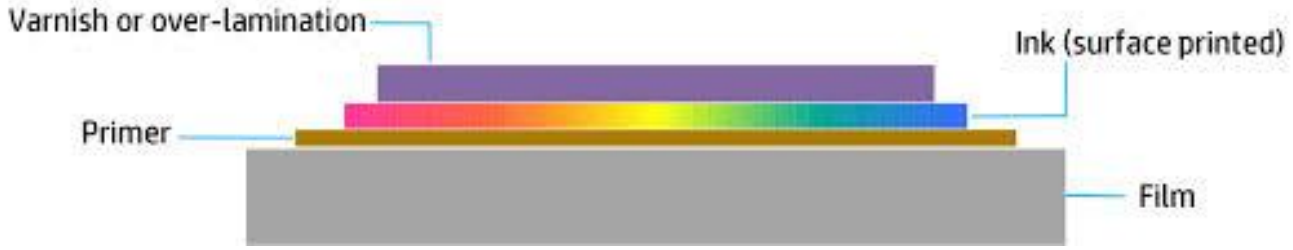



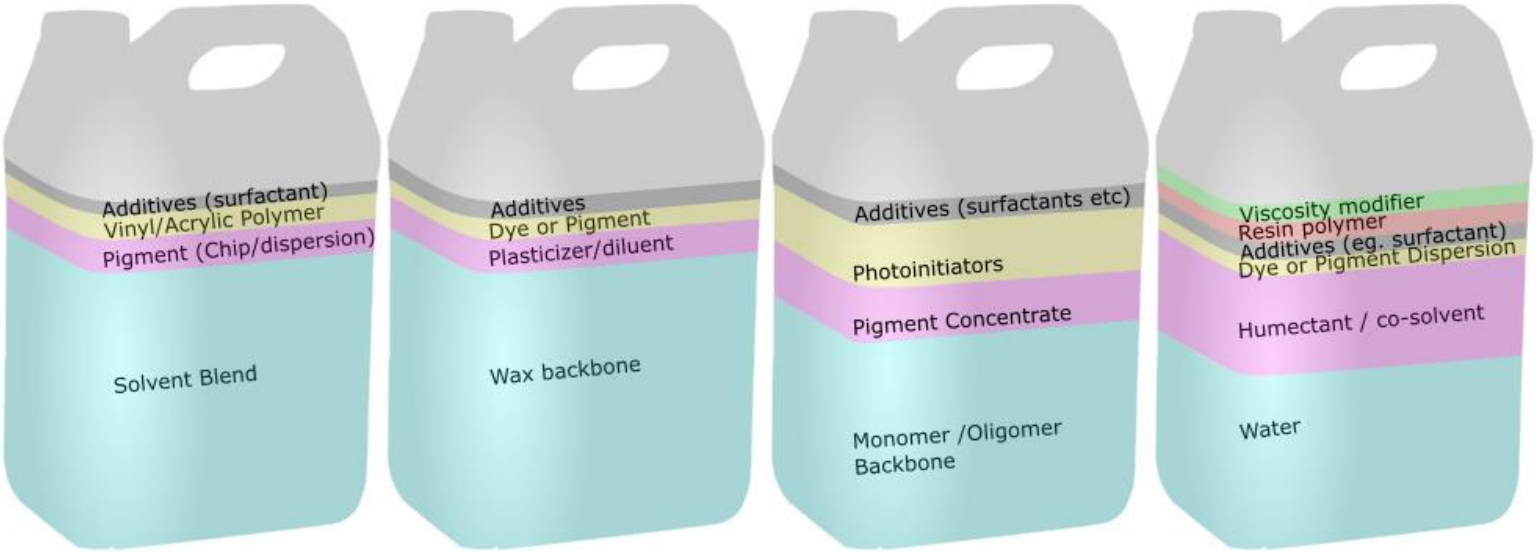




**8. *Avoid Adding Foreign Species to the Separation Sequence.*** **It is best to avoid adding mass separating agents, such as in azeotropic distillation and leaching, because these agents subsequently must be recovered, often creating a separation problem. This is one reason why energy separating agents often are preferred.**

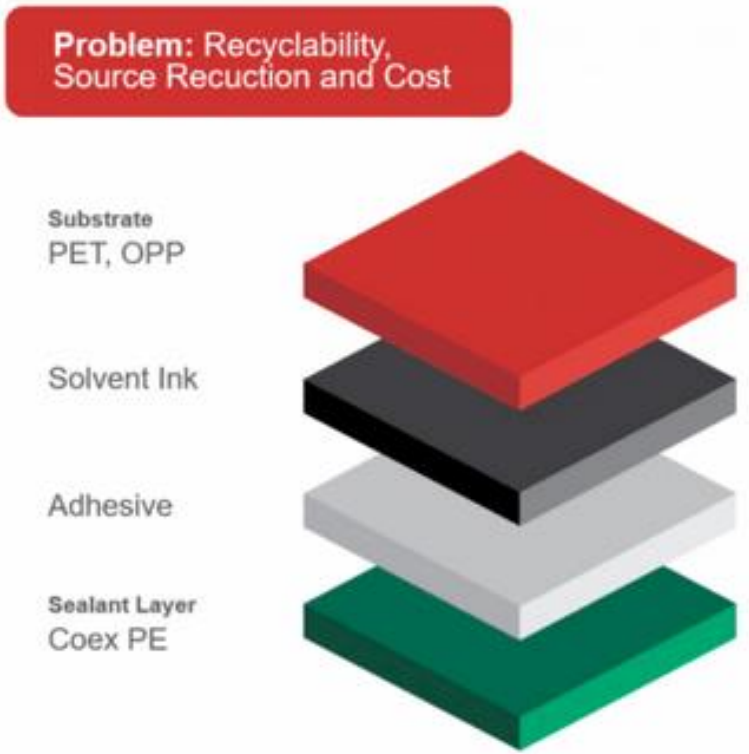
# Deinking



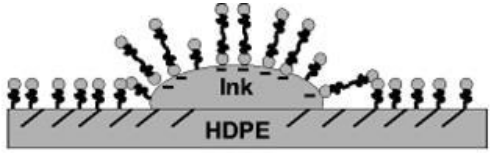

Do not underestimate the chemistry of ink structures!



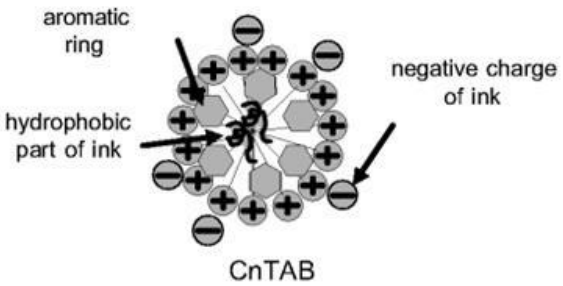




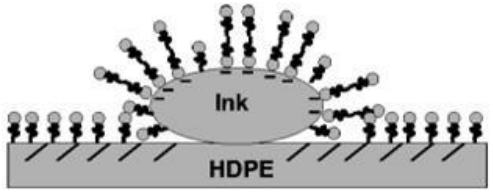
# Deinking



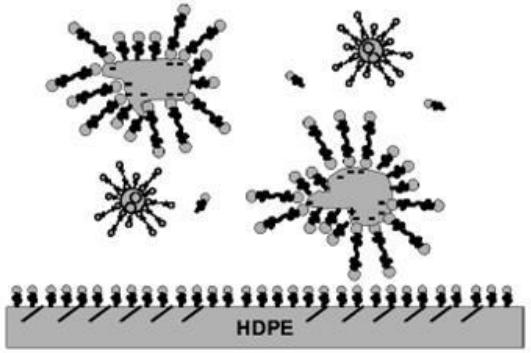

a Step 1: surface adsorption




b Step 2: solubilization of binder

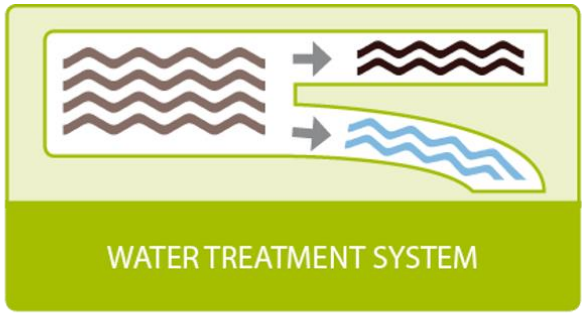



c Step 3: detachment of pigment particles

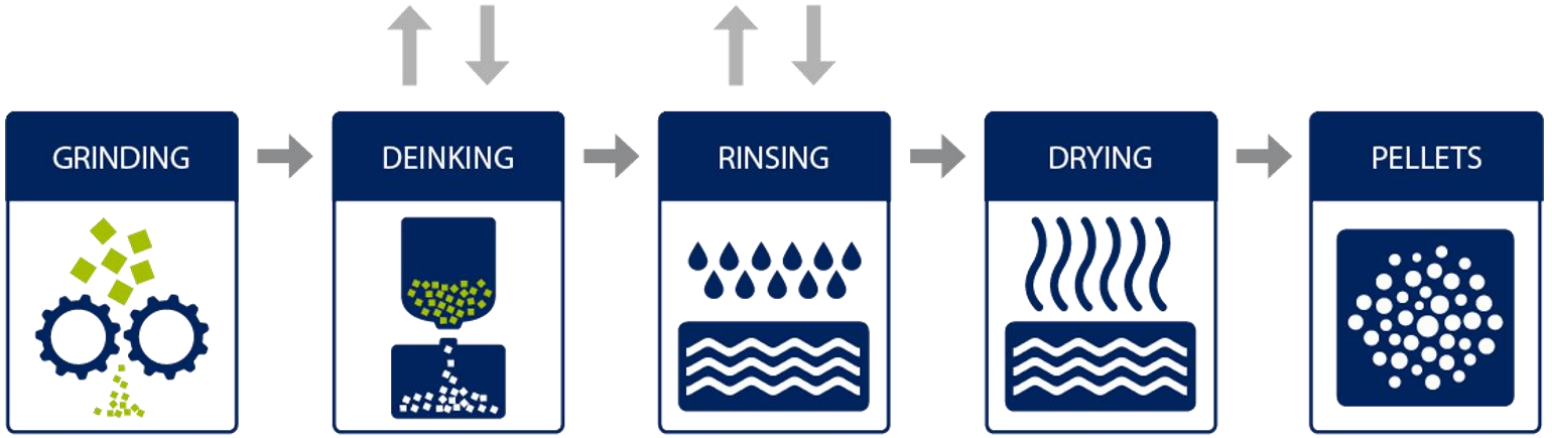


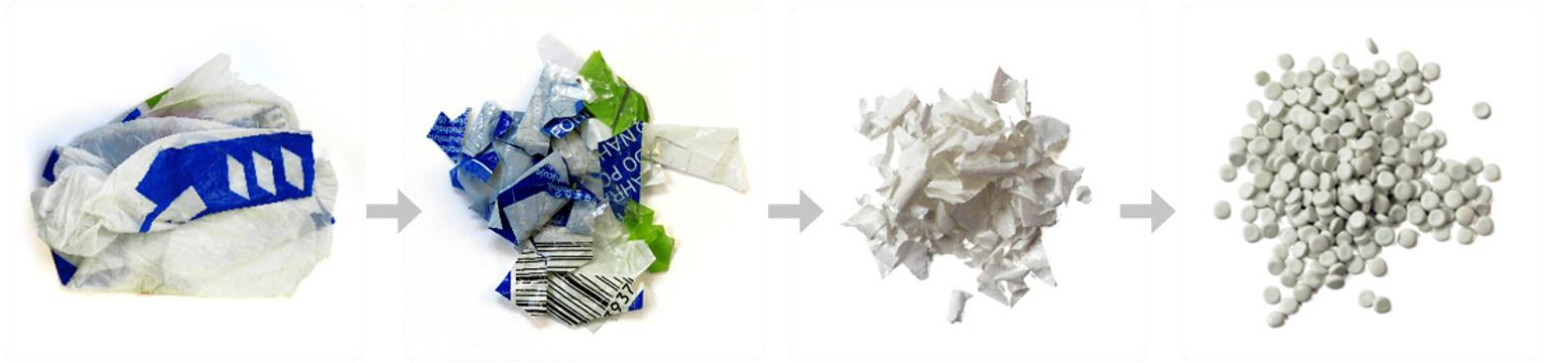

d Step 4: stabilization and dispersion of detached pigment particles

NOREC®




CADEL DEINKING



1 B

1 A

2 B

3 A

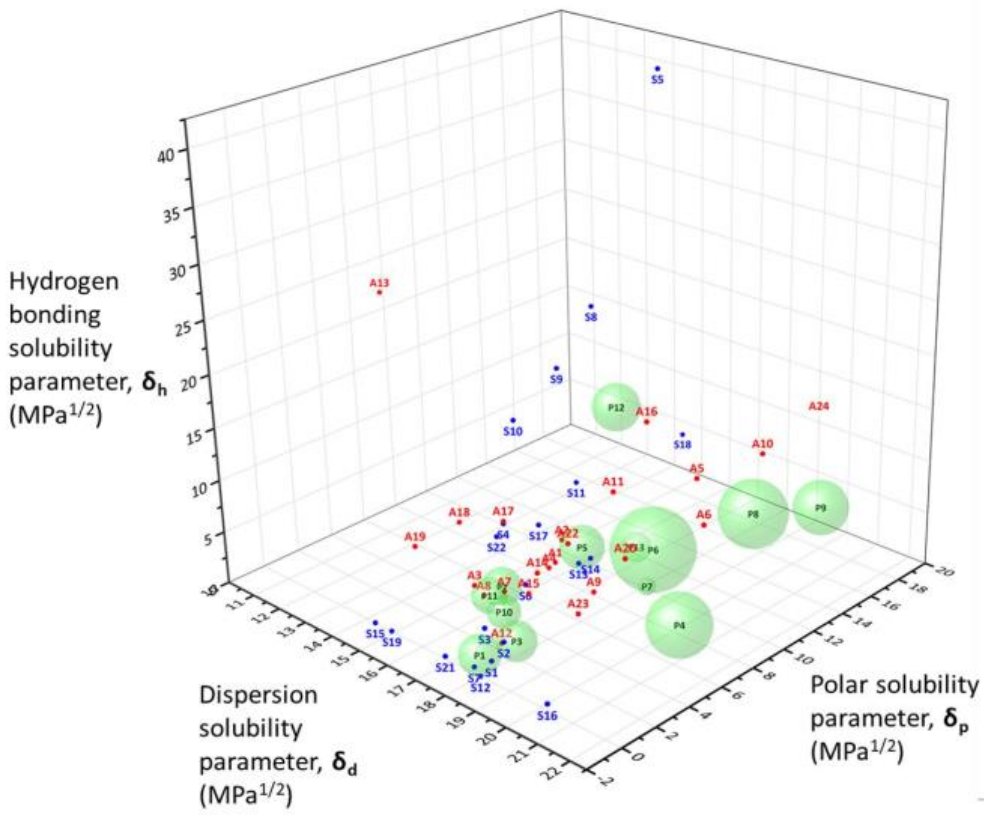
4 A

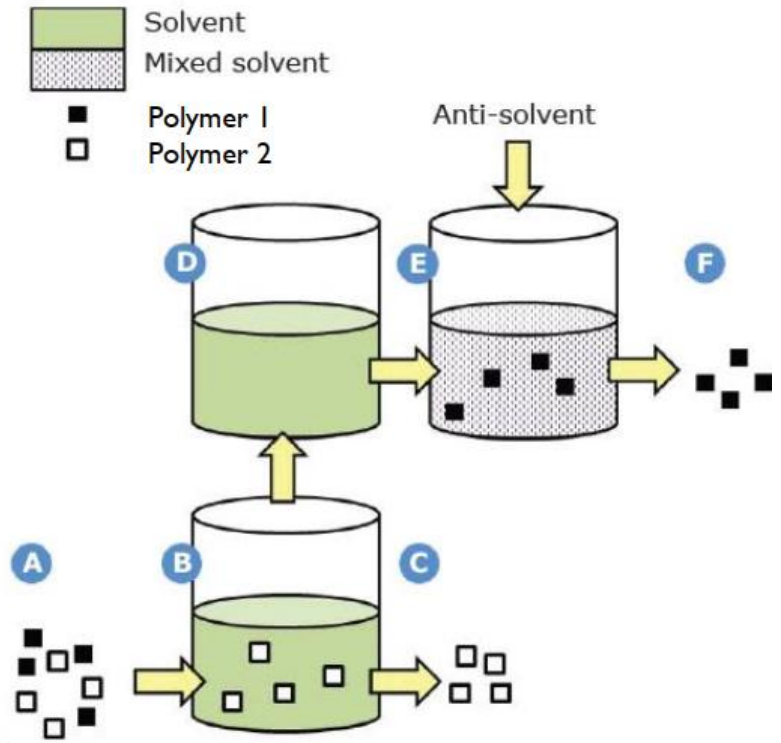
5 B

Complete deinking & delamination

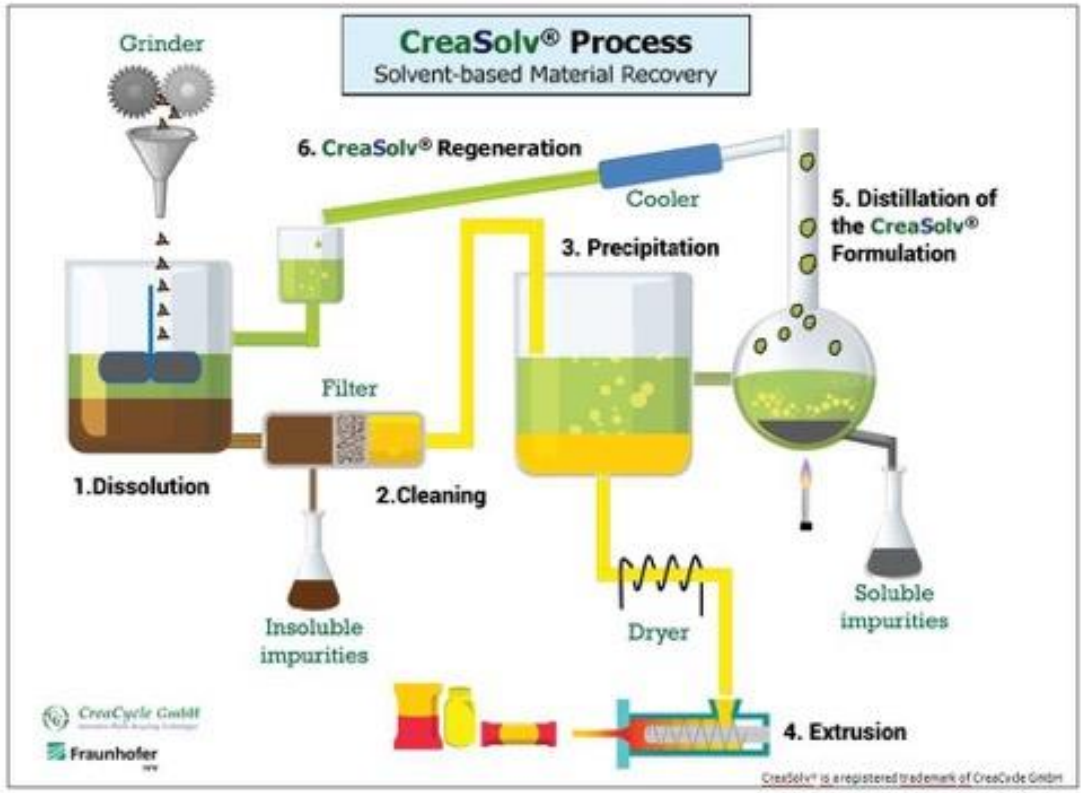
GHENT UNIVERSITY

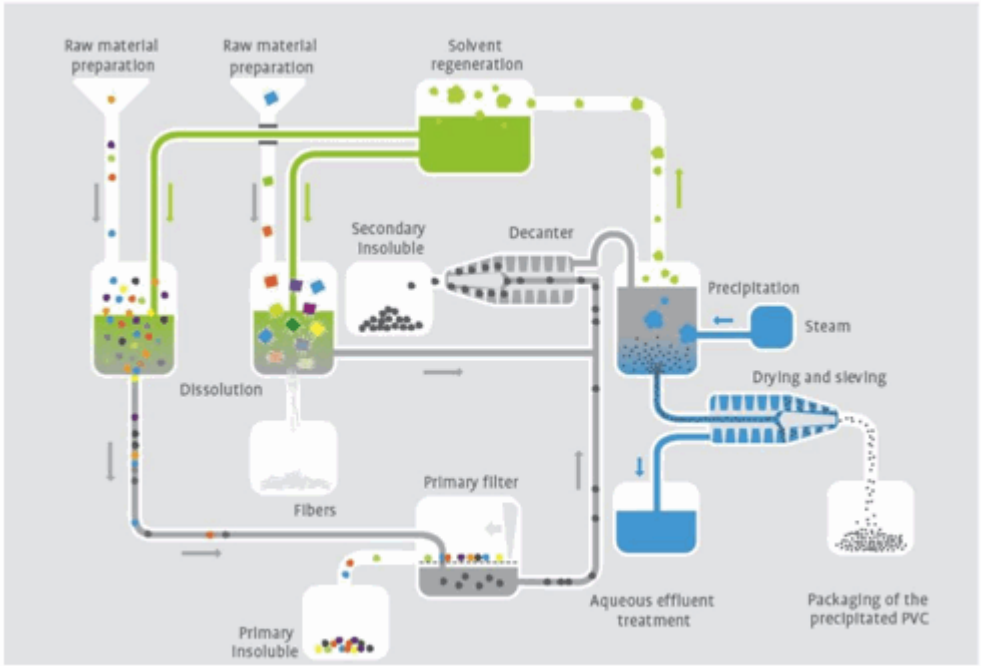
# Solvent based pretreatment/recycling



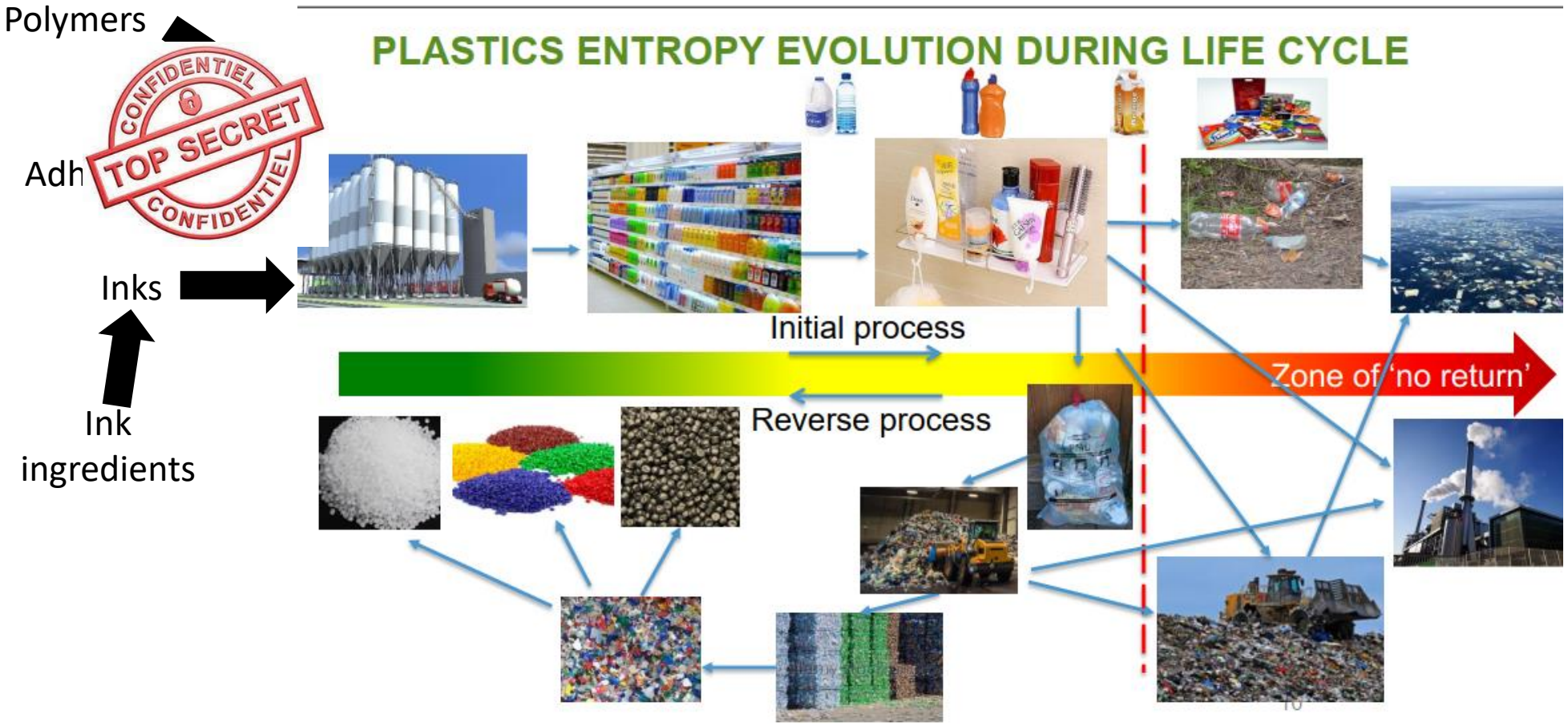
# Solvent based pretreatment/recycling



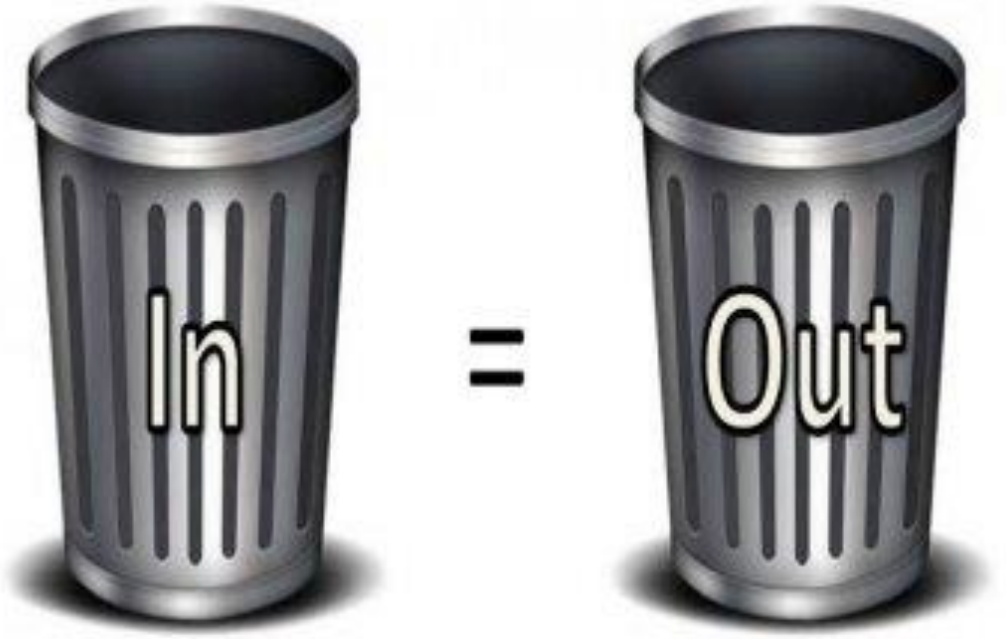

Il processo VinyLoop®

# Conclusions




* Fig. by Herman Van Roost (Total)

# Conclusions




- Different steps:
  - Logistics
  - Sorting (dry pretreatment)
  - ‘Recycling’ (wet pretreatment)
- Very hard to get consistent data on composition, especially further than the main polymer composition
- Probably further pretreatment needed
- Also chemical recycling (might) need(s) pretreatment
- All this has to be done for <750€/t
- We need more books

FACULTY OF
BIOSCIENCE ENGINEERING

# Prof. Dr. Ir. Steven De Meester


DEPARTMENT OF GREEN CHEMISTRY
AND TECHNOLOGY

E Steven.demeester@ugent.be
T +32 (0) 56 241236
F +32 (0) 56 241224

www.lcpe.ugent.be


- Ghent University
- @ugent
- Ghent University


This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No. 859885.