# Polymers identification: a critical step for plastics recycling

Ana C. Marques, DEQ, IST-UL (2021)

ulisses

UNIVERSITY OF LISBON
INTERDISCIPLINARY STUDIES
ON SUSTAINABLE ENVIRONMENT AND SEAS

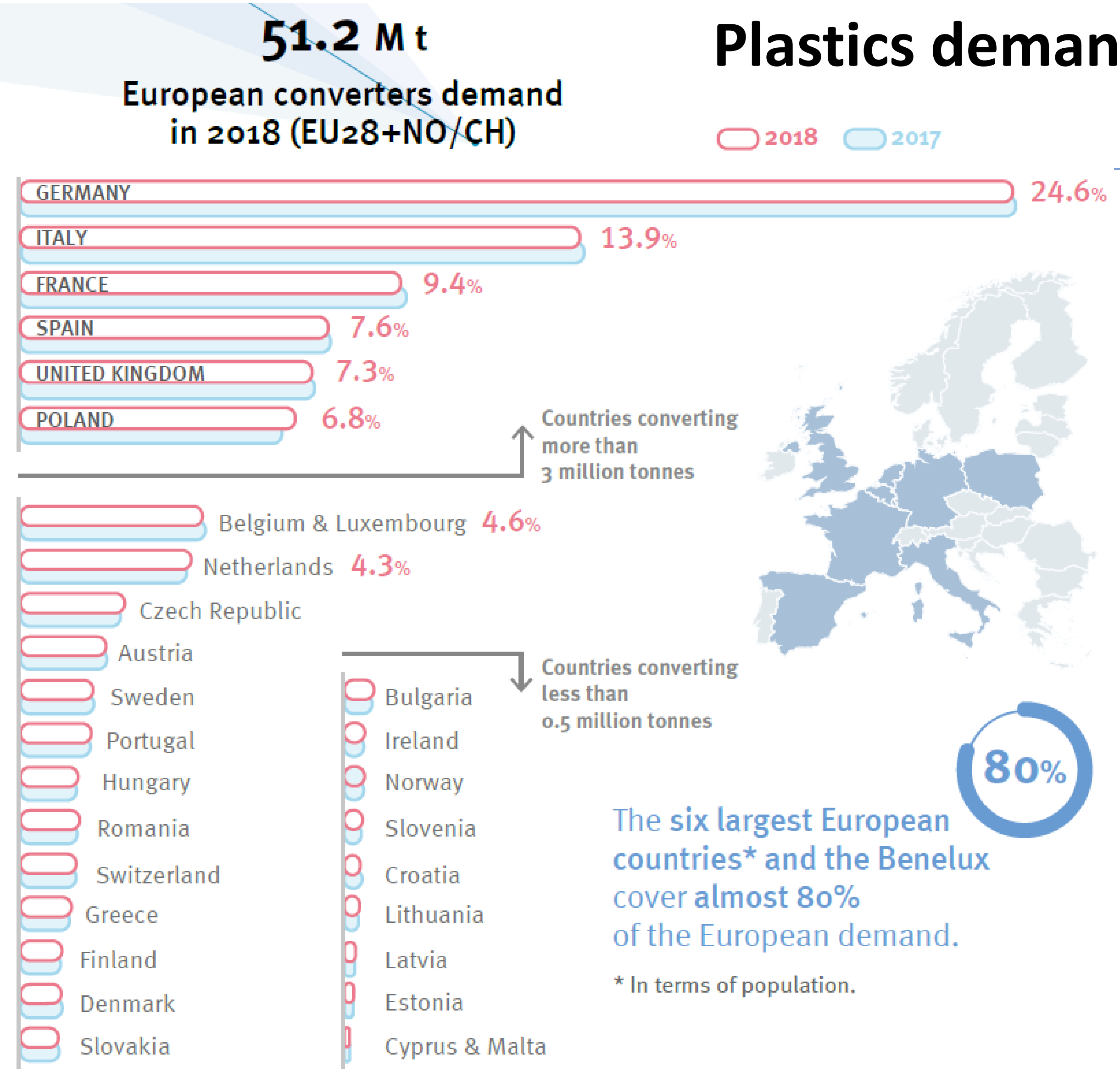


unite! University Network for Innovation, Technology and Engineering
U LISBOA UNIVERSIDADE DE LISBOA
Co-funded by the Erasmus+ Programme of the European Union

# Outline

1. Plastics demand and plastics packaging recycling rate, by country (Europe)
2. Types of polymers
3. Non-instrumental identification tests for polymers
4. Mechanical recycling process
5. Plastic recyclates: where are they used
6. Glossary

# Plastics demand by country



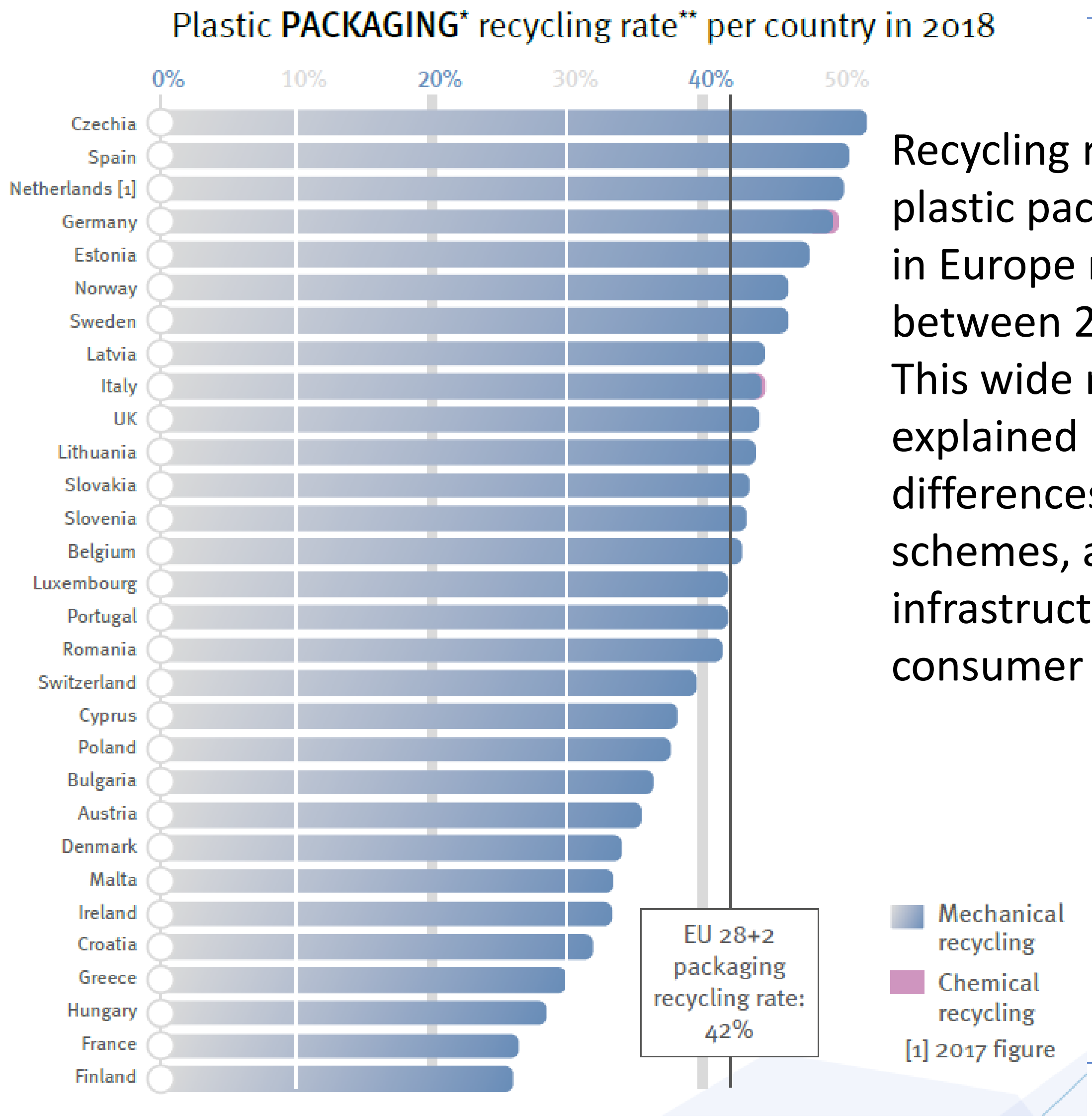

Source: **Plastics – the Facts 2019**

275,000 tonnes of plastic are used annually in the UK, for example. This is equivalent to 15 million bottles per day!

Plastic waste issues have been extensively noticed by the media, due to the large quantities that have been reaching the world's oceans.

Once in the ocean, plastic can enter the food chain and have dramatic effects on marine ecology.

# Plastics packaging recycling rate by country




Recycling rates of plastic packaging waste in Europe range between 26% and 52%. This wide range can be explained by differences in collection schemes, available infrastructure and consumer behaviour.

Source: **Plastics – the Facts 2019**

European countries have challenging plastic packaging recycling targets by the next years!

The new Directive (EU) 2018/852 on Packaging and Packaging Waste sets higher recycling targets per material (50% for plastic packaging by 2025 and 55% by 2030).

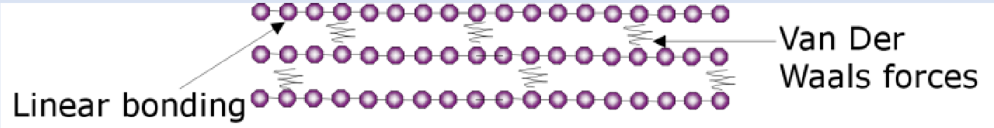
**However, after collecting plastic waste and before it can be recycled, it is necessary to separate the various types of plastic.**

**For that it is necessary to classify them!**

Co-funded by the Erasmus+ Programme of the European Union

# Types of polymers

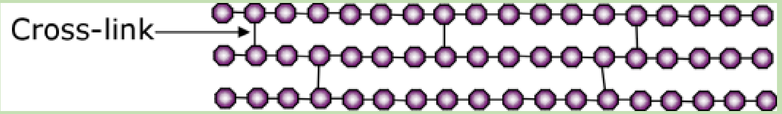
## Thermoplastics




Typically linear or branched chains, with covalent intramolecular bonds and secondary intermolecular bonds. They can be subjected to multiple heating and cooling cycles without substantially altering the molecular structure of the polymer.

*Exs: Commodities: HDPE, LDPE/LLDPE, PP, PVC, PS, PET; Engineering: PA, PC, PMMA, POM, PU,…; Speciality: Kevlar, Kapton, PEEK, …*

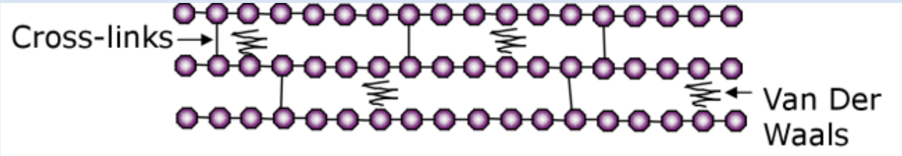
## Thermosets




Polymer chains with intramolecular covalent bonds within a 3D cross-linked network. (10-50% of cross-links).
They chemically transform (cure) into a rigid structure, catalysed by heating.
They don´t soften with a subsequent heating, but they suffer degradation or burning at too high temperatures.
Stiffer than thermoplastics, with higher dimensional stability.

*Exs: Phenolics (phenol-formaldehyde); Amino-based (urea-formaldehyde, melamine-formaldehyde,…); Unsaturated poliesters; Epoxides; Polyurethan*

## Elastomers




Significant elastic behavior, typical of rubber. $T_g$<RT. Less cross-links than for thermosets, which together with entanglements inhibit plastic deformation or flow.

Cross-links → amorphous structure

Exs: Chemically cross-linked (isoprene, butadiene, isobutylene,…)
Physicaly cross-linked / thermoplastic elastomers (ABS, SAN, SBS, …)

# Types of polymers

Each polymer has a characteristic melting point, for instance. Knowing which type of polymer a certain object is made of, is essential for recycling it. It becomes even more complicated if such plastic object results from a polymer formulation, consisting of different types of additives besides the polymer matrix.

*Some physical properties of common plastics*

| Number | Plastic Type and Composition | Density/(g/mL) | Glass Transition Temperature/°C *(7)* | Melting Temperature/°C *(7)* |
|---|---|---|---|---|
| 1 | PET or PETE: poly(ethylene terephthalate) | 1.38–1.39 | 60–85 | 250–265 |
| 2 | HDPE: high-density polyethylene | 0.95–0.97 | ~−125 | ~138 |
| 3 | PVC or V-poly(vinyl chloride) | 1.16–1.35 | 81–98 | 200–300 |
| 4 | LDPE: low-density polyethylene | 0.92–0.94 | −128 to −30 | ~138 |
| 5 | PP: polypropylene (isotactic when all methyl groups are on the same side of the chain) | 0.90–0.91 | −8 | 174–177 |
| 6 | PS: polystyrene | 1.05–1.07 | 80–100 | 240 |
| 7 | PLA: polylactic acid *(8)* (D and L conformations cause numbers to differ) | 1.25–1.26 | 50–80 | 173–178 |

*M.E. Harris, B. Walker, A Novel, Simplified Scheme for Plastics Identification, Journal of Chemical Education, edited by Erica K. Jacobsen, Vol. 87 No. 2 (2010).*

# Non-instrumental identification tests for polymers

By performing a few simple tests, such as a flame or burn test, you may be able to determine which type of polymer you have. The following slides show procedures, or flowcharts of different complexity that can be followed in order to identify a polymer.

Test 1. Look at the sample. Is it transparent, translucent or opaque?

Test 2. Feel the sample. Does it bend? Can it be scratched? What does the surface feel like?

Test 3. Cut the sample with a sharp knife. Does it cut easily? Are the edges smooth or jagged? Does it crumble or flake?

Test 4. Subject the sample to a float test (in water). Does it float or sink? (Note: not applicable to expanded foam materials. Water should be around room temperature).

Test 5. Try to burn a small piece of the sample. What is the size and colour of the flame? Do molten drips fall from the sample and continue to burn? Does the sample self-extinguish? Is there any odour when the flame has been extinguished?

*https://www.twi-global.com/technical-knowledge/faqs/faq-how-using-simple-manual-tests-can-i-identify-an-unknown-plastic-material*

# Non-instrumental identification tests for polymers

| Material | Test no. | Observation |
|---|---|---|
| Low density polyethylene (LDPE) | 1 | Transparent only as thin film, translucent in thicker sections |
| | 2 | Fairly flexible; soft, 'waxy' feel, easily scratched |
| | 3 | Easily and smoothly cut |
| | 4 | Floats |
| | 5 | Not self-extinguishing; molten droplets which usually go out on reaching bench or floor; blue flame with yellow tip and little smoke, smell of burning candle/paraffin when flame is extinguished |
| High density polyethylene (HDPE) | 1 | Transparent only as thin film, translucent in thicker sections |
| | 2 | Fairly stiff and hard, can be scratched by fingernail |
| | 3 | Easily cut with smooth edges |
| | 4 | Floats |
| | 5 | Not self-extinguishing; molten droplets which usually go out on reaching bench or floor; blue flame with yellow tip and little smoke, smell of burning candle/paraffin when the flame is extinguished |
| Polypropylene (PP) | 1 | Transparent only as thin film, translucent in thicker sections |
| | 2 | Stiff; hard, can be scratched by fingernail |
| | 3 | Easily cut, fairly smooth edges, when cut with chisel leaves white mark |
| | 4 | Floats |
| | 5 | Not self-extinguishing; molten droplets which usually go out on reaching bench or floor; flame mainly yellow with a trace of clear blue at the bottom; smell of burning candle/diesel when flame is extinguished. |
| Polyvinyl Chloride, Unplasticised (uPVC) | 1 | Transparent (unless fillers or pigments have been added) |
| | 2 | Stiff; hard |
| | 3 | Fairly easy to cut, smooth edges |
| | 4 | Sinks |
| | 5 | Burns with difficulty, self-extinguishing; yellow flame, blue-green at bottom edges; unpleasant, acrid odour of hydrochloric acid. |

*https://www.twi-global.com/technical-knowledge/faqs/faq-how-using-simple-manual-tests-can-i-identify-an-unknown-plastic-material*

unite! University Network for Innovation, Technology and Engineering
LISBOA UNIVERSIDADE DE LISBOA
Co-funded by the Erasmus+ Programme of the European Union

# Non-instrumental identification tests for polymers

Polymers will float or sink in each of these solutions, depending on their density.

**Details for preparing solutions of different densities**

| Density in g / cm$^3$ | Solution |
|---|---|
| 0.79 | Ethanol (IDA) |
| 0.91 | 47.1 g of ethanol in 43.9 cm$^3$ of distilled water. This concentration is still **flammable**. Keep away from any sources of ignition. **Harmful** if swallowed; can cause **damage to organs.** |
| 0.94 | 35.4 g of ethanol in 58.6 cm$^3$ of distilled water. **Harmful** if swallowed; can cause **damage to organs.** |
| 1.00 | Distilled water |
| 1.15 | 18.4 g of $K_2CO_3$ in 96.5 cm$^3$ of distilled water. **IRRITANT** at this concentration. |
| 1.38 | 51.3 g of $K_2CO_3$ in 86.6 cm$^3$ of distilled water. It will be necessary to place this on a mechanical stirrer to speed up dissolving all the $K_2CO_3$. **IRRITANT** at this concentration. |

Densities of various common polymers

| Polymer | Density (g cm$^{-3}$) |
|---|---|
| Silicone rubber | 0.80 |
| PP | 0.85–0.92 |
| LDPE | 0.89–0.93 |
| Natural rubber | 0.92–1.00 |
| UHMWPE | 0.94 |
| HDPE | 0.94–0.98 |
| Nylon 12 | 1.01–1.04 |
| Nylon 11 | 1.03–1.05 |
| PS | 1.04–1.06 |
| ABS | 1.04–1.08 |
| SAN | 1.06–1.10 |
| Nylon 6,10 | 1.07–1.09 |
| Polyester resins | 1.10–1.40 |
| Epoxy resins | 1.10–1.40 |
| Nylon 6 | 1.12–1.15 |
| Nylon 6,6 | 1.13–1.16 |
| PAN | 1.14–1.17 |
| PVA | 1.17–1.20 |
| Nylon 4,6 | 1.18 |
| PMMA | 1.16–1.20 |
| PC | 1.20–1.22 |
| PU | 1.20–1.26 |
| PVAl | 1.21–1.31 |
| Cellulose acetate | 1.25–1.35 |
| PEEK | 1.26–1.32 |
| PEI | 1.27 |
| P–F resins | 1.26–1.28 |
| PET | 1.38–1.41 |
| PBT | 1.31 |
| Cellulose nitrate | 1.34–1.40 |
| PES | 1.37 |
| Unplasticized PVC | 1.38–1.41 |
| Polyimide | 1.42 |
| Kevlar | 1.44 |
| Amino resins | 1.47–1.52 |
| PPS | 1.66 |
| PVDF | 1.76 |
| PTFE | 2.10–2.30 |

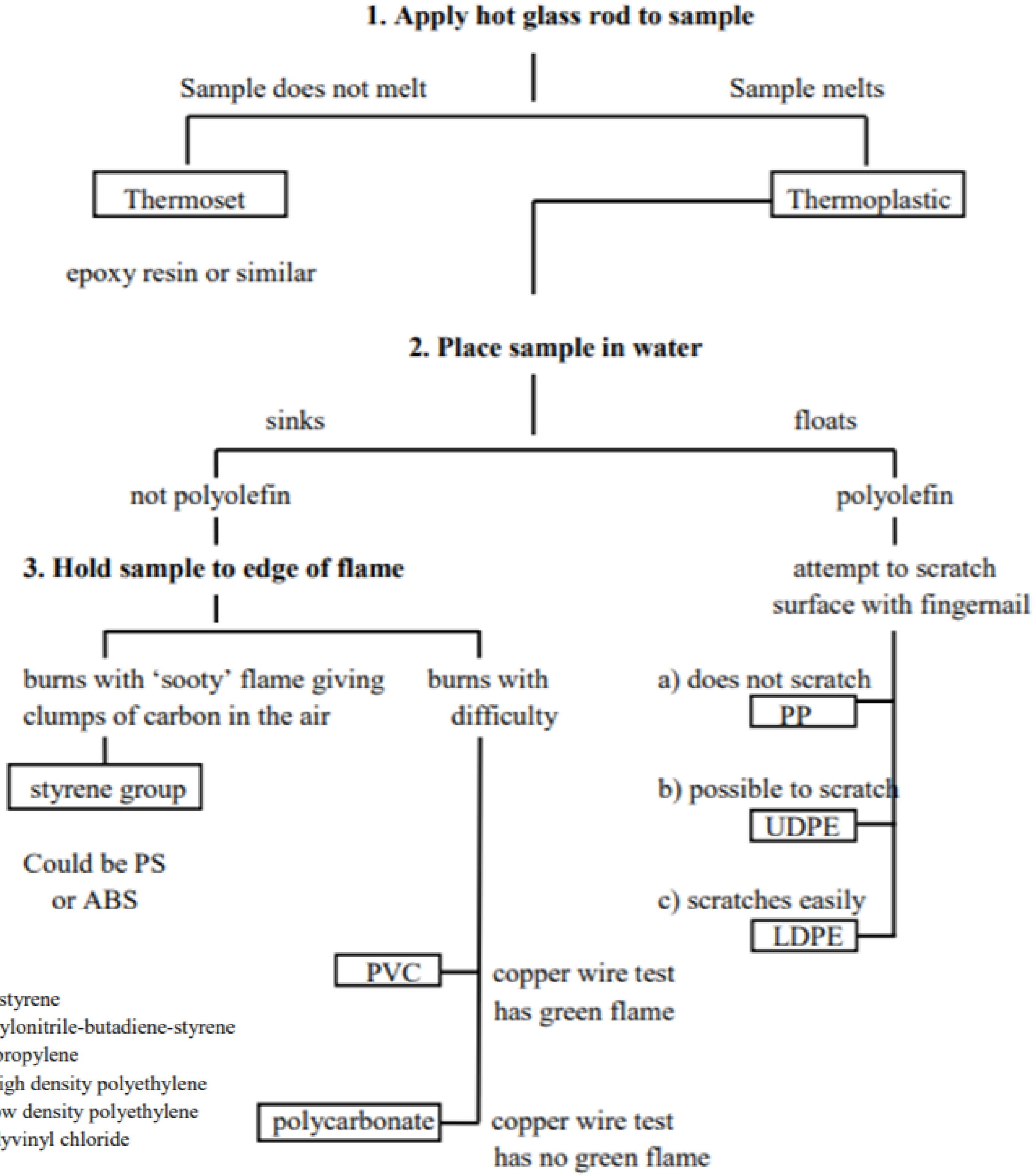
# Non-instrumental identification tests for polymers

Besides density, there are other properties characteristic for thermoplastic or thermoset polymers:

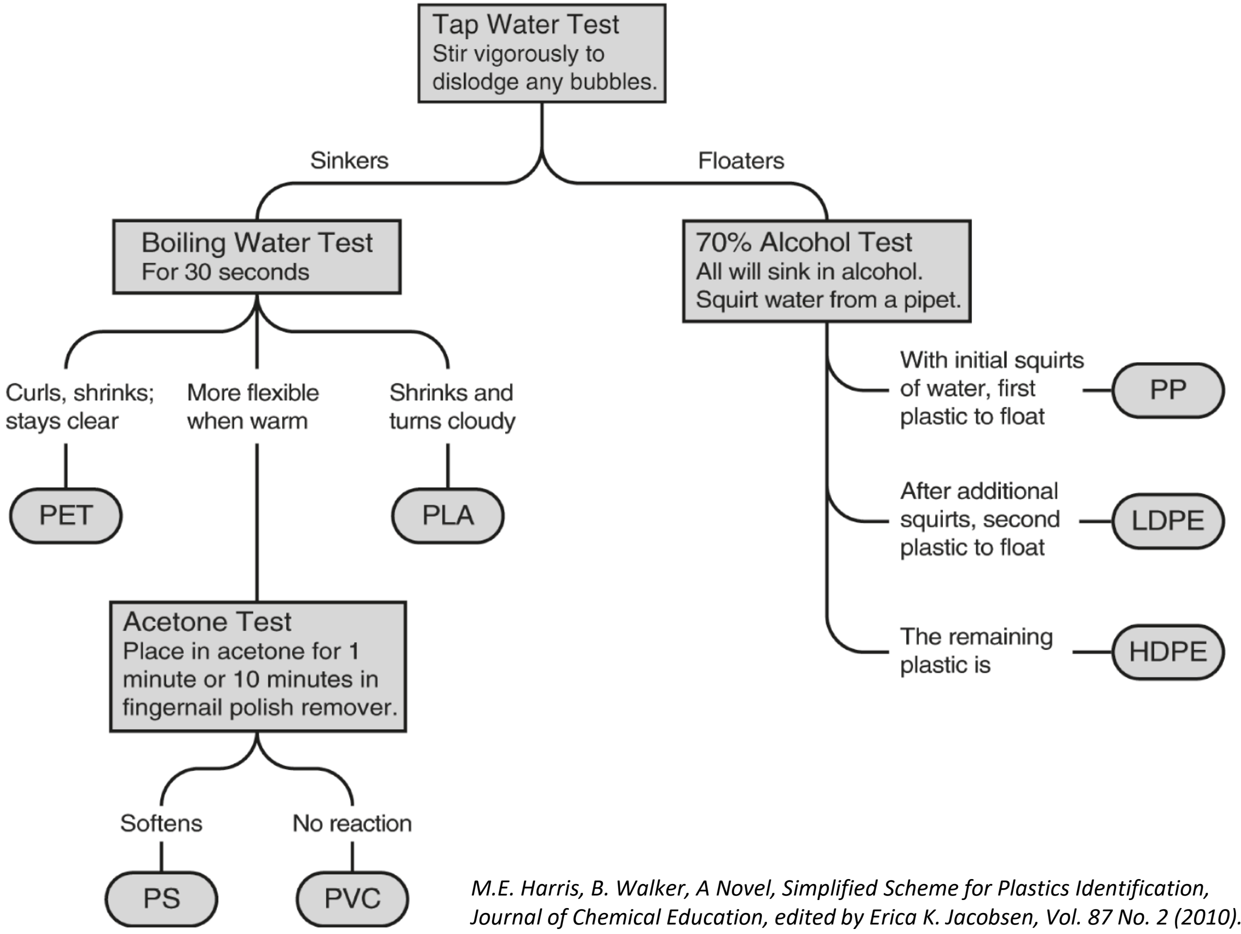
| | Appearance | | | | Stiffness | | | Surface | | | Burn test | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Transparent | Transparent (thin film) | Transluscent | Opaque | Flexible (resilient) | Semi-rigid | Rigid (Brittle) | Glassy | Waxy | Dull | Black soot | Burns clean | Self extinguishing | Drips | Does not drip | Yellow flame | Blue flame | Green flame |
| PE-LD | | ● | ● | | ● | | | | ● | | | ● | | | ● | | ● | |
| PE-HD | | ● | ● | | ● | | | | ● | | | ● | | | ● | | ● | |
| PP | | ● | ● | | | ● | | | ● | | | ● | | | ● | | ● | |
| PP-CO | | ● | ● | | | ● | | | ● | | | ● | | | ● | | ● | |
| PS | ● | | | | | | ● | ● | | | ● | | | ● | | ● | | |
| PS-HI | | | | ● | | ● | | | | ● | ● | | | ● | | ● | | |
| SAN | ● | | | | | | ● | ● | | | ● | | | ● | | ● | | |
| ABS | | | | ● | | ● | | | | ● | ● | | | ● | | ● | | |
| PVC-R | ● | | | | | ● | | ● | | | ● | | ● | | | | | ● |
| PVC-P | ● | | | | ● | | | ● | | | ● | | ● | | | | | ● |
| PTFE | | | | ● | ● | | | ● | | | | ● | ● | | | | ● | ● |
| PVDF | ● | | | | | | ● | | | | | | ● | | | | | |
| PVAC | | | | | ● | | | | | | ● | | | | | ● | | |
| PVAL | ● | | | | ● | | | | | | | ● | | | | ● | | |
| PMMA | ● | | | | | | ● | ● | | | | ● | | ● | | | ● | |
| POM | | | | ● | | ● | | ● | | | | ● | | | ● | | ● | |
| PA6 | | | ● | | | ● | | ● | | | | ● | | | ● | | ● | |
| PA66 | | | ● | | | ● | | ● | | | | ● | | | ● | | ● | |
| PSU | ● | | | | | ● | | ● | | | ● | | | ● | | ● | | |
| PI | | | ● | | | | ● | | | | | | ● | | | ● | | |
| CA | ● | | | | | ● | | ● | | | ● | | | ● | | ● | | |
| CAB | ● | | | | | ● | | ● | | | | ● | | | ● | | ● | |
| CN | ● | | | | | | ● | ● | | | ● | | | | | ● | | |
| PC | ● | | | | | ● | | ● | | | ● | | | ● | | ● | | |
| PET | ● | | | | | ● | | ● | | | ● | | | | ● | ● | | |
| PBT | ● | | | | | ● | | ● | | | ● | | | | ● | ● | | |
| PF | | | | ● | | | ● | ● | | | ● | | ● | | | | | |
| PF-MF | | | | ● | | | ● | ● | | | ● | | ● | | | | | |
| PF-OF | | | | ● | | | ● | ● | | | ● | | ● | | | | | |
| UP | | | | ● | | | ● | ● | | | ● | | | | | ● | | |
| EP | ● | | | | | | ● | ● | | | ● | | ● | | | ● | | |
| PUR | | | | ● | ● | ● | ● | | | | | | | ● | | ● | | |
| SI | ● | | | | ● | | | | | ● | | | ● | | | | | |

unite! University Network for Innovation, Technology and Engineering
U LISBOA UNIVERSIDADE DE LISBOA
Co-funded by the Erasmus+ Programme of the European Union

# Non-instrumental identification tests for polymers

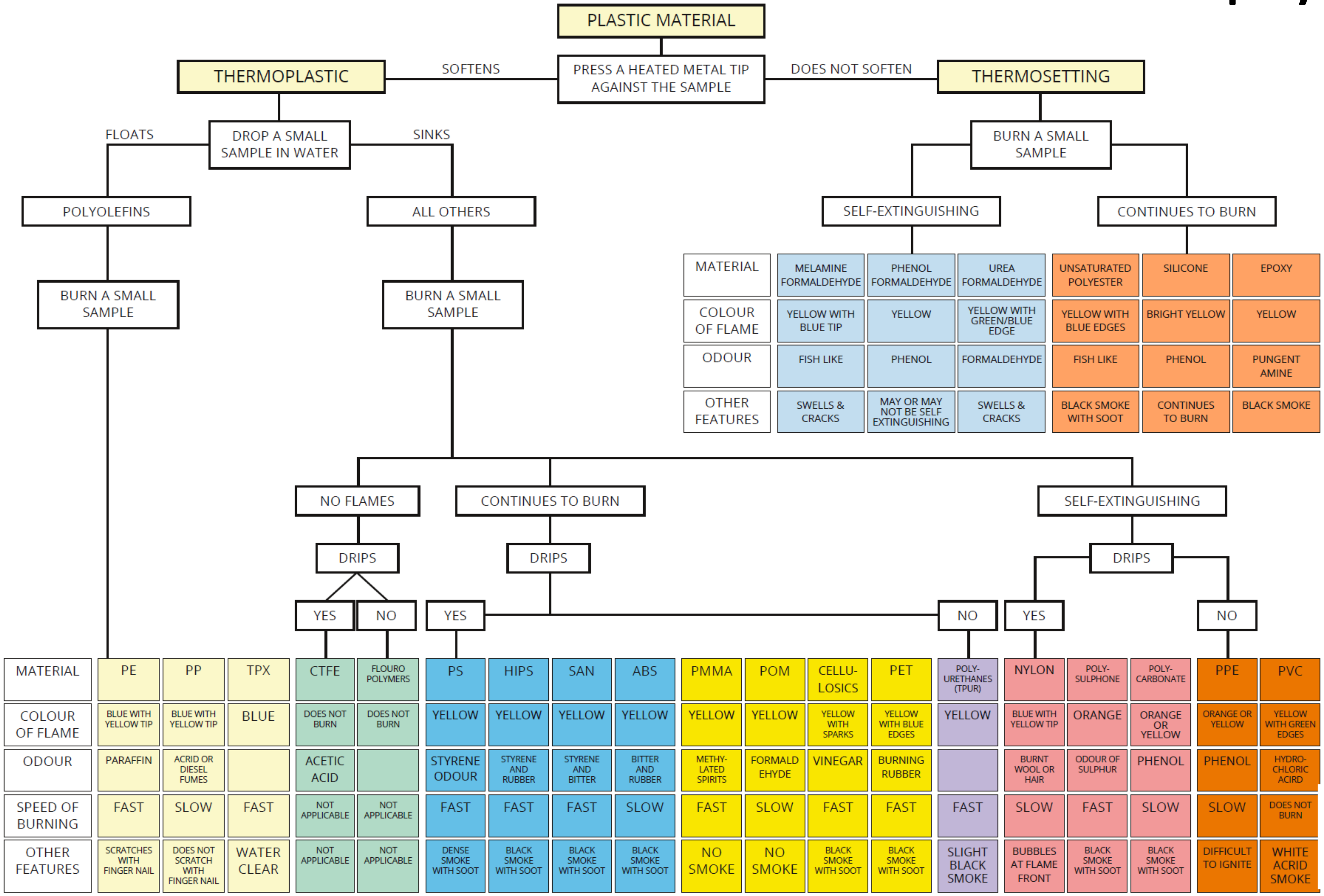



PS = polystyrene
ABS = acrylonitrile-butadiene-styrene
PP = polypropylene
HDPE = high density polyethylene
LDPE = low density polyethylene
PVC = polyvinyl chloride




*M.E. Harris, B. Walker, A Novel, Simplified Scheme for Plastics Identification, Journal of Chemical Education, edited by Erica K. Jacobsen, Vol. 87 No. 2 (2010).*

# Non-instrumental identification tests for polymers




| MATERIAL | MELAMINE FORMALDEHYDE | PHENOL FORMALDEHYDE | UREA FORMALDEHYDE | UNSATURATED POLYESTER | SILICONE | EPOXY |
|---|---|---|---|---|---|---|
| COLOUR OF FLAME | YELLOW WITH BLUE TIP | YELLOW | YELLOW WITH GREEN/BLUE EDGE | YELLOW WITH BLUE EDGES | BRIGHT YELLOW | YELLOW |
| ODOUR | FISH LIKE | PHENOL | FORMALDEHYDE | FISH LIKE | PHENOL | PUNGENT AMINE |
| OTHER FEATURES | SWELLS & CRACKS | MAY OR MAY NOT BE SELF EXTINGUISHING | SWELLS & CRACKS | BLACK SMOKE WITH SOOT | CONTINUES TO BURN | BLACK SMOKE |

| MATERIAL | PE | PP | TPX | CTFE | FLOURO POLYMERS | PS | HIPS | SAN | ABS |
|---|---|---|---|---|---|---|---|---|---|
| COLOUR OF FLAME | BLUE WITH YELLOW TIP | BLUE WITH YELLOW TIP | BLUE | DOES NOT BURN | DOES NOT BURN | YELLOW | YELLOW | YELLOW | YELLOW |
| ODOUR | PARAFFIN | ACRID OR DIESEL FUMES | | ACETIC ACID | | STYRENE ODOUR | STYRENE AND RUBBER | STYRENE AND BITTER | BITTER AND RUBBER |
| SPEED OF BURNING | FAST | SLOW | FAST | NOT APPLICABLE | NOT APPLICABLE | FAST | FAST | FAST | SLOW |
| OTHER FEATURES | SCRATCHES WITH FINGER NAIL | DOES NOT SCRATCH WITH FINGER NAIL | WATER CLEAR | NOT APPLICABLE | NOT APPLICABLE | DENSE SMOKE WITH SOOT | BLACK SMOKE WITH SOOT | BLACK SMOKE WITH SOOT | BLACK SMOKE WITH SOOT |

| MATERIAL | PMMA | POM | CELLU-LOSICS | PET | POLY-URETHANES (TPUR) | NYLON | POLY-SULPHONE | POLY-CARBONATE | PPE | PVC |
|---|---|---|---|---|---|---|---|---|---|---|
| COLOUR OF FLAME | YELLOW | YELLOW | YELLOW WITH SPARKS | YELLOW WITH BLUE EDGES | YELLOW | BLUE WITH YELLOW TIP | ORANGE | ORANGE OR YELLOW | ORANGE OR YELLOW | YELLOW WITH GREEN EDGES |
| ODOUR | METHY-LATED SPIRITS | FORMALD EHYDE | VINEGAR | BURNING RUBBER | | BURNT WOOL OR HAIR | ODOUR OF SULPHUR | PHENOL | PHENOL | HYDRO-CHLORIC ACRID |
| SPEED OF BURNING | FAST | SLOW | FAST | FAST | FAST | SLOW | FAST | SLOW | SLOW | DOES NOT BURN |
| OTHER FEATURES | NO SMOKE | NO SMOKE | BLACK SMOKE WITH SOOT | BLACK SMOKE WITH SOOT | SLIGHT BLACK SMOKE | BUBBLES AT FLAME FRONT | BLACK SMOKE WITH SOOT | BLACK SMOKE WITH SOOT | DIFFICULT TO IGNITE | WHITE ACRID SMOKE |

*https://www.stanmech.com /articles/plastics-identification-flow-chart*

# Non-instrumental identification tests for polymers

For more information on polymers and elastomers´ properties, you can consult a handbook on this topic, such as the following one:

Cardarelli F. (2018) Polymers and Elastomers. In: Materials Handbook. Springer, Cham.
https://doi.org/10.1007/978-3-319-38925-7_11

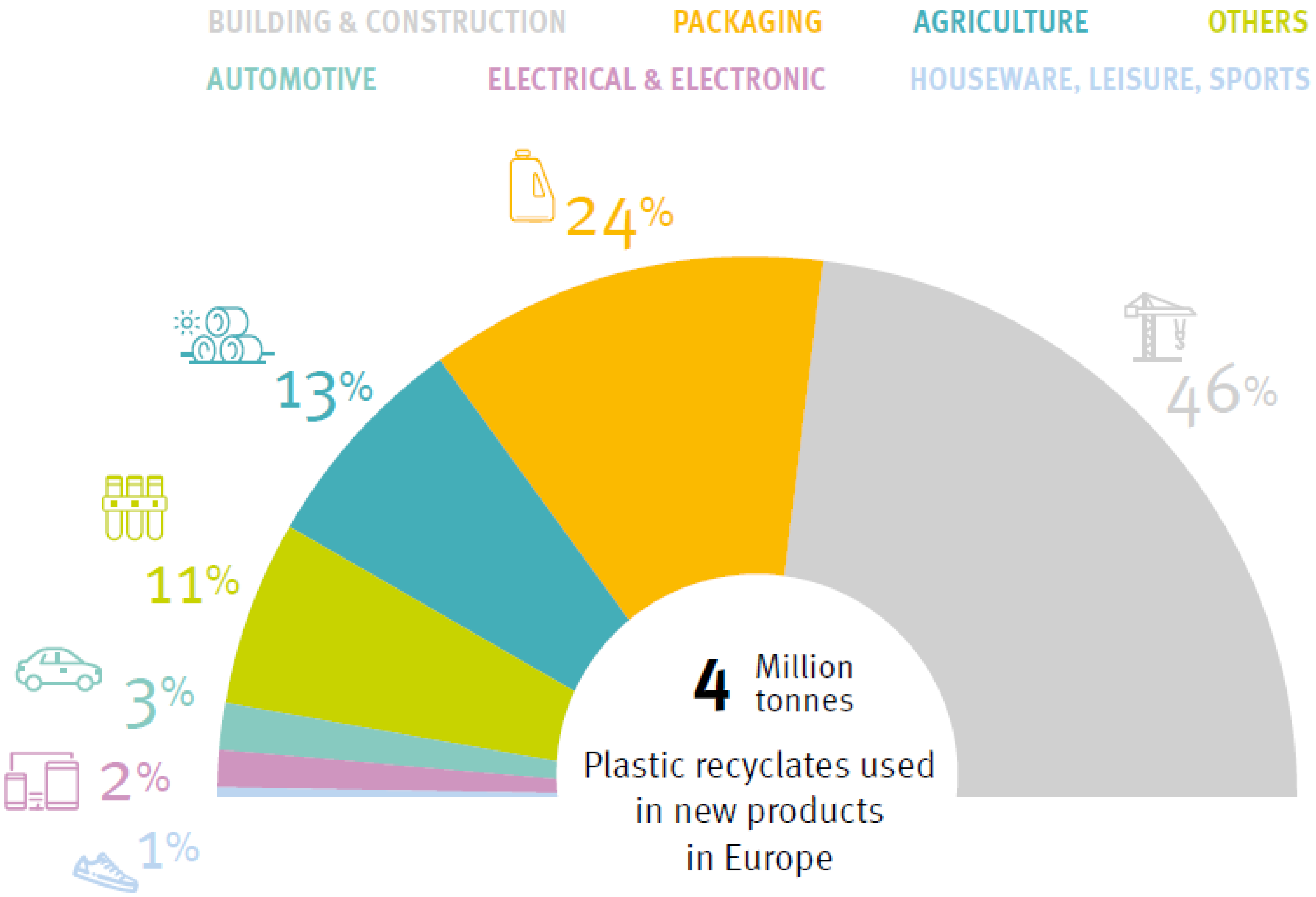
# Plastics: mechanical recycling process

In 2018, close to 5 million tonnes of plastic recyclates were produced in European recycling facilities.


Source: 

# Plastic recyclates: where are they used

In 2018, from the 5 million tonnes of plastic recyclates produced in Europe, 80% re-entered the European economy in order to manufacture new products. The rest was exported outside Europe to re-enter other regions of the world's economies.




Source: © 2020 PlasticsEurope.

Co-funded by the Erasmus+ Programme of the European Union

# Glossary of terms

| | |
|---|---|
| ABS | Acrylonitrile butadiene styrene resin |
| ASA | Acrylonitrile styrene acrylate resin |
| bn | Billion |
| CH | Switzerland |
| CIS | Commonwealth of Independent States |
| Conversio | Conversio Market & Strategy GmbH |
| EU | European Union |
| EPRO | European Association of Plastics Recycling and Recovery Organisations |
| EPS | Expandable polystyrene |
| ETP | Engineering Thermoplastics |
| GDP | Gross domestic product |
| kt | Kilo tonnes |
| M t | Million tonnes |
| NAFTA | North American Free Trade Agreement |
| NO | Norway |
| Other plastics | Thermosets, adhesives, coatings and sealants |
| PA | Polyamides |
| PBT | Polybutylene terephthalate |
| PC | Polycarbonate |
| PE | Polyethylene |
| PEEK | Polyetheretherketone |
| PE-HD | Polyethylene, high density |
| PE-LD | Polyethylene, low density |
| PE-LLD | Polyethylene, linear low density |
| PE-MD | Polyethylene, medium density |
| PEMRG | PlasticsEurope Market Research Group |
| PET | Polyethylene terephthalate |
| Plastic materials | Thermoplastics + Polyurethanes |
| PMMA | Polymethyl methacrylate |
| POM | Polyoxymethylene |
| PP | Polypropylene |
| PS | Polystyrene |
| PTFE | Polytetrafluoroethylene |
| PUR | Polyurethane |
| PVC | Polyvinyl chloride |
| SAN | Styrene-acrylonitrile copolymer |
| Thermoplastics | Standard plastics (PE, PP, PVC, PS, EPS, PET [bottle grade]) + Engineering plastics (ABS, SAN, PA, PC, PBT, POM, PMMA, Blends, and others including High Performance Polymers) |
| Thermosets | Urea-formaldehyde foam, melamine resin, polyester resins, epoxy resins, etc. |

Available videos on processing and characterization of polymers:

1. Plastic compounding in a twin screw extruder
2. Plastic compounding in a mini-extruder
3. Pelletization
4. Melt Flow Rate (MFR) measurement
5. Dynamic Mechanical Analysis (DMA)


ulisses
UNITE!
University Network for Innovation, Technology and Engineering
LISBOA
UNIVERSIDADE DE LISBOA