<INSERT YOUR LOCATION HERE>

Training Package - Materials

Contents:

1. Paper
2. Plastics and Bioplastics
3. Bio-composites

Part 1

Paper

PAPER = CELLULOSE PULP + ADDITIVES

CELLULOSE PULP is prepared from ligno-cellulose natural sources: mainly wood or annual plants

wood is composed by three main polymers:

- ✓ Cellulose (homo-polysaccharide)
- ✓ Hemicelluloses (hetero-polysaccharides)
- ✓ Lignin (aromatic polymer- phenylpropane units)

Their content in paper vary as a function of the process used to obtain cellulose from wood.

CELLULOSE PULPS FOR PAPER PRODUCTION

- ✓ **VIRGIN CELLULOSE PULP** obtained from wood or annual plants
    - ✓ Mechanical pulp
    - ✓ Chemical pulp
- ✓ **RECYCLED PAPER PULP** obtained from recovered used paper
    - ✓ Domestic collection
    - ✓ Industrial collection

MECHANICAL PULP

Mechanical processes lead to high yield pulp; low amount of lignin and hemicelluloses are lost in the process

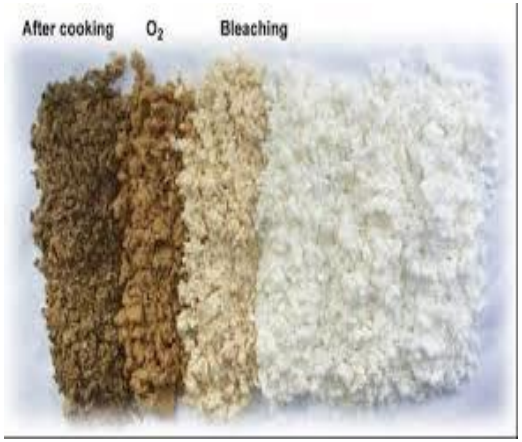
Acronym	Process description	Yield
SWG	*Stone Groundwood Pulp.*	> 98
RMP *TMP*	*Refiner Mechanical Pulp* *Thermo-mechanical Pulp*	> 97
CMP	*Chemi-mechanical Pulp*	80-90
CTMP	*Chemi-thermomechanical Pulp*	>90

CHEMICAL PULP FROM WOOD

Chemical process

- ✓ **Sulphite process** (weak acid): reagent **SO2**
- ✓ **Sulphate process** (strong alkaline) > 80% world production – reagents: **NaOH e Na_2S (+Oxygen)**

Unbleached Kraft Pulp, UKP



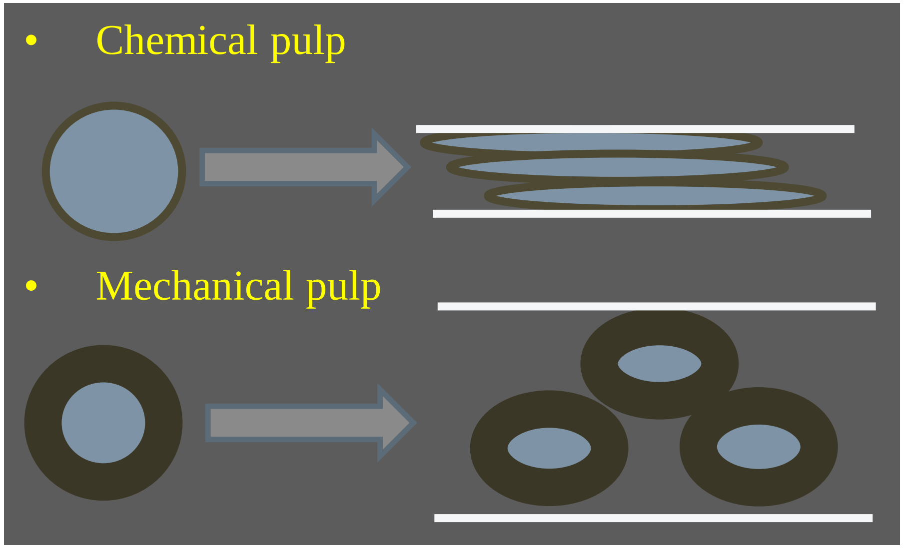
Bleaching process

- ✓ Chlorine dioxide
- ✓ Peroxide
- ✓ Ozone

Bleached Kraft Pulp, BKP

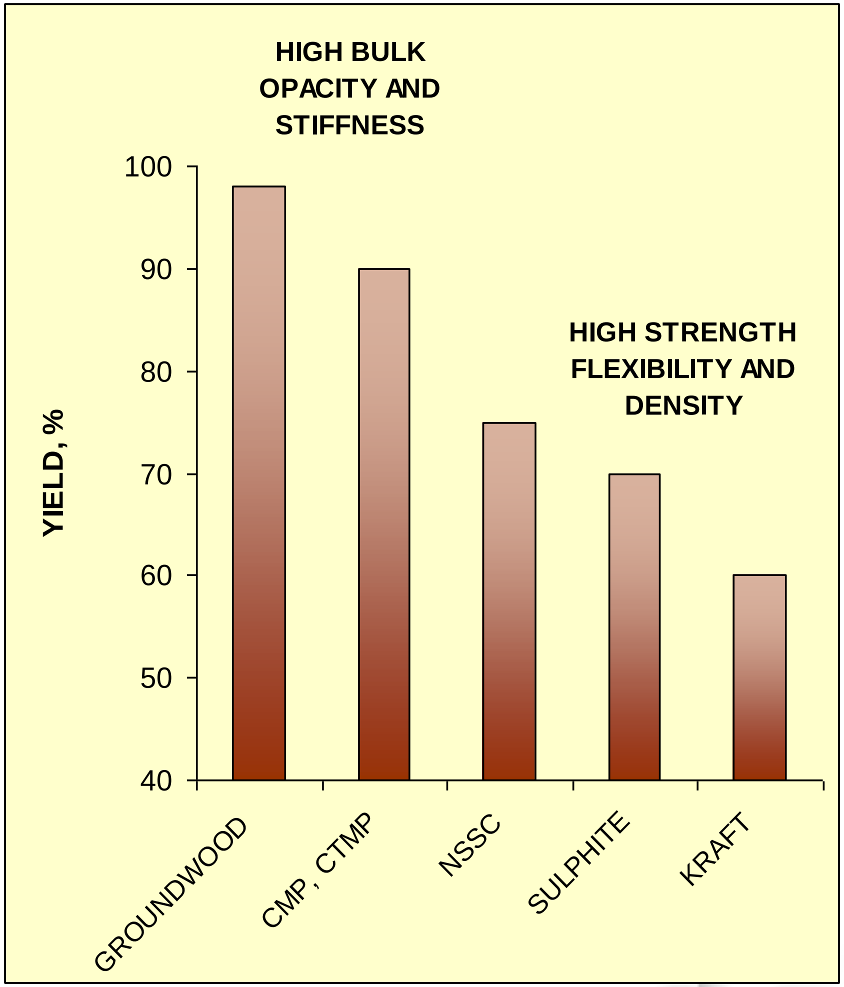
YIELD: 50-60%, most of lignin and hemicellulose is solubilized in the process

PULP PROPERTIES



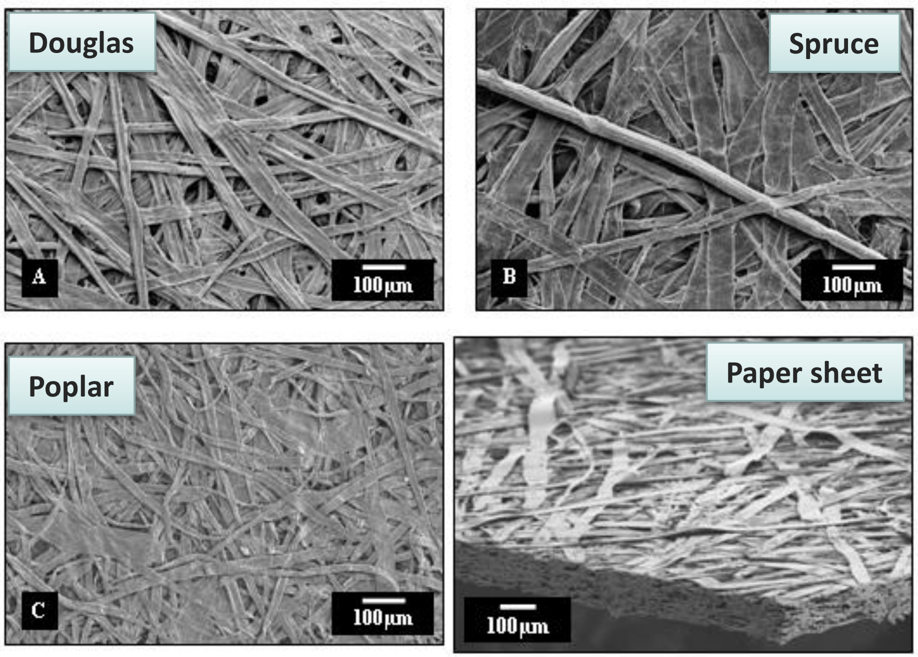
Chemical Pulp fibres **are flexible and strong**
Mechanical Pulp fibres **are rigid and bulky**

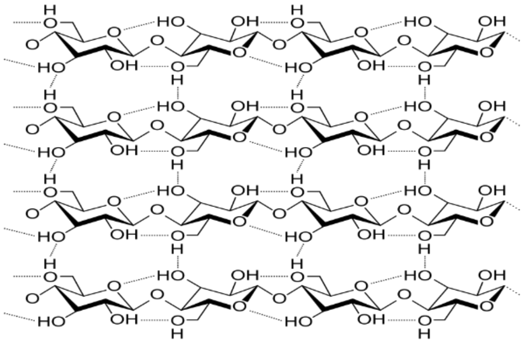
MECHANICAL PAPER PROPERTIES ARE MAINLY FUNCTION OF THE PULP USED IN PAPERMAKING

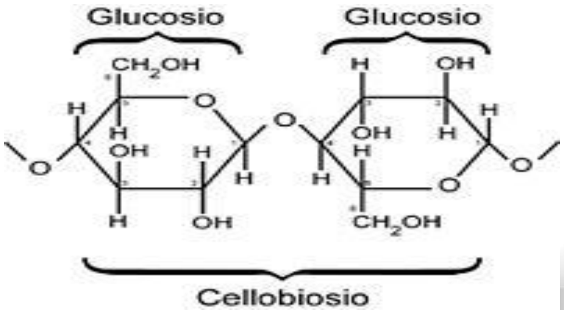


PAPER MATERIAL DEFINITION

PAPER is a network of cellulose fibres entangled by hydrogen bonds





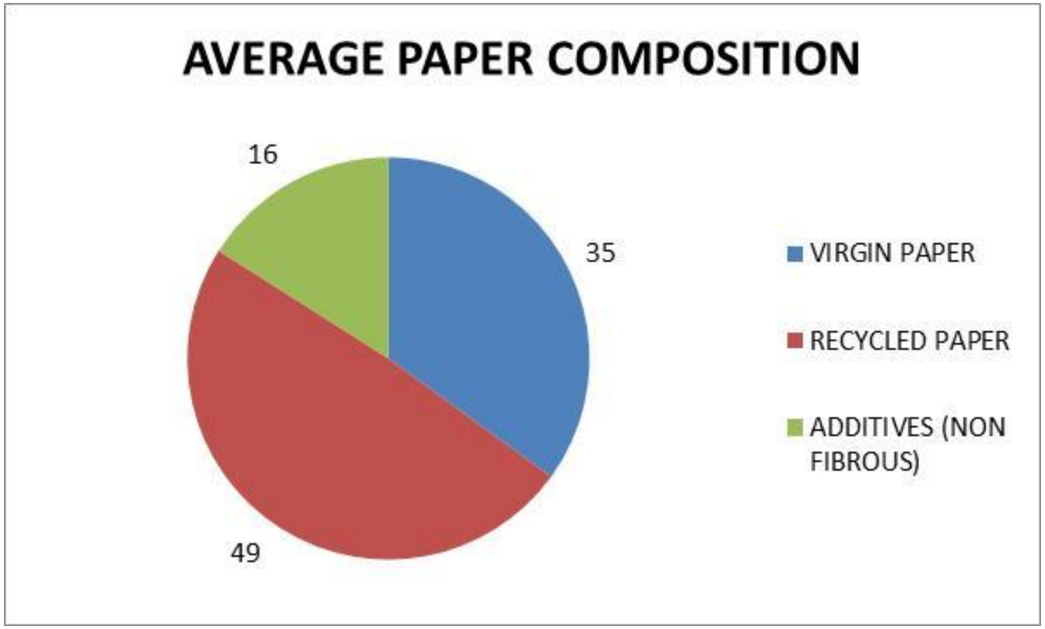


MAIN ADDITIVES IN PAPER PRODUCTION

- Production aids
  - Retention aids
  - starch
  - Biocides
- Fillers
  - Calcium/magnesium carbonate
  - Silicates
- Auxiliary substances
  - Wet strength resins (e.g. epichloridrin, ASA, AKD)
  - Grease proof resins
  - Starch
  - Proteins

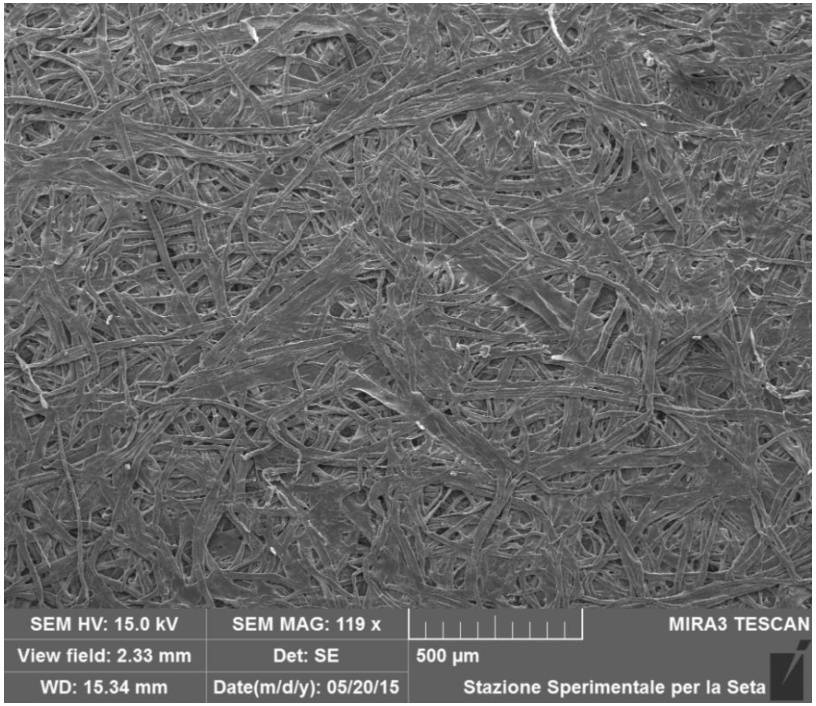
MATERIAL COMPOSITION

- ✓ **Paper is mainly composed by cellulose fibres (virgin or recycled)**
- ✓ **Inorganic fillers represents a significant amount of material in several paper grades for surface coatings**
  - ✓ *Fillers are mostly recycled back into the products in the paper recycling process.*

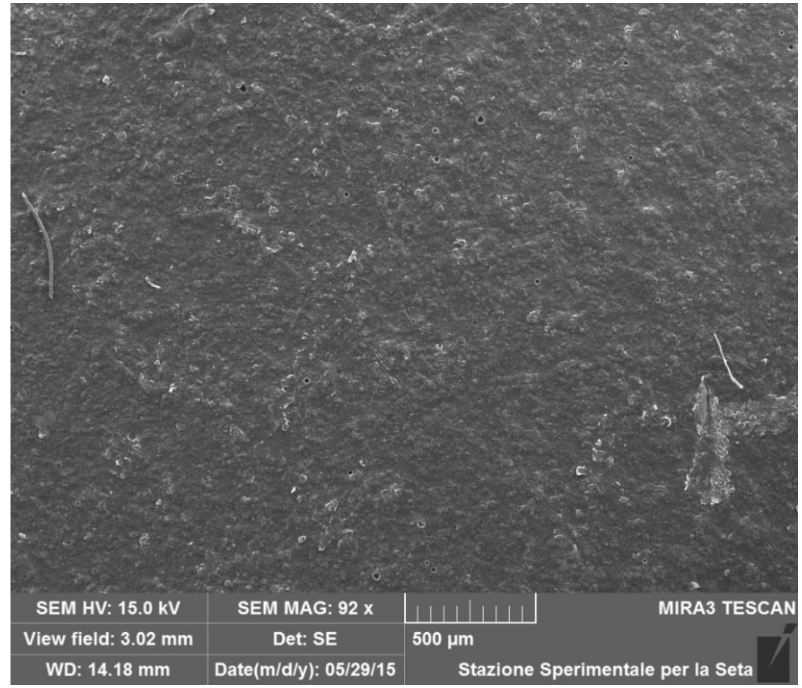


Source: Assocarta

PAPER VS. COATED PAPER



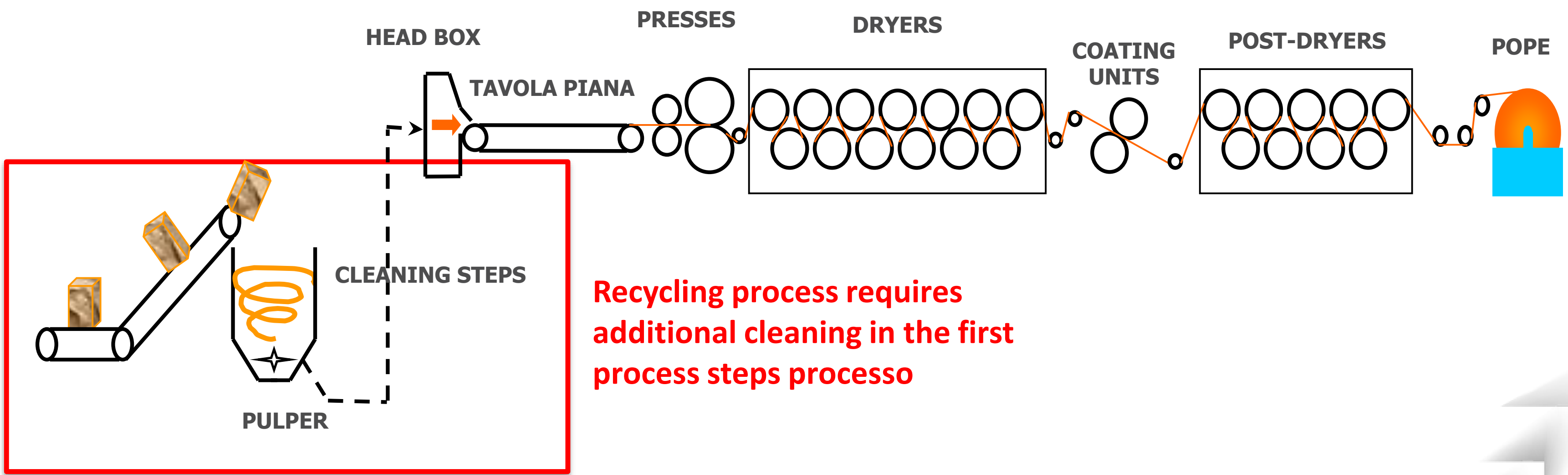
Natural paper



Coated paper

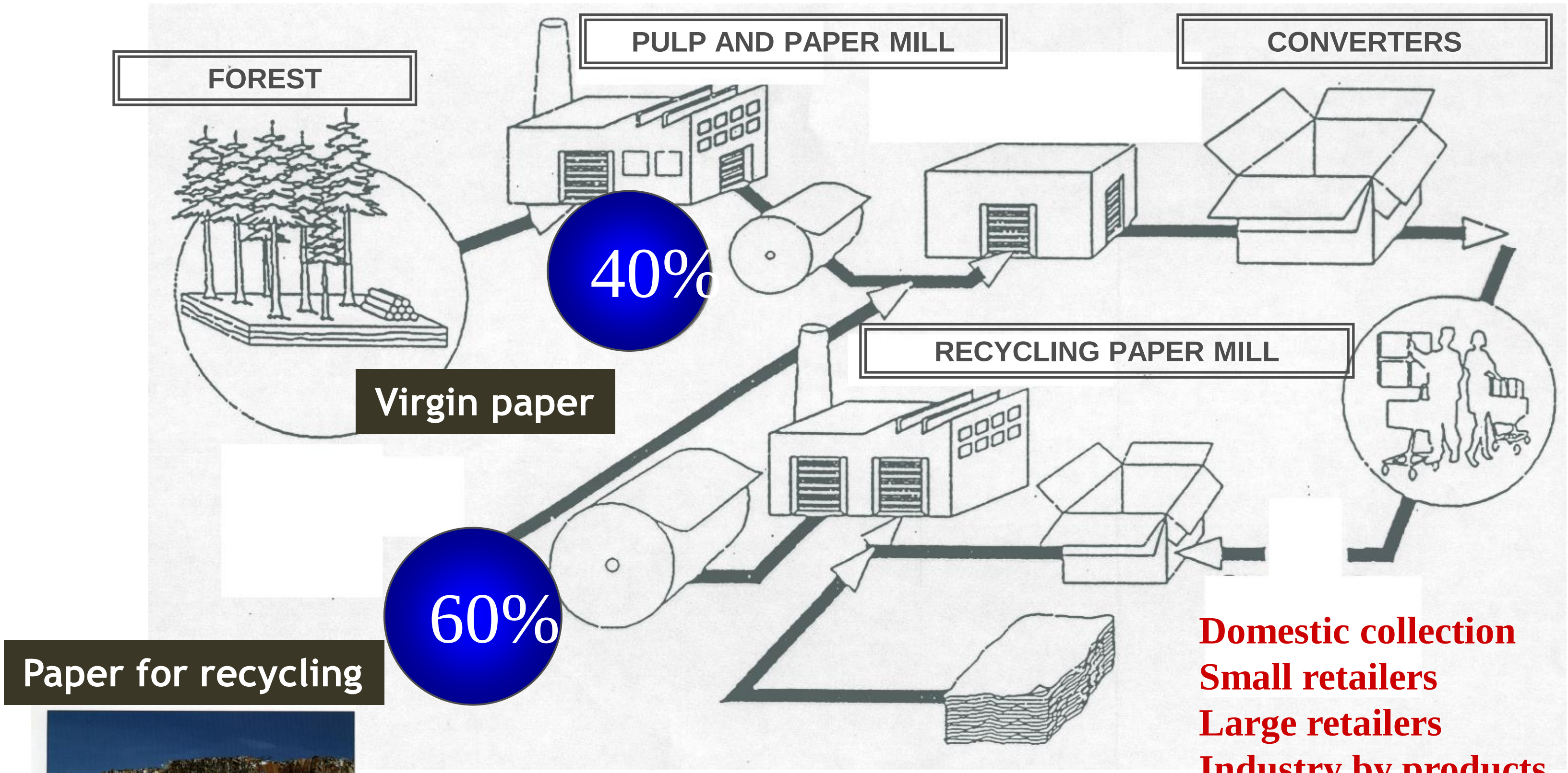
Coating increases functionality reducing the size of the paper pores reducing liquid/gas diffusion

PAPERMAKING PROCESS



Recycling process requires additional cleaning in the first process steps processo

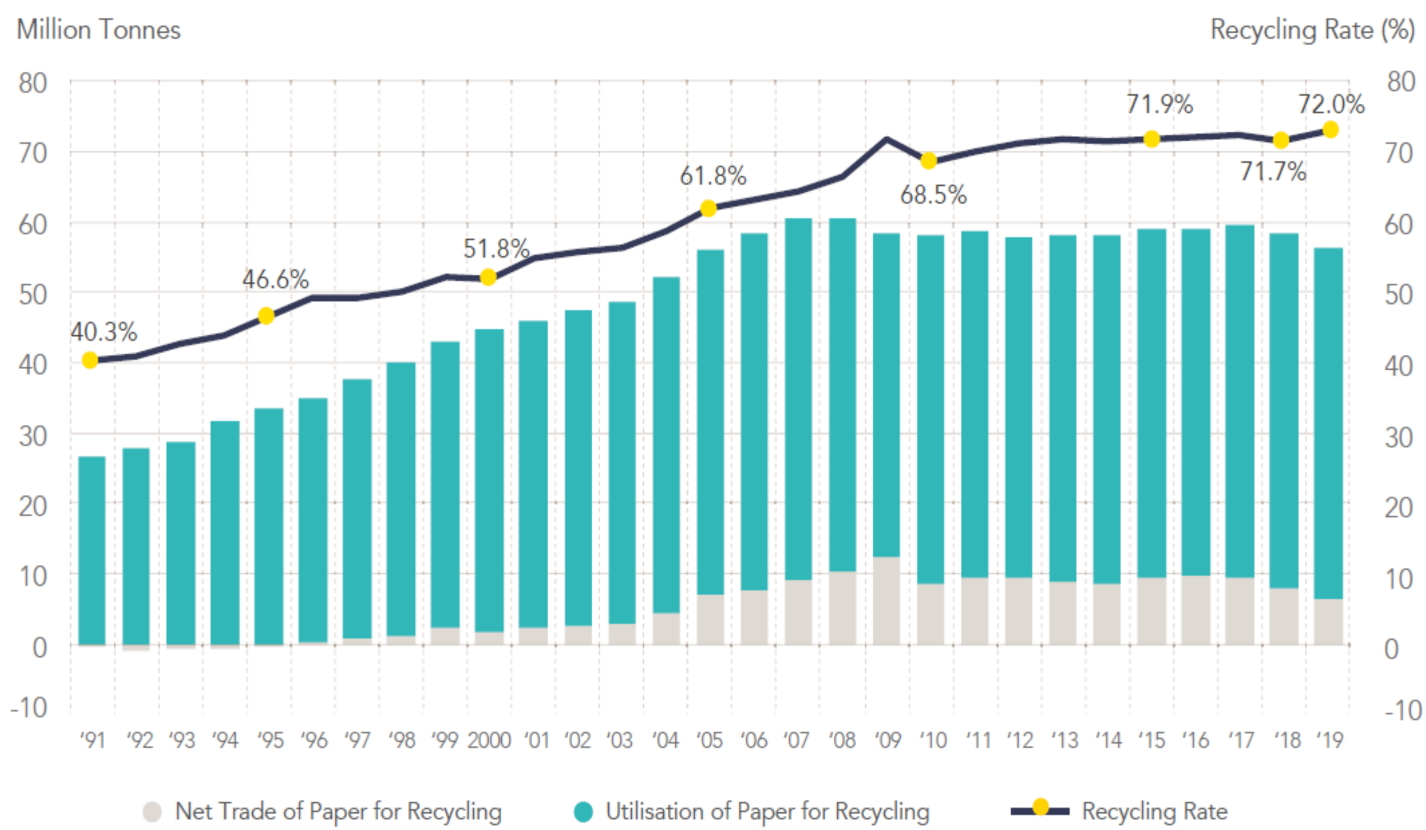
PAPER LOOP



Domestic collection
Small retailers
Large retailers
Industry by products

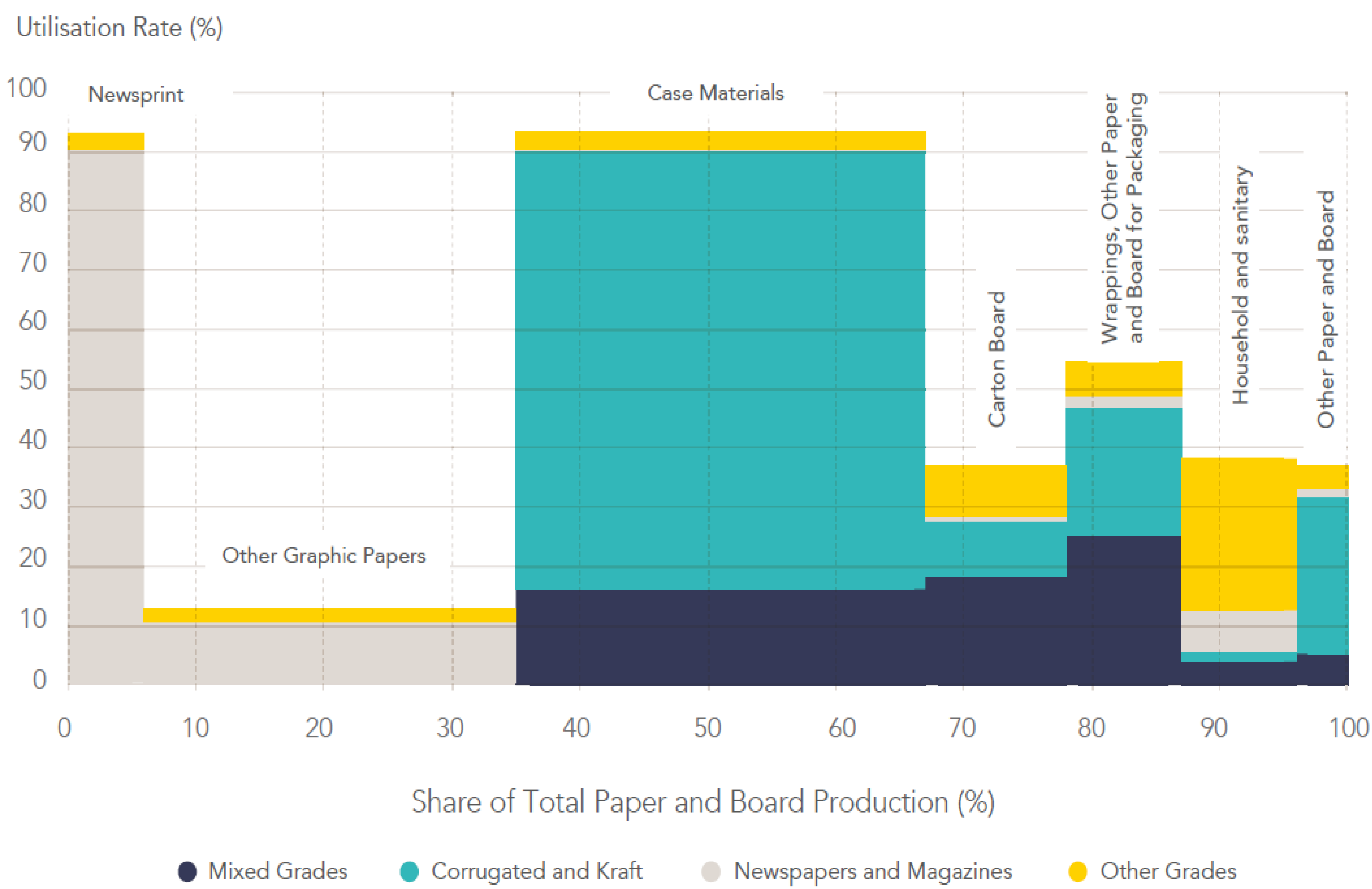
PAPER FOR RECYCLING

- ✓ Paper for recycling represents globally the main raw material for the paper industry.
- ✓ Europe shows the highest recycling rate worldwide



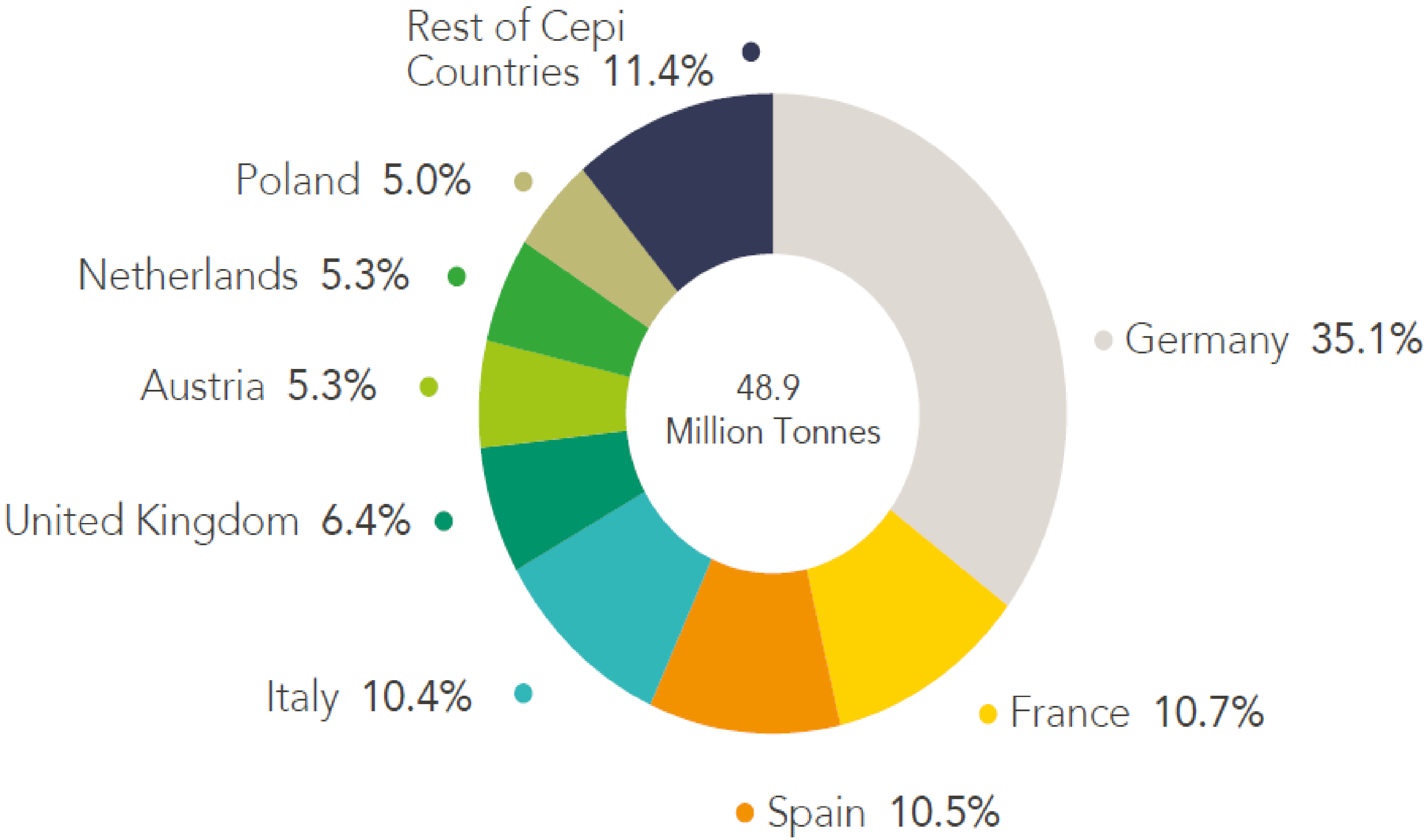
Source: Key statistics CEPI 2020

PAPER FOR RECYCLING UTILIZATION BY SECTOR IN 2019



Source: Key statistics CEPI 2020

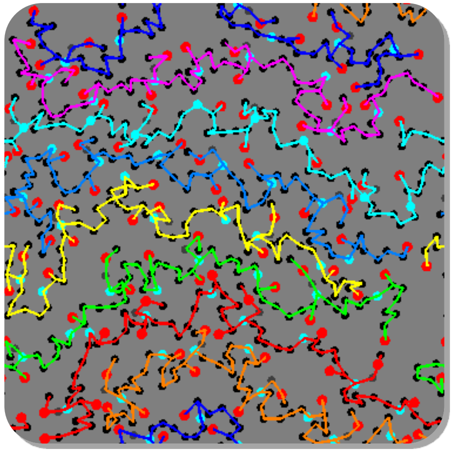
PAPER FOR RECYCLING UTILIZATION IN EUROPE IN 2019



Source: Key statistics CEPI 2020

Part 2

Plastics and Bioplastics



Polymer - macromolecule composed of many repeating units.

A simplified analogy of a polymer is a **pearl necklace** composed of individual pearls (as monomers) arranged in a linear fashion.

MATERIALS - PLASTICS

- **Polymers** (poly-mer from Greek: poly - many, meros - parts) can contain thousands of repeating units (monomers) **arranged linear** or **branched.**

- **Polymers** are found in **nature** or are **man-made** (artificial, synthetic).
  - **Natural polymers** (= biopolymers) are specific and crucial **constituents of living organisms.**
  - **Man-made polymers** are a large and diverse group of **compounds not known in nature.** They are synthesized through chemical or biochemical methods. The global annual production of man-made polymers was 230 million tons in 2009 (Plastics – The Facts 2010).

- The main use of man-made polymers is in the **production of plastics.**

MATERIALS - PLASTICS

Plastics – polymer-based material that is characterized by its plasticity.

The main component of **plastics** (from Greek: plastikos - fit for moulding, plastos - moulded) is **a polymer**, which is “formulated” by the addition of additives and fillers to yield the technological material – **plastics.** Plastics are defined by their **plasticity** – a state of a **viscous fluid** at some point during **processing**.

Polymer ≠ Plastics

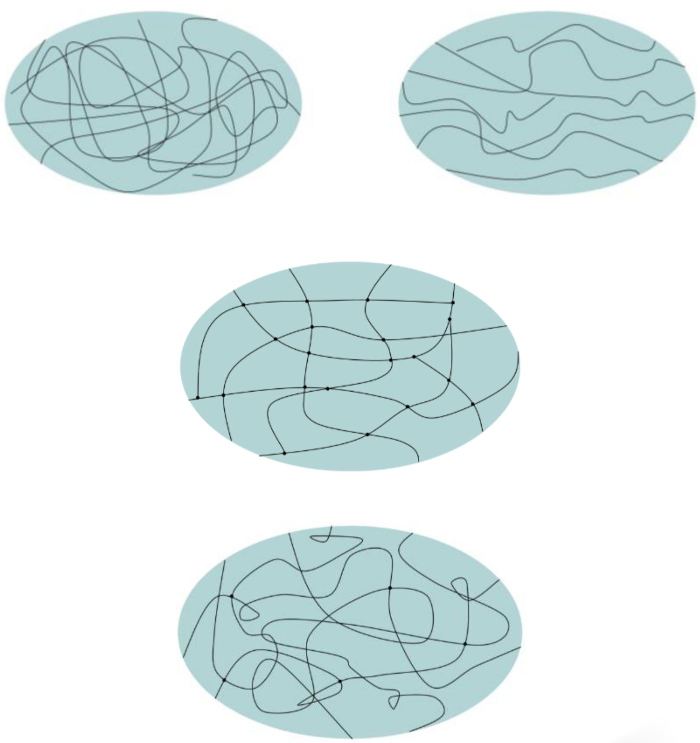
Plastics = Polymer + Additives

We can classify polymers by:

- physicochemical properties
- origin
- origin of the raw material
- susceptibility to microorganism enzymes activity
- and many other..

PHYSICOCHEMICAL PROPERTIES

- **Thermoplasts** – they become **soft when influenced by heat**, become **hard after a decrease of temperature.**
  - E.g. acrylonitrile-butadiene-styrene – ABS, polycarbonate – PC, polyethylene – PE, polyethylene terephthalate – PET, polyvinyl chloride – PVC, poly(methyl methacrylate) – PMMA, polypropylene – PP, polystyrene – PS, extruded polystyrene foam – EPS.
- **Thermoset (duroplasts)** – after **formed they stay hard**, they do not become soft when influenced by heat.
  - E.g. polyepoxide – EP, phenol formaldehyde resins – PF, polyurethane – PUR, polytetrafluoroethylene – PTFE.
- **Elastomers** – materials, which we could **stretch and squeeze, which follow deformations** but they **reshape back afterwards.**
  - Indian rubber/caoutchouc has been almost entirely replaced with elastomers. Also many new adaptions have been discovered.



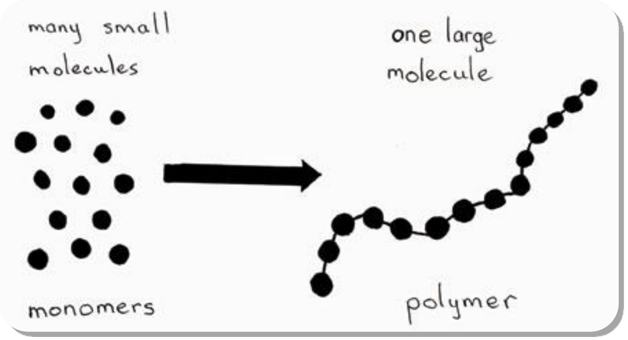
Source: http://www.chempage.de/theorie/kunststoffe.htm

ORIGIN

- **Synthetic polymers** – originate from **chemical synthesis** (polymerization , copolymerization , poly-condensation)

- **Natural polymers** – produced by **organisms**
  - e.g. cellulose, protein, nucleic acids

- **Modified polymers** – those are **natural polymers, chemically changed** to receive new functional properties
  - e.g. cellulose acetate, modified protein, thermoplastic starch



ORIGIN OF RAW MATERIALS

Renewable resources

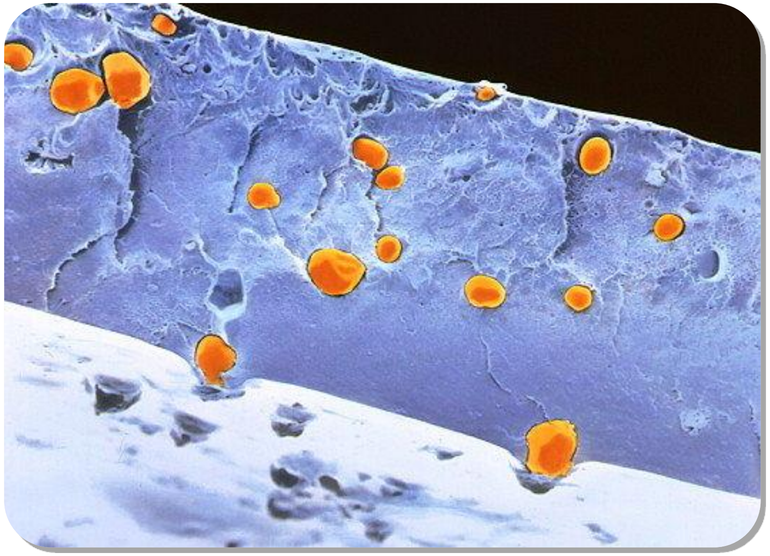
plant and animal

Non-renewable (fossil) resources

petroleum, coal

SUSCEPTIBILITY TO MICROORGANISM ENZYMES ACTIVITY

- **Biodegradable** (polylactide – PLA, regenerated cellulose, starch)
- **Non-degradable** (polyethylene – PE, polystyrene - PS)



PLASTICS - HISTORY

First plastics were produced in the **2nd half of 19th and beginning of 20th century. Celluloid and cellophane** were first ones and they were bio-based.

After 2nd World War plastics became very popular. From ’60 till ’90 they have mainly been **produced from petrochemical resources.**

In ’80 plastics **production was bigger than steel** production.

In ’90 **environment protection policies** became more **important**.

New technologies were put into practice e.g. producing polymer plastics based on **renewable resources**; production technologies of **biodegradable materials.**

MATERIALS - PLASTICS

- Universal, used in many different fields:
  - Packaging
  - Constructions
  - Transport
  - Electric and electronic
  - Agriculture
  - Medicine
  - Sport
  - Many others
- Properties can be modified to virtually any requirement

- Lightweight products (due to small density).
- Excellent thermo insulating and electro insulating properties.
- Resistant to corrosion.
- Transparent and therefore used in optical devices.

CONVENTIONAL - PETROCHEMICAL PLASTICS

Conventional plastics are produced from **fossil resources** and find use in many areas of life.

MATERIALS - PLASTICS

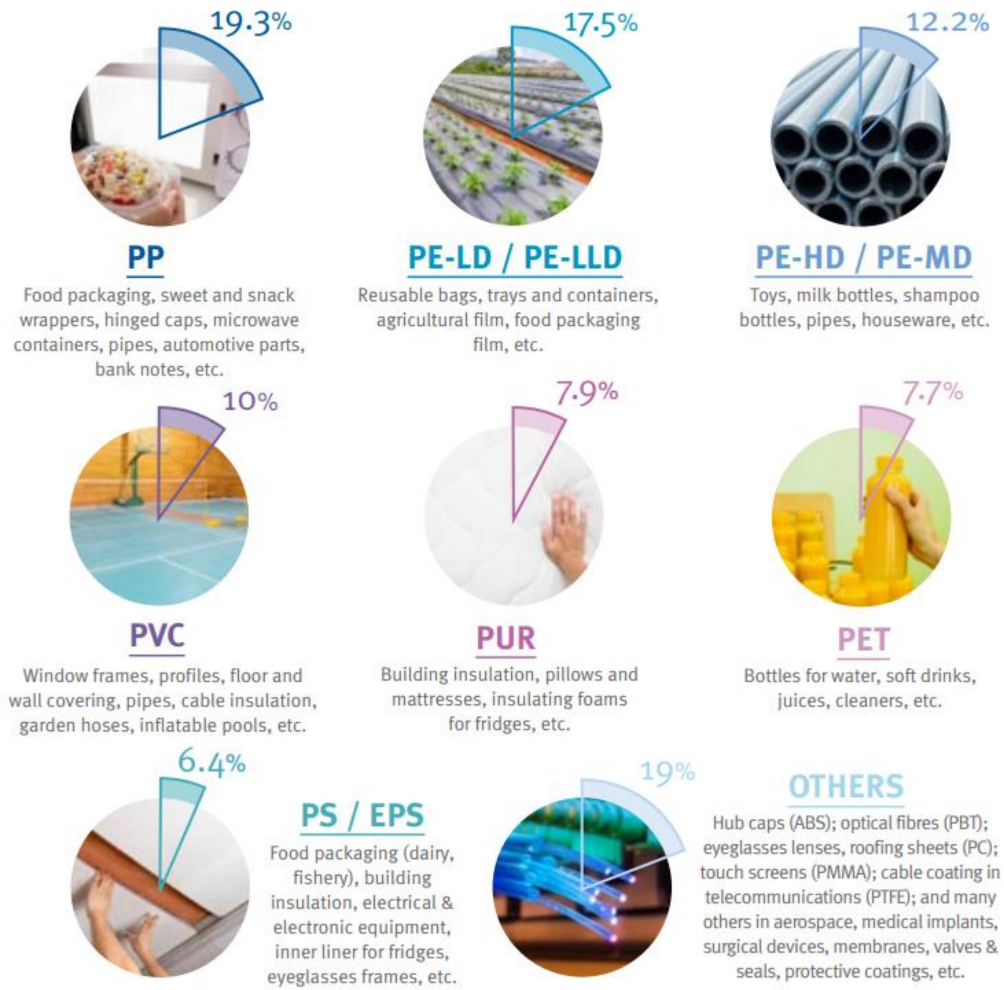
The "big five" plastics with largest market share:

- Polyethylene (PE)
- Polypropylene (PP)
- Polyvinyl chloride (PVC)
- Polystyrene (solid – PS and foamed – EPS)
- Polyethylene terephthalate (PET)

Big role in industry is also attributed to:

- Acrylonitrile butadiene styrene (ABS)
- Polycarbonate (PC)
- Polymethyl methacrylate (PMMA) Plexi glass
- Polytetrafluoroethylene (PTFE) Teflon

MATERIALS - PLASTICS

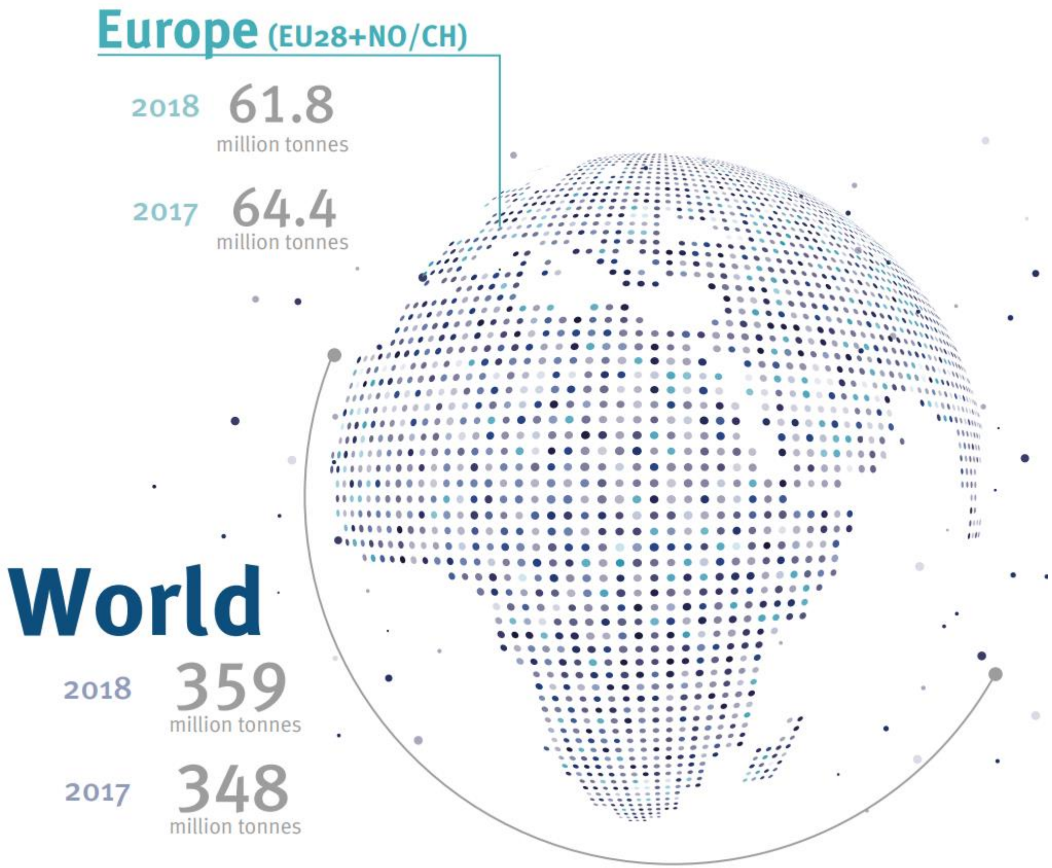


Source: PlasticsEurope 2019

WE LIVE IN THE „PLASTIC AGE“

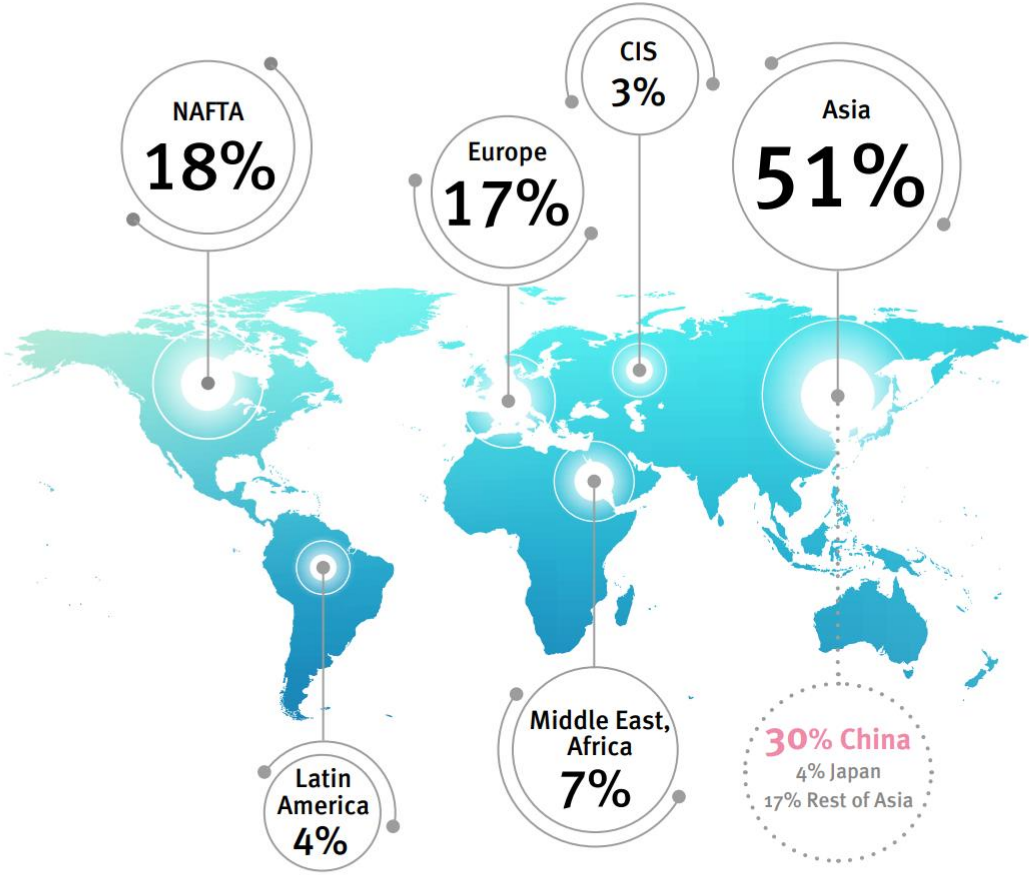
- High resistant polymeric materials, also resistant to natural degradation => **landfill crisis!**
- Thermal conversion of plastics? Generation of **toxins**
- **GHG**
- Price related directly to oil prices

CLASSIC PETROCHEMICAL PLASTICS PRODUCTION



Source: PlasticsEurope 2019

CLASSIC PETROCHEMICAL PLASTICS PRODUCTION



Source: PlasticsEurope 2019

CLASSIC PETROCHEMICAL PLASTICS PRODUCTION

Source: PlasticsEurope 2019

MATERIALS - PLASTICS

Source: PlasticsEurope 2019

BIOPLASTICS

Bioplastics are bio-based and/or biodegradable plastics.

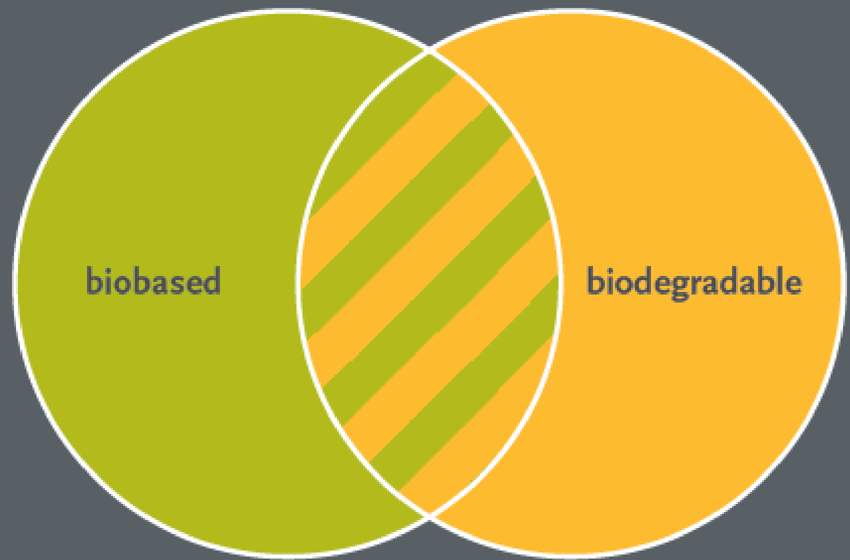
The term was coined by **European Bioplastics**

european bioplastics

Driving the evolution of plastics

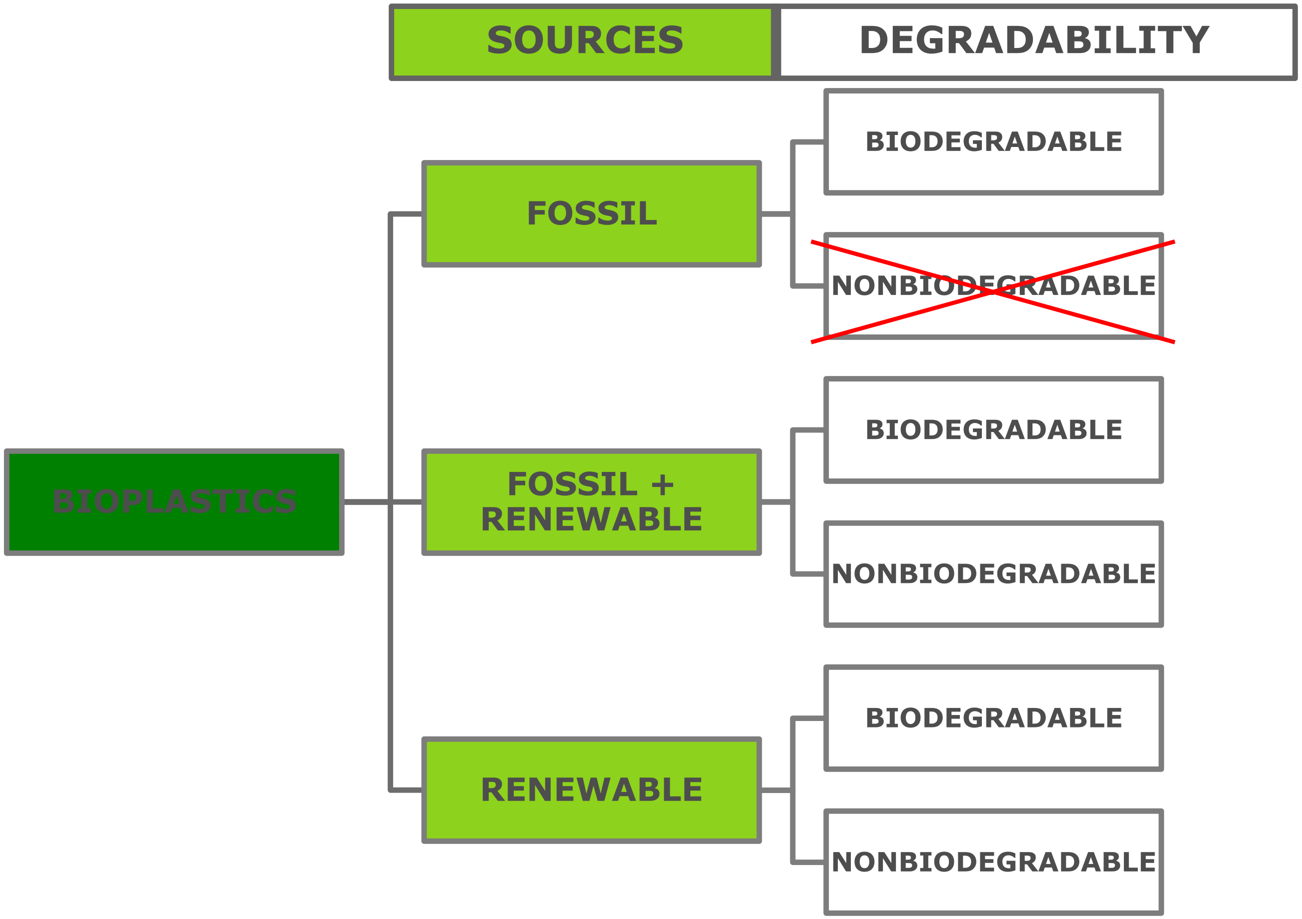
Biobased and biodegradable plastics

MATERIALS - BIOPLASTICS

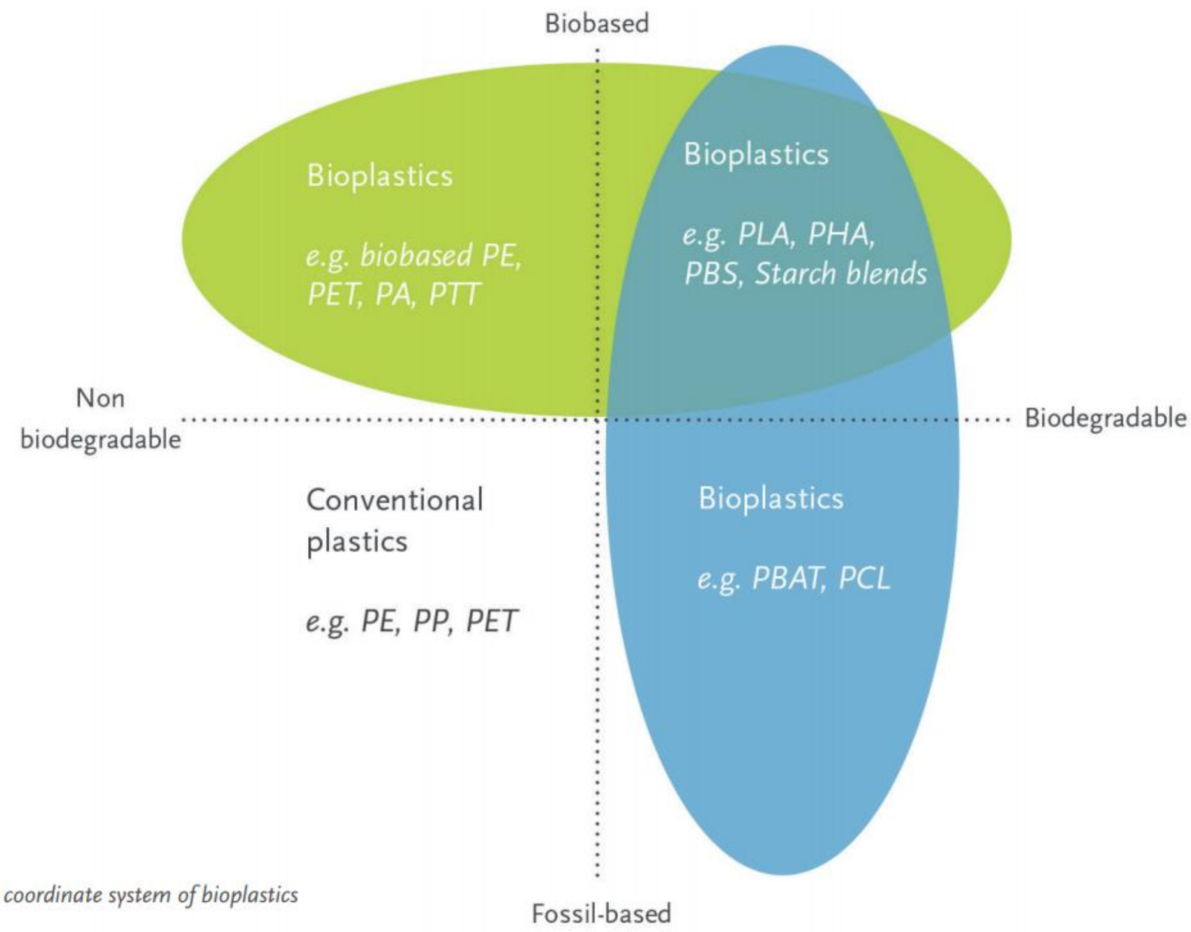


According to European Bioplastics' definition, bioplastics are biobased, biodegradable, or both.

MATERIALS - BIOPLASTICS



MATERIALS - BIOPLASTICS



Graph: Material coordinate system of bioplastics

DIFFERENCE BETWEEN PLASTICS AND BIOPLASTICS

The term **bioplastics** encompasses a whole family of materials which are **biobased**, **biodegradable**, or **both**.

Biobased means that the material or product is (partly) derived from biomass (plants). Biomass used for bioplastics stems from e.g. corn, sugarcane, or cellulose.

The term **biodegradable** depicts a chemical process during which micro-organisms that are available in the environment convert materials into natural substances such as water, carbon dioxide and compost (artificial additives are not needed). The process of biodegradation depends on the surrounding environmental conditions (e.g. location or temperature), on the material and on the application.

Of course, **materials** and **products** can feature **both** properties. They then offer all the benefits and additional options outlined.

Source: http://en.european-bioplastics.org/bioplastics/

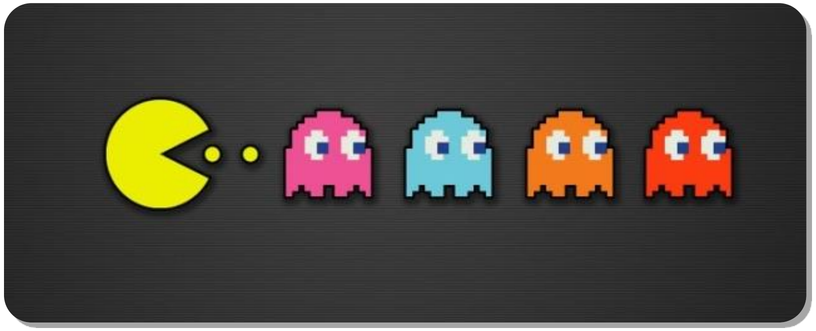
MATERIALS - BIOPLASTICS

Research of new materials and their **production technologies** is closely linked to:

- **Knowledge development in environmental sciences**, which show negative influence of plastics in its whole life cycle
- Improving **evaluation methods** of plastics **influence on environment**, especially **through LCA**
- Using **sustainable development** policies, which in manufacturing and trading practice means environmental aspects equal to social and economic aspects

BIODEGRADABLE PLASTICS

Plastics susceptible to biodegradation



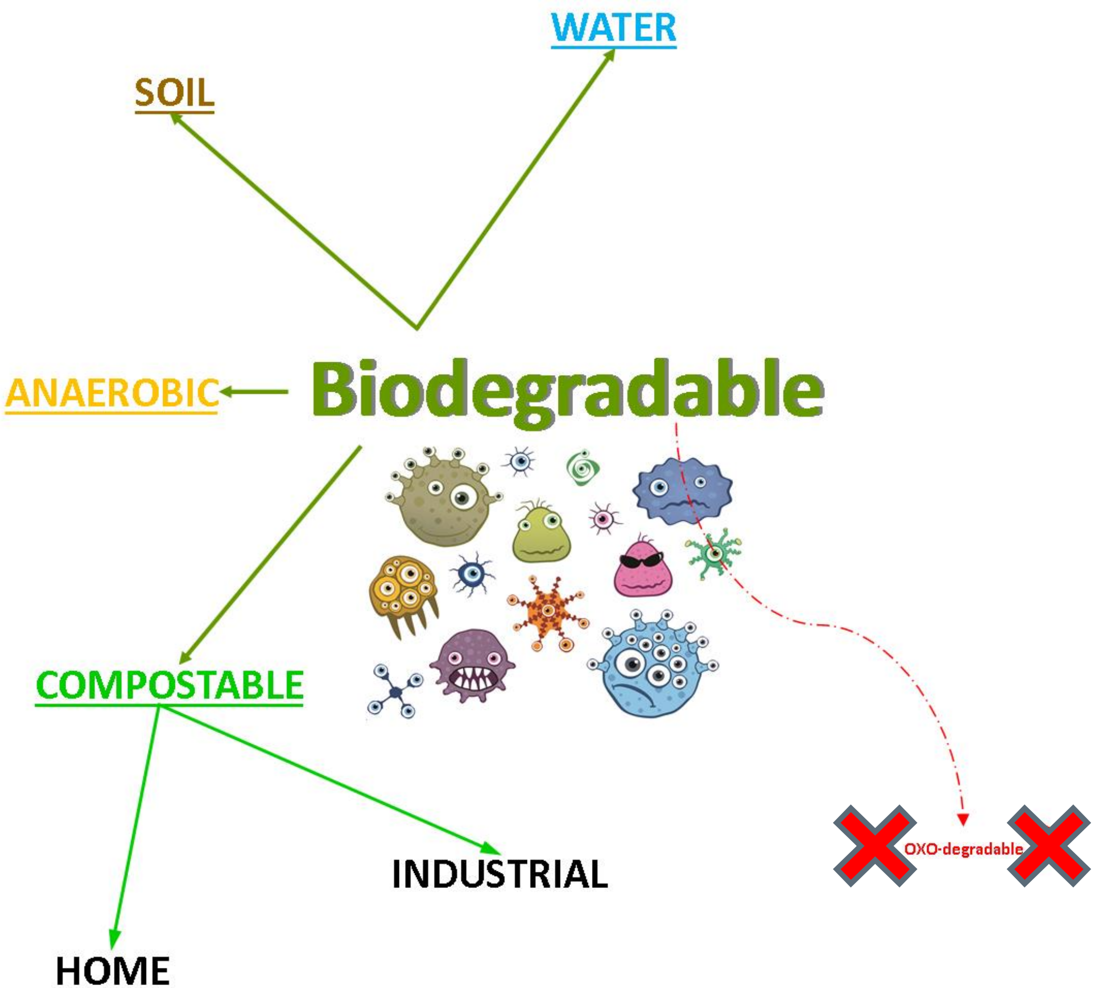
BASIC TERM

Microorganisms recognize biodegradable plastics as food and consume and digest it.

DIFFERENT TYPES OF BIODEGRADABILITY

- Compostable in industrial composting facilities
- Home compostable
- Soil degradable
- Water degradable
- Anaerobic degradable

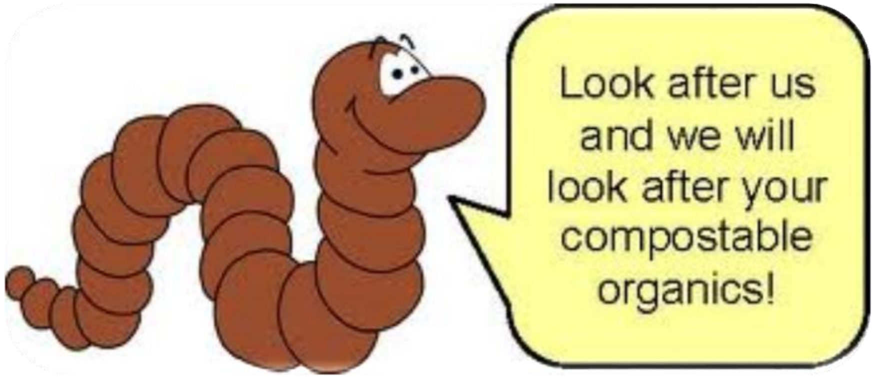
MATERIALS - BIOPLASTICS



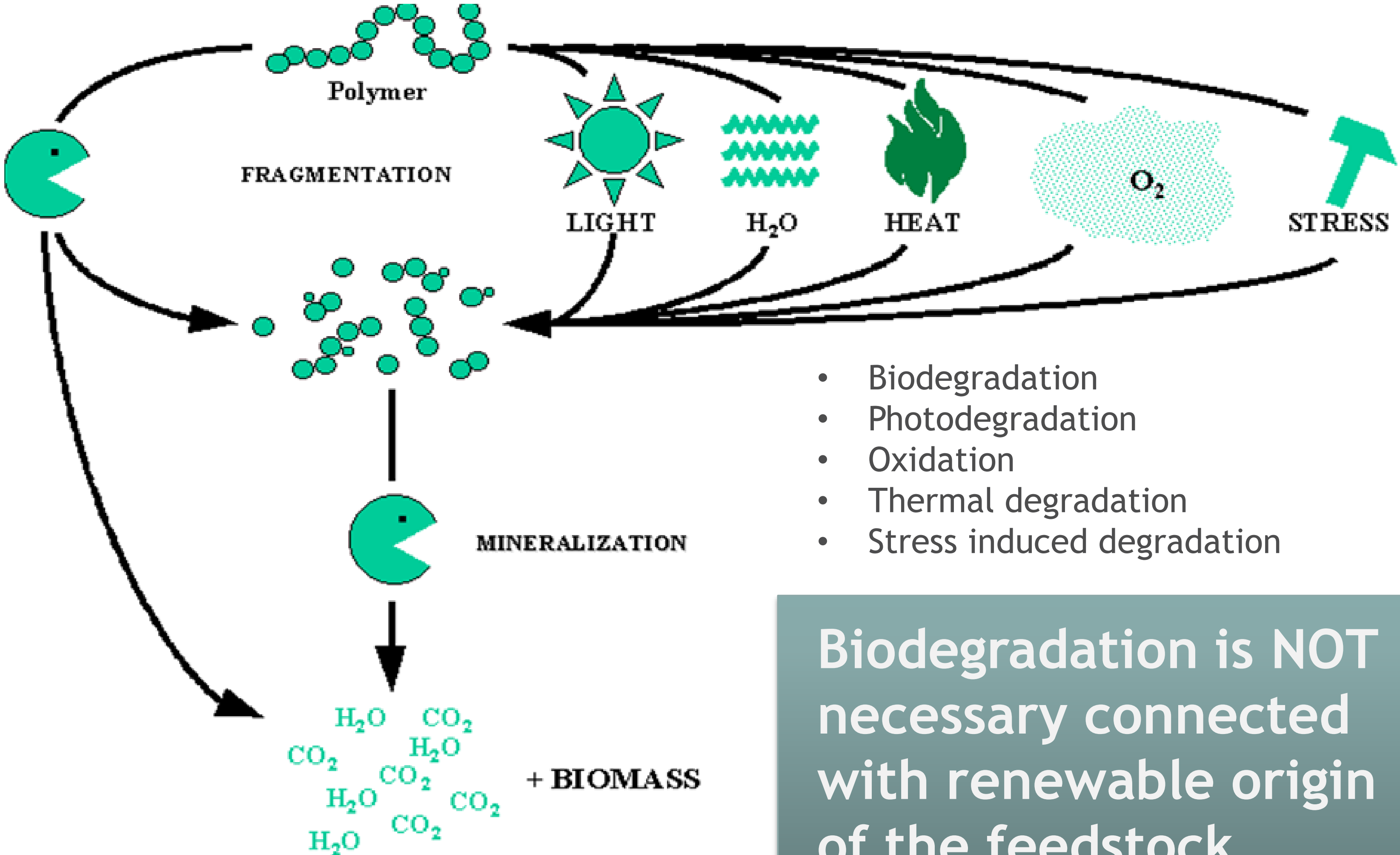
WHAT IS BIODEGRADATION?

Different parallel or subsequent abiotic and biotic steps, it **must** include the step of biological **mineralization**.

Takes place if the organic material of a plastic is used as a source of nutrients by the biological system (organism).



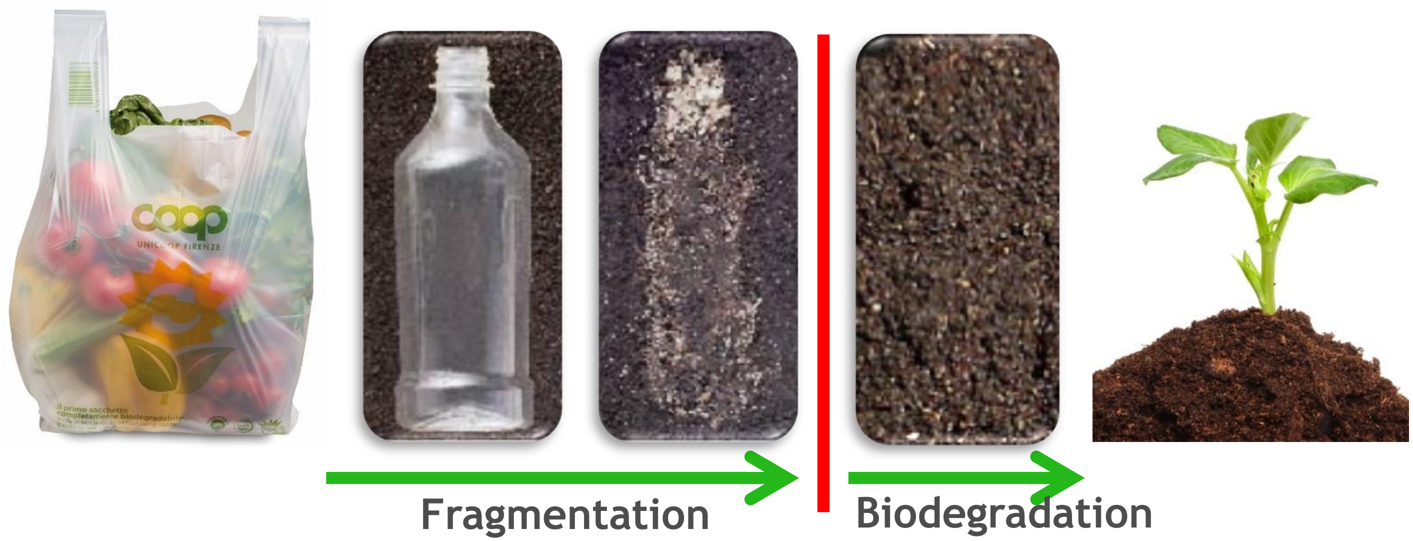
MATERIALS - BIOPLASTICS



- Biodegradation
- Photodegradation
- Oxidation
- Thermal degradation
- Stress induced degradation

Biodegradation is NOT necessary connected with renewable origin of the feedstock

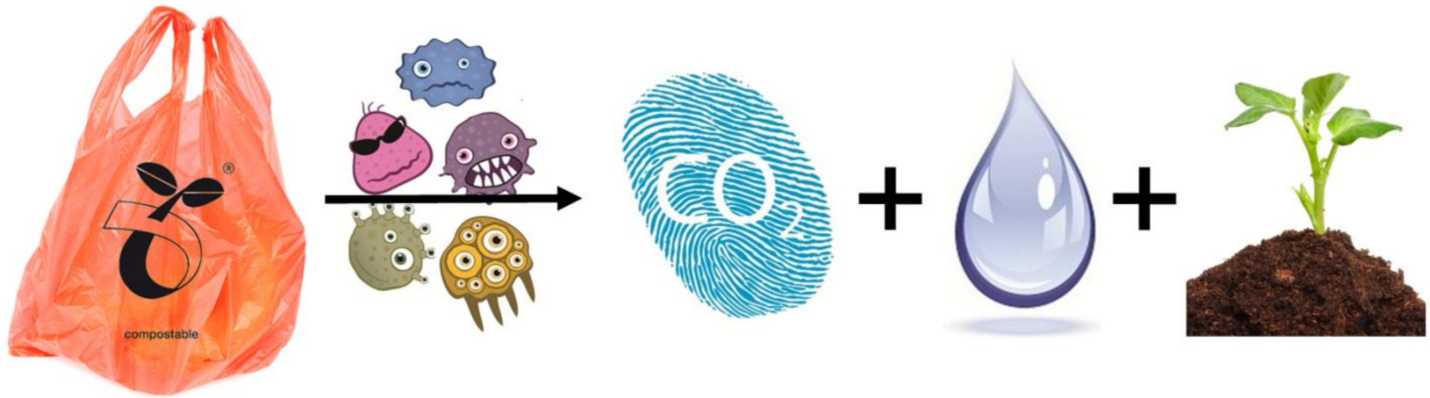
DEGRADATION VS. BIODEGRADATION



Fragmentation: first step in the biodegradation, material is broken down into microscopic fragments

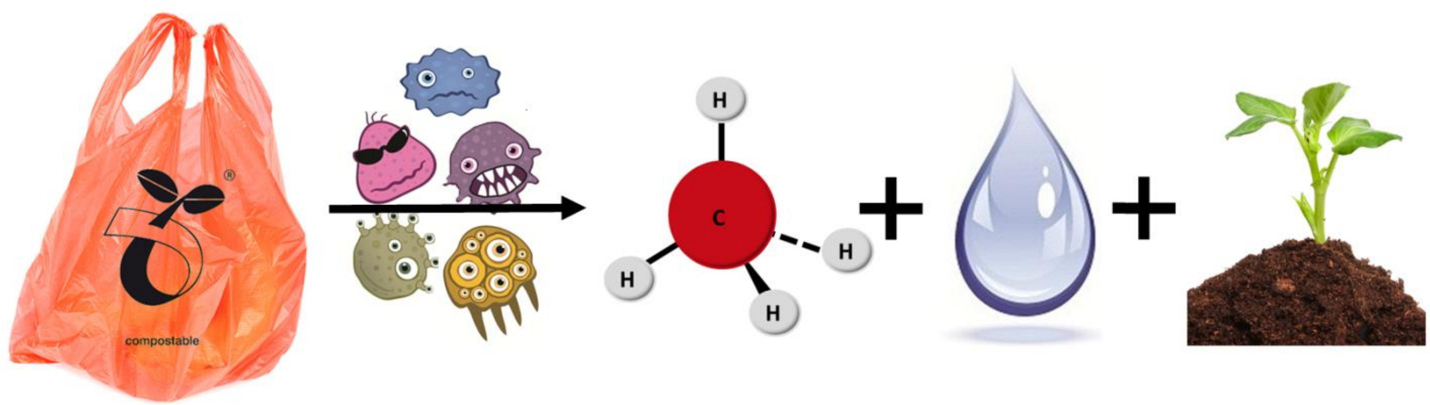
Biodegradability: Complete microbial assimilation of the fragmented material as a food source by the microorganisms

Compostability: Complete assimilation within 180 days in a composting environment



AEROBIC DEGRADATION

CARBON DIOKSIDE WATER BIOMASS



ANAEROBIC DEGRADATION

METHANE WATER BIOMASS

Composting (organic recycling)

oxygen processing capability of bio-waste

strict controlled conditions by **microorganisms**, which turn carbon in to carbon dioxide (mineralization).

Product of this process is organic matter called **compost**.

Composting is a manner of organic waste treatment carried out under aerobic conditions (presence of oxygen) where the organic material is converted by naturally occurring microorganisms. During industrial composting the temperature in the composting heap can reach temperatures up to 70 °C.
Composting is done in moist conditions.
One composting cycle lasts up to 6 months.

COMPOSTABLE PLASTICS

Biodegrade under the conditions and in the timeframe of the composting cycle

Biodegradation of a Bioplastic bottle during composting

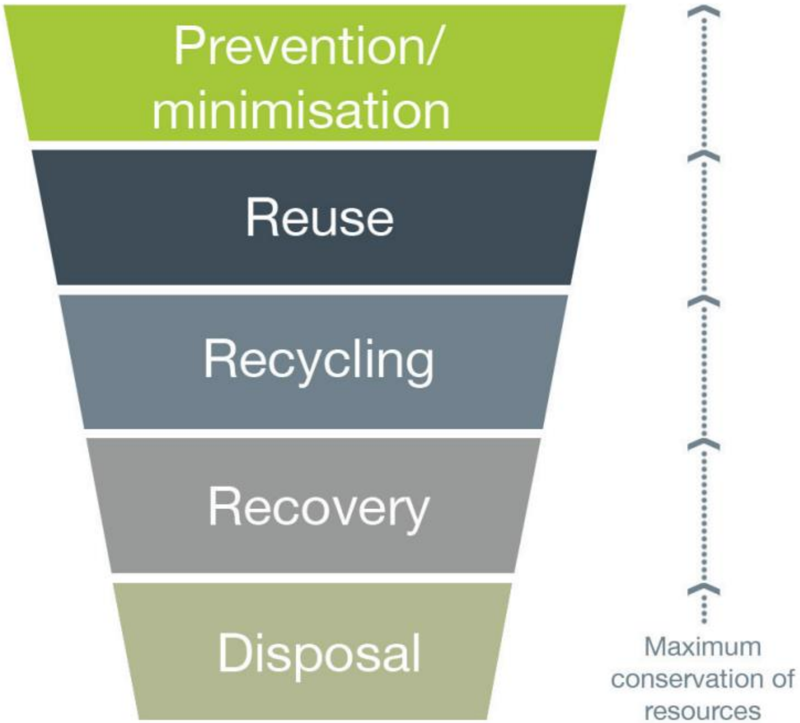
Biodegradable ≠ Compostable

Compostable = Biodegradable

LEGISLATION

Directive 2008/98/EC of the European Parliament and of the Council of 19 November on waste, article 4: Waste hierarchy:

(a) Prevention
(b) Preparing for re-use
(c) Recycling
(d) Other recovery, e.g. energy recovery
(e) Disposal



Graph: EU waste hierarchy

LEGISLATION

European Parliament and Council Directive 94/62/EC of 20 December 1994 on packaging and packaging waste, article 3.9 says:

Organic recycling shall mean the aerobic and anaerobic treatment under controlled conditions and using microorganisms, of the biodegradable parts of packaging waste, which produces stabilized organic residues or methane. Landfill shall not be considered a form of organic recycling.

Article 6: By 31 December 2008 the following minimum recycling targets for materials contained in packaging waste will be attained:
(iv) 22,5 % by weight for plastics, counting exclusively material that is recycled back into plastics.

And composting is obviously **not** "back to plastics". That means, that composting of packaging is defined as recycling, but this recycling does not count to the fulfilment of the plastics packaging recycling quota.

Compostable plastics **are defined by a series of national and international standards** e.g. EN 13432, ASTM D-6400 and other.

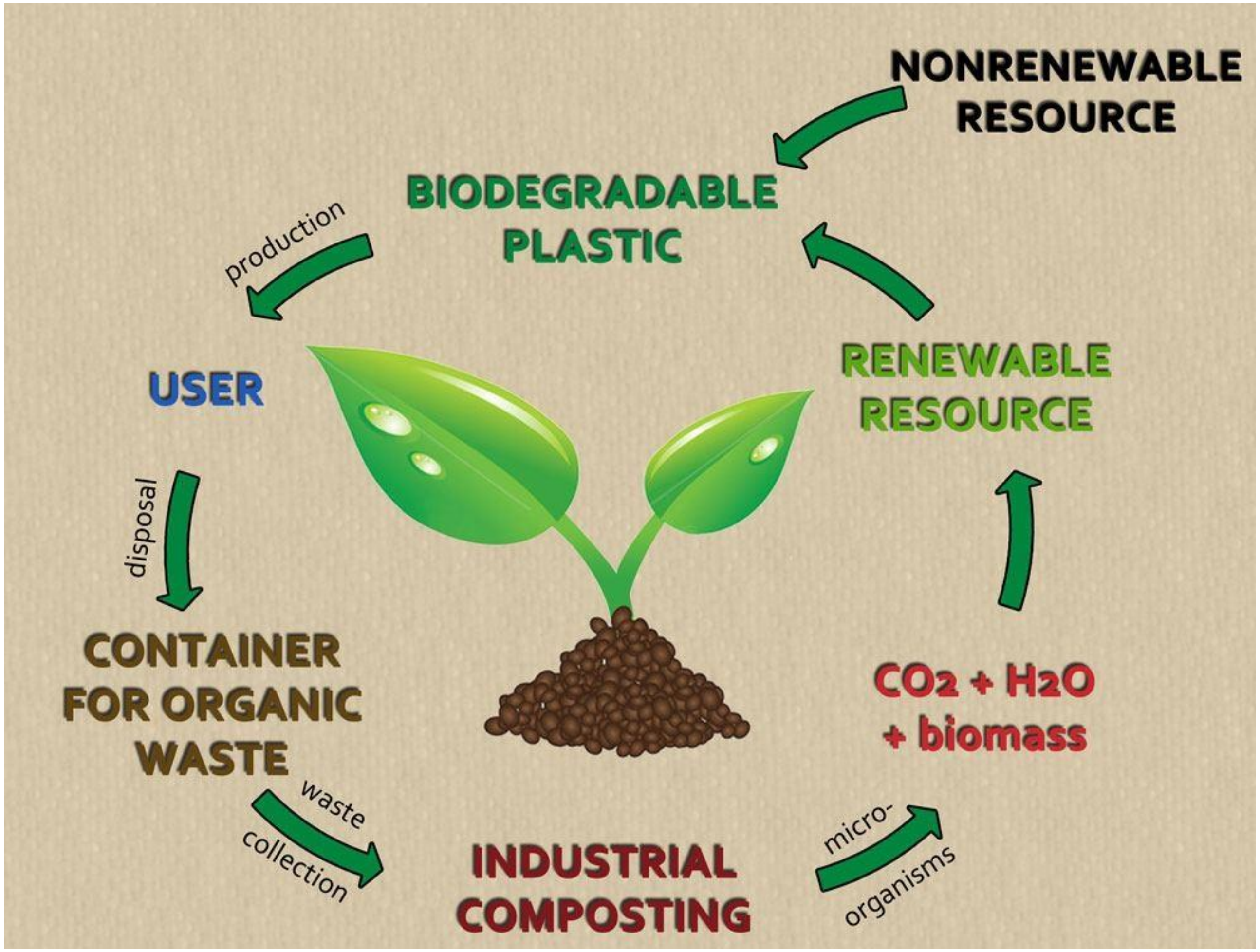
More about this topic on Certification and End-of-Life Training Package

MATERIALS - BIOPLASTICS

Graph: Post-consumer waste collection options for bioplastics

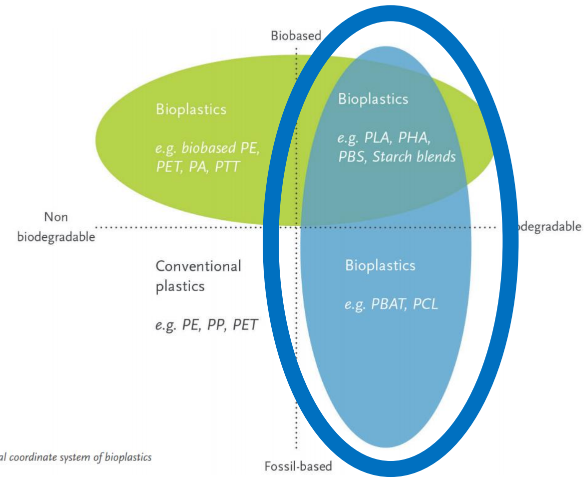
Source: PlasticsEurope 2019

MATERIALS - BIOPLASTICS



Biodegradable plastics can be divided into 2 groups:

1. Biodegradable plastics from renewable resources
2. Biodegradable plastics from fossil resources



Graph: Material coordinate system of bioplastics

BIODEGRADABLE PLASTICS FROM RENEWABLE RESOURCES

- **Thermoplastic starch (TPS)**
- **Polyhydroxyalkanoates; PHAs (made by microorganisms)**
  PHBV, P3HB, P4HB, PHV
- **Polylactide (polylactic acid, PLA)**
- **Cellulose based plastics**

Those polymers often appear in mixtures

BIODEGRADABLE PLASTICS FROM FOSSIL RESOURCES

Polyesters made of fossil resources including:

- Synthetic aliphatic polyesters – polycaprolactone **(PCL)**;
- Synthetic and half-synthetic aliphatic copolymers **(AC)** and polyesters **(AP)**;
- Synthetic aliphatic-aromatic copolymers **(ACC);**
- Polymers soluble in water – poly(vinyl alcohol) **(PVOH)**

PAPER BIO PACK

Interreg CENTRAL EUROPE BIOCOMPACK-CE

BIODEGRADABLE PLASTICS PRODUCTS

Biodegradable plastics **are not designed** to be **disposed in the nature!!!**

Biodegradability is **not function** of **origin** of the raw material but **is only related to structure**!

'OXO-DEGRADABLE' PLASTICS

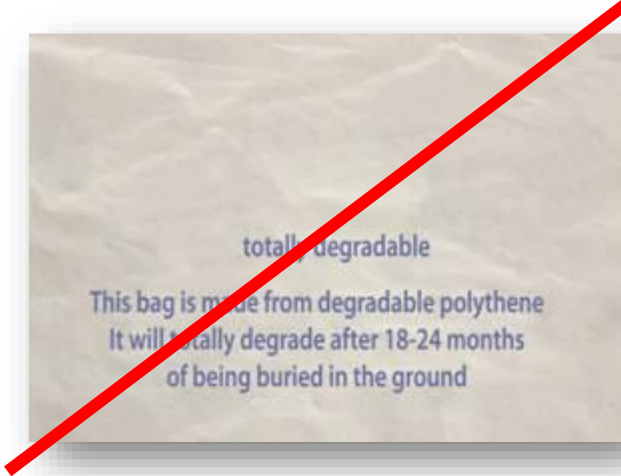
Aggressively promoted materials, available on the market

- Catalyst catalysing oxidation is added to nondegradable plastics
- Thermal and/or photo activated catalysation

Fragmentation is inconclusive

Biodegradation e.g. mineralization is not proved.

NOT biodegradable, NOT compostable, available on the market – misleading marked – GREENWASHING!!

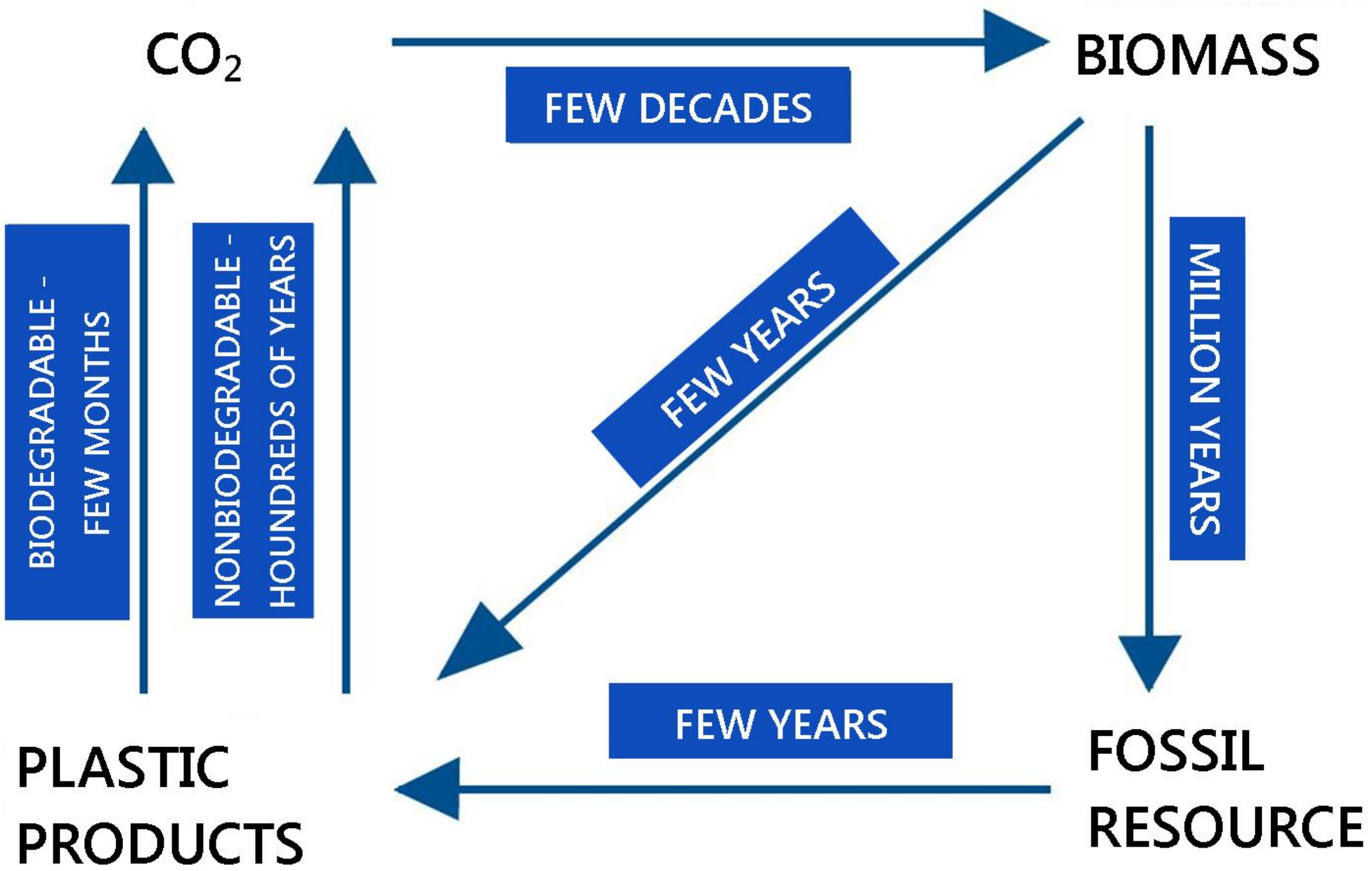


BIO-BASED PLASTICS

Biobased - derived from biomass, made from renewable resources

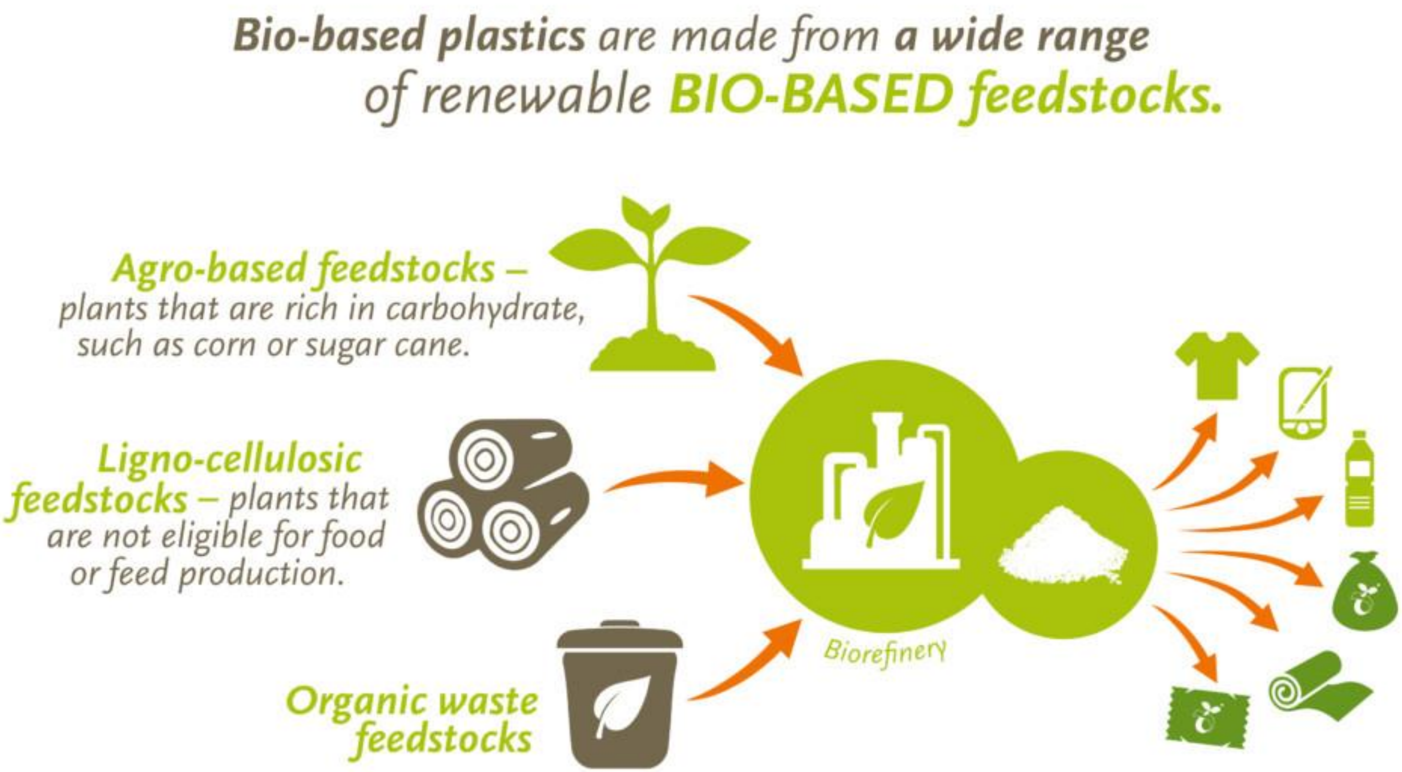
- Plastics can be fully or partially based on biomass (= renewable resources). The use of renewable resources should lead to a higher sustainability of the plastics because of the lower carbon footprint.
- Although fossil resources are natural they are not renewable and are not considered a basis for biobased plastics.

CARBON CYCLE



Source: R. Narayan

MATERIALS - BIOPLASTICS



BIO POLYETHYLENE (GREEN PE)

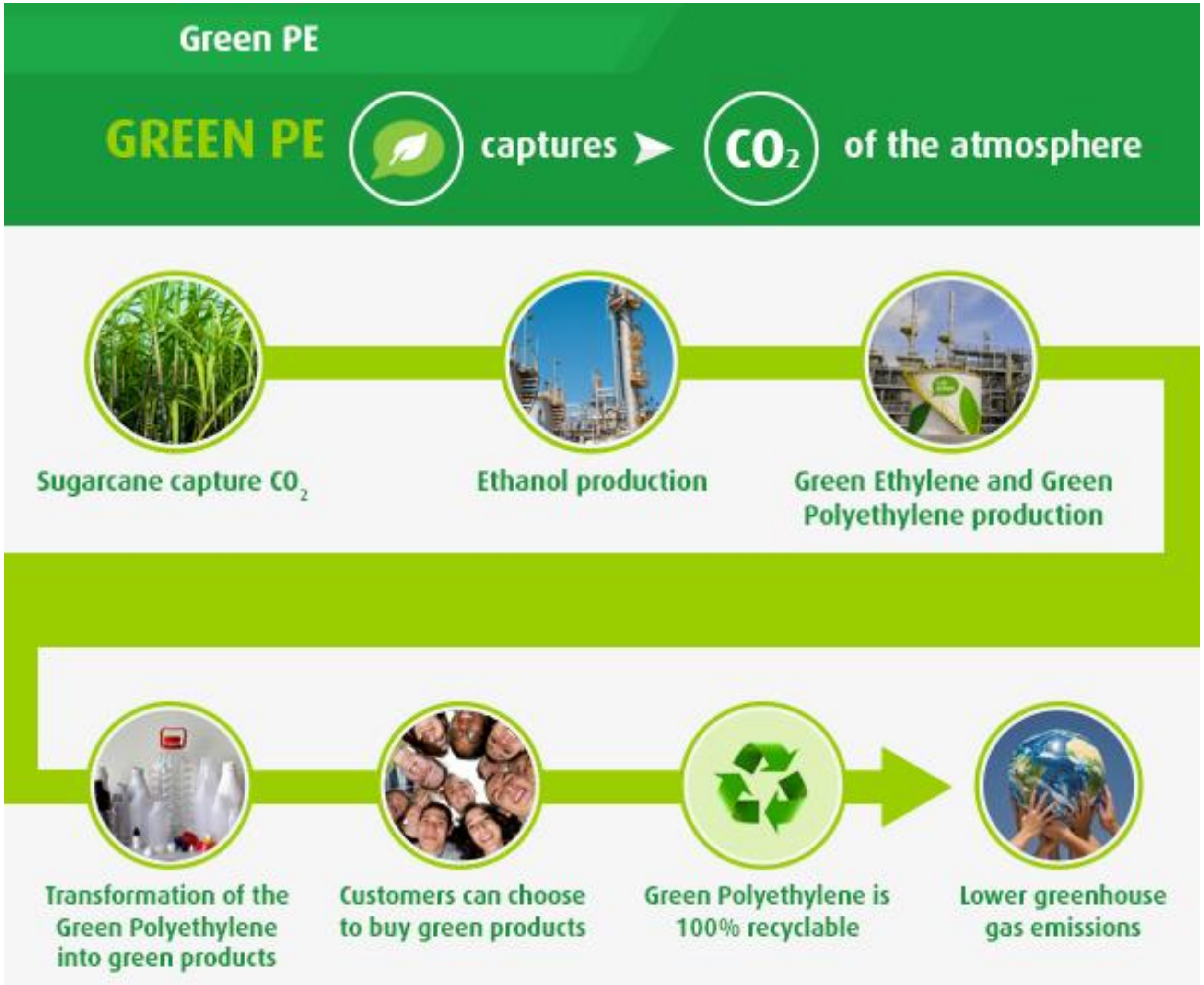
Plastics, made from ethanol which is produced from sugarcane.

- Equivalent to traditional PE with the same chemical formula :$-CH_2-CH_2-CH_2-$
- 100 % biobased (ASTM 6866)
- NON-biodegradable
- Braskem 2009, 200.000 t/a, Dow 2011, 350,000 t/a

$$C_6H_{12}O_{6(l)} + H_2O_{(l)} \rightarrow 2C_2H_5OH_{(l)} + 2CO_{2(g)} + H_2O_{(l)} + heat$$

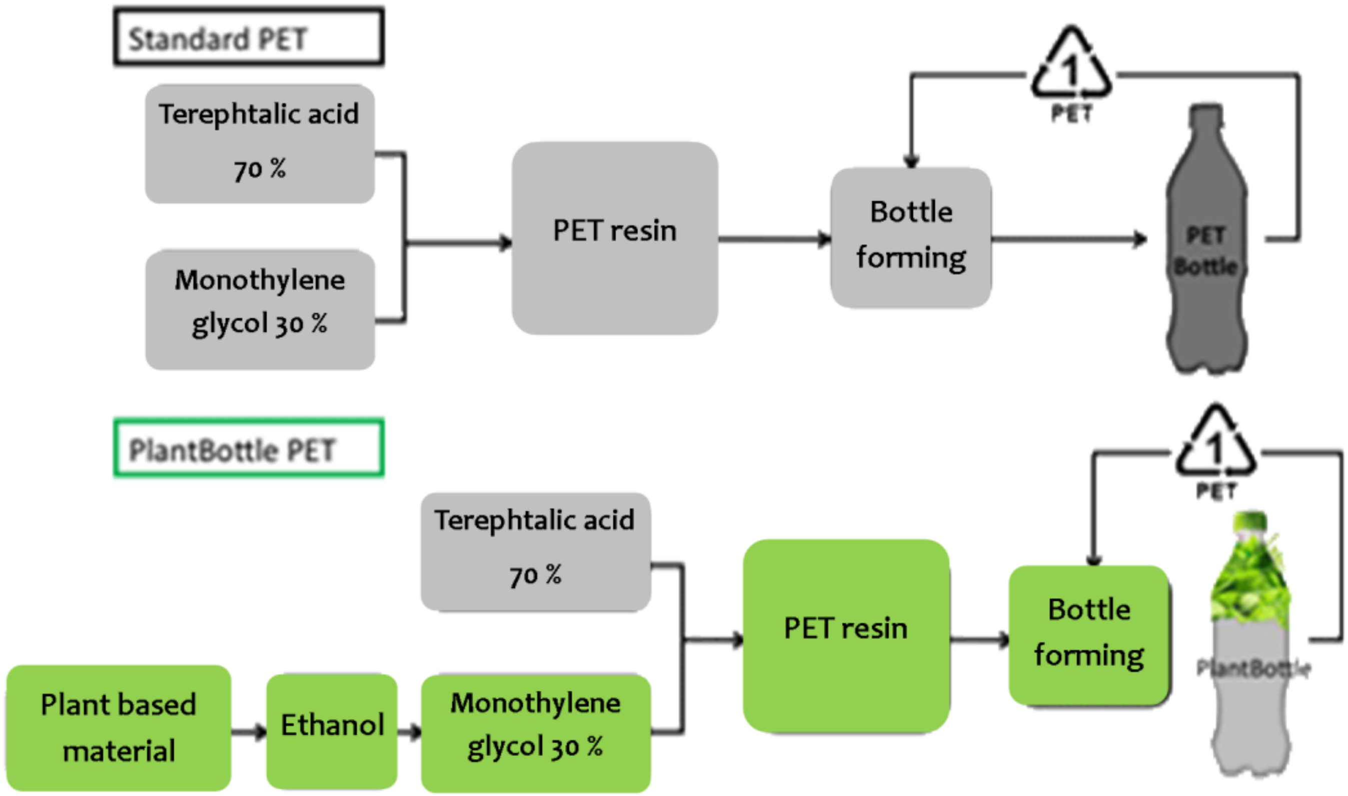
Sugarcane
↓ fermentation, distillation
Ethanol
↓ dehydration
Ethylene
↓polymerization
PE

MATERIALS - BIOPLASTICS



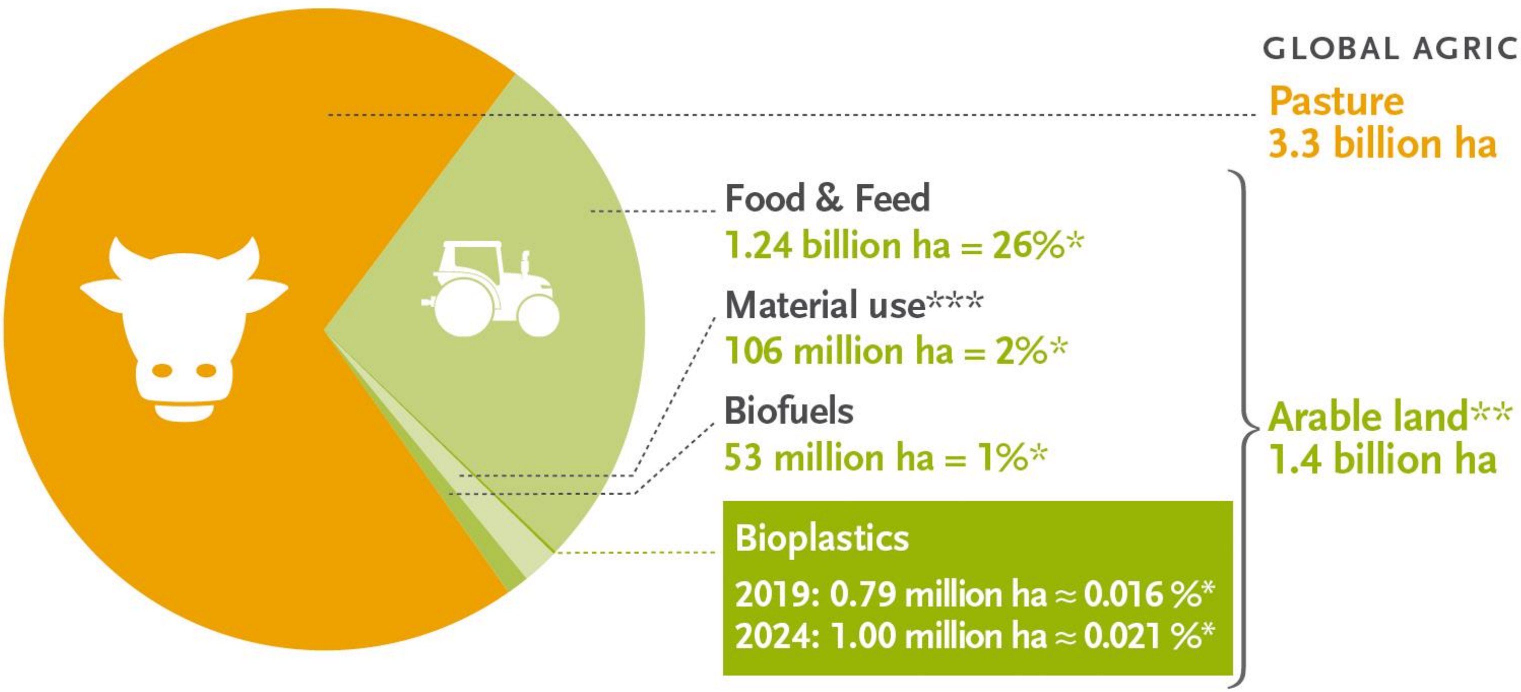
MATERIALS - BIOPLASTICS

BIO PET / GREEN PET



MATERIALS - BIOPLASTICS

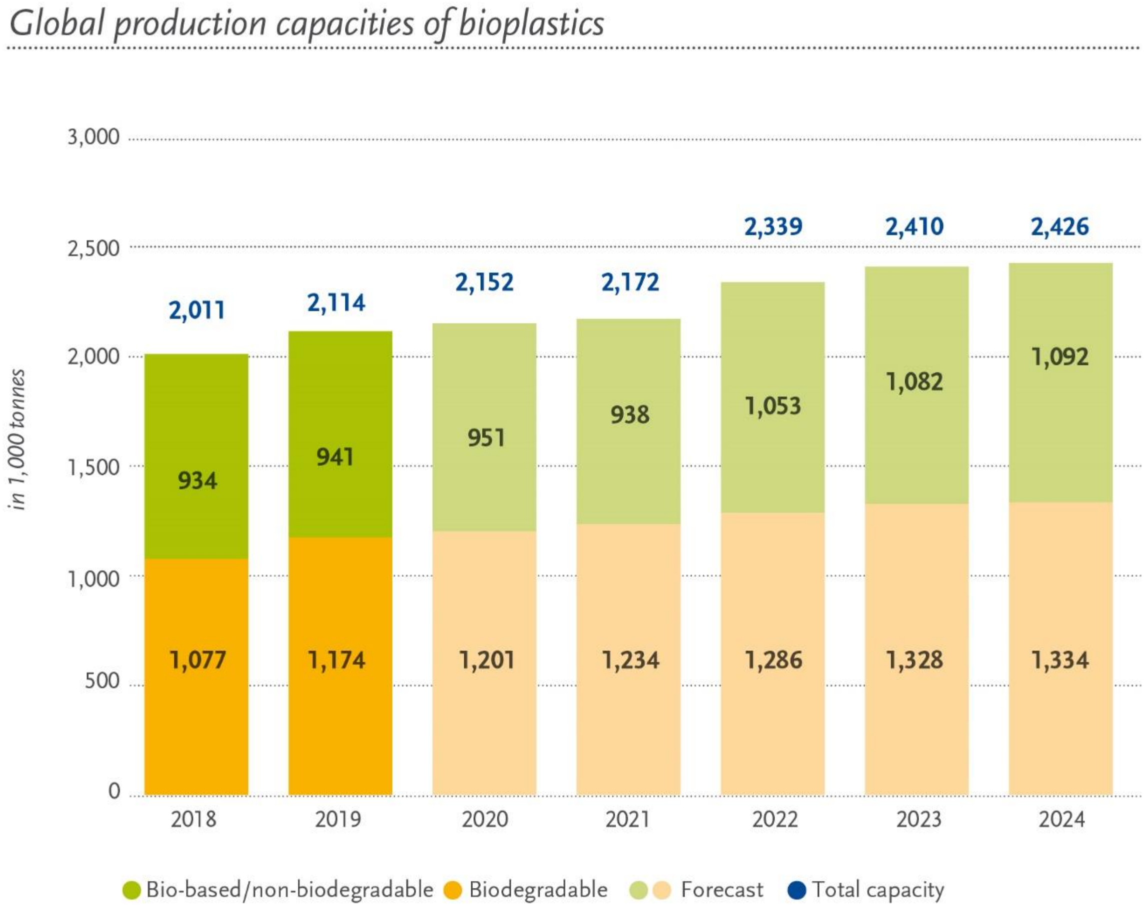
Land use estimation for bioplastics 2019 and 2024



Source: European Bioplastics (2019), FAO Stats (2017), nova-Institute (2019), and Institute for Bioplastics and Biocomposites (2019). More information: ***www.european-bioplastics.org***

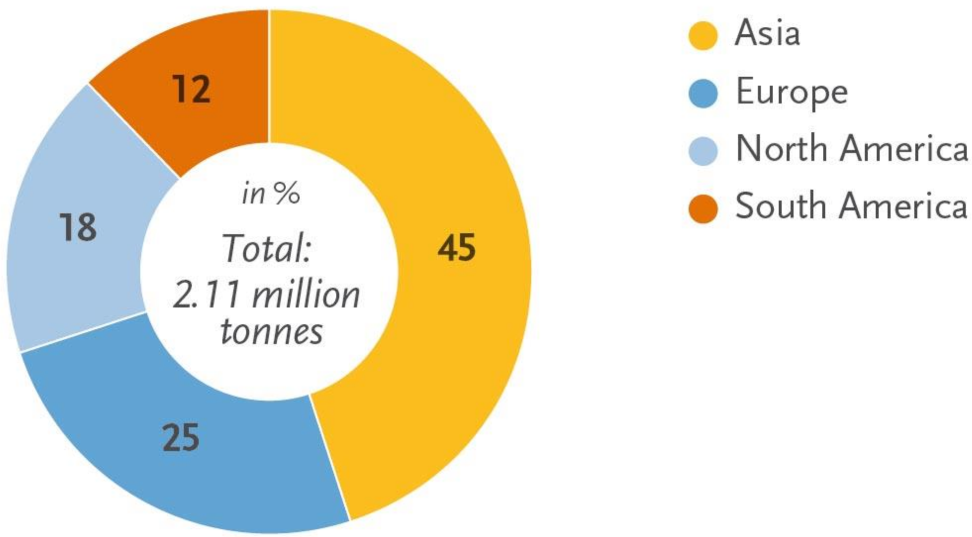
** In relation to global agricultural area*
*** Including approx. 1% fallow land*
**** Land-use for bioplastics is part of the 2% material use*

MATERIALS - BIOPLASTICS



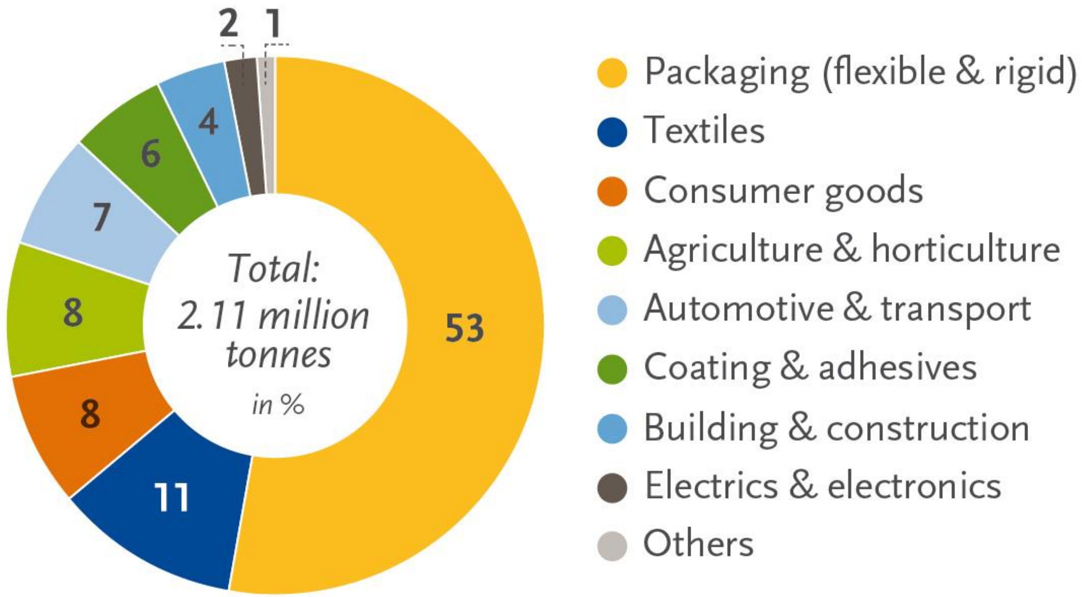
Source: European Bioplastics, nova-Institute (2019)
More information: ***www.european-bioplastics.org/market*** *and* ***www.bio-based.eu/markets***

Global production capacities of bioplastics in 2019 (by region)



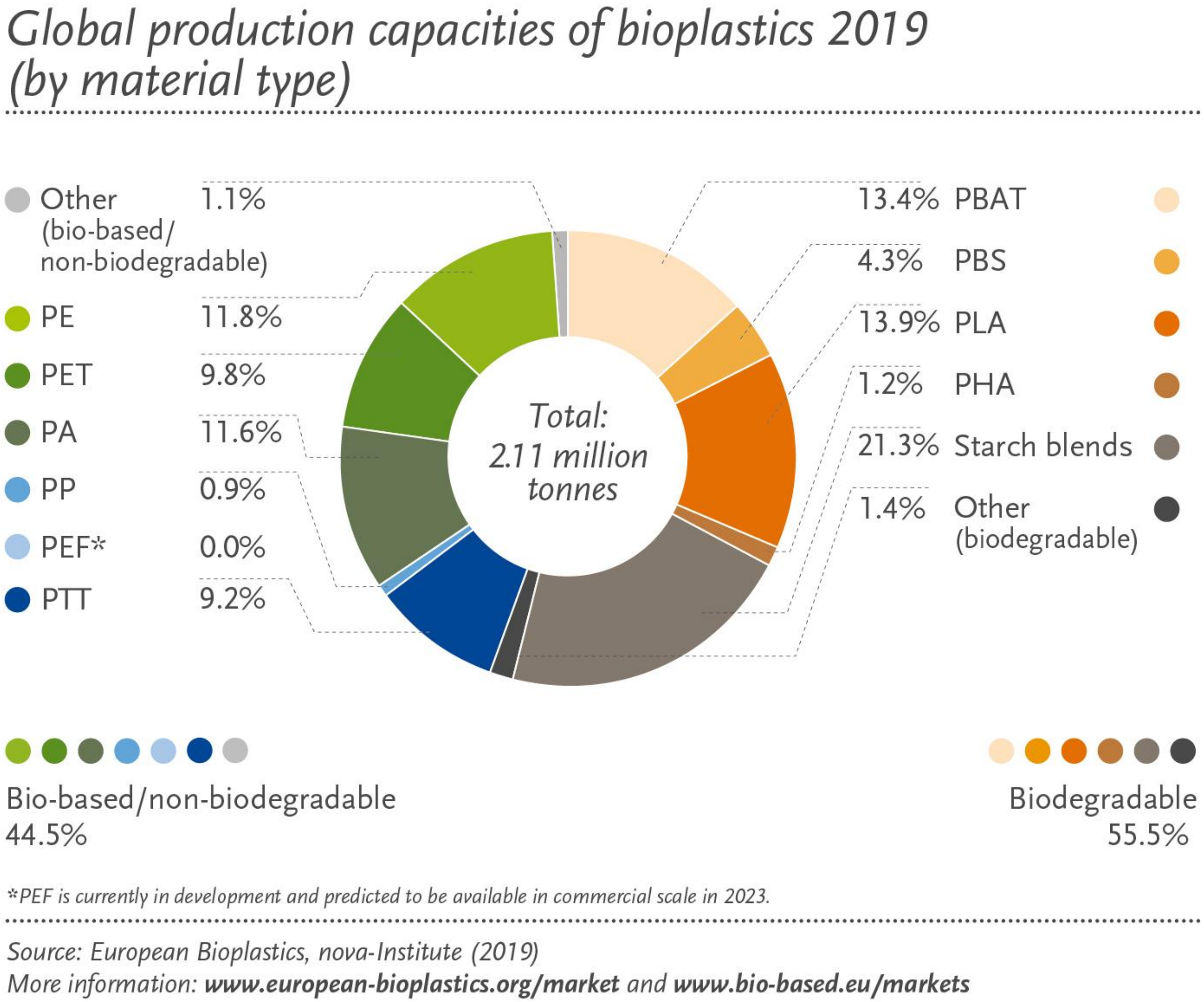
Source: European Bioplastics, nova-Institute (2019). More information: **www.european-bioplastics.org/market** and **www.bio-based.eu/markets**

Global production capacities of bioplastics in 2019 (by market segment)



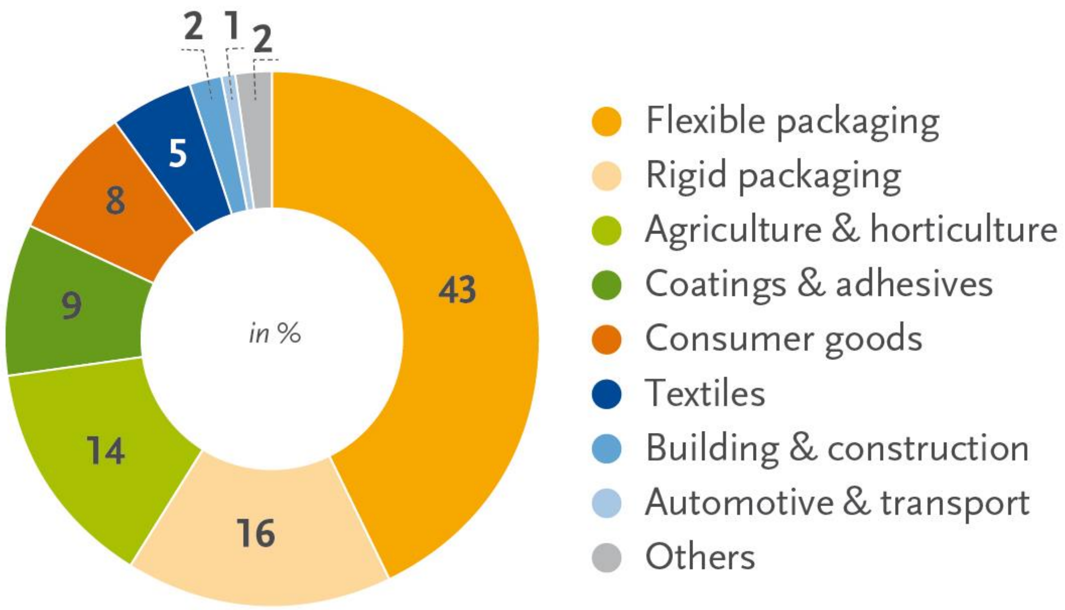
Source: European Bioplastics, nova-Institute (2019). More information: ***www.european-bioplastics.org/market*** *and* ***www.bio-based.eu/markets***

MATERIALS - BIOPLASTICS



MATERIALS - BIOPLASTICS

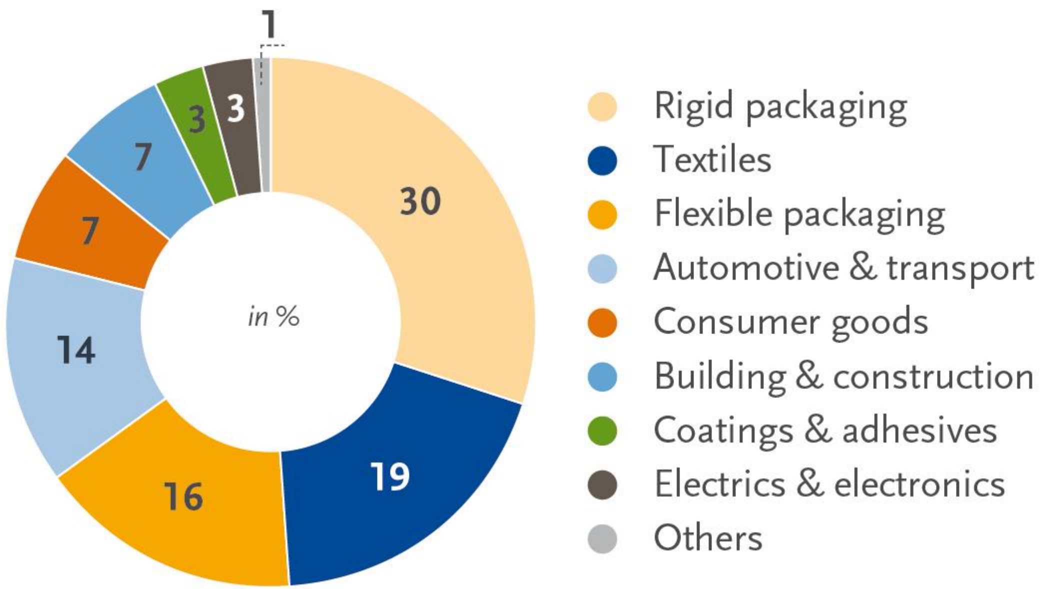
Biodegradable plastics (by market segment) 2019



Source: European Bioplastics, nova-Institute (2019). More information:
www.european-bioplastics.org/market** and **www.bio-based.eu/markets

MATERIALS - BIOPLASTICS

Bio-based plastics (by market segment) 2019



Source: European Bioplastics, nova-Institute (2019). More information:
www.european-bioplastics.org/market** and **www.bio-based.eu/markets

Part 3

Biocomposites

OPTIONS TO COMBINE BIOPLSTIC WITH PAPER

- Lamination
- Extrusion coating

LAMINATION PROCESS

Laminating is the process through which two flexible packaging webs are joined together by using a bonding agent.

The substrates making up the webs consist of film and paper.

In general terms an adhesive is applied to the less absorbent substrate web, after which the second web is pressed against it to produce a duplex-layer.

LAMINATION PROCESS

The solvent solventless

Where the adhesives used do not contain solvents. solventless adhesive generally indicates a specific type of adhesive composed by two components reacting with each other and consequently not requiring drying.

LAMINATION APPLICATIONS

Web laminating is used to improve the appearance and barrier properties of substrates.

The choice of the most suitable web laminating process is mainly dictated by the end-use of the product.

LAMINATION

Advantages:

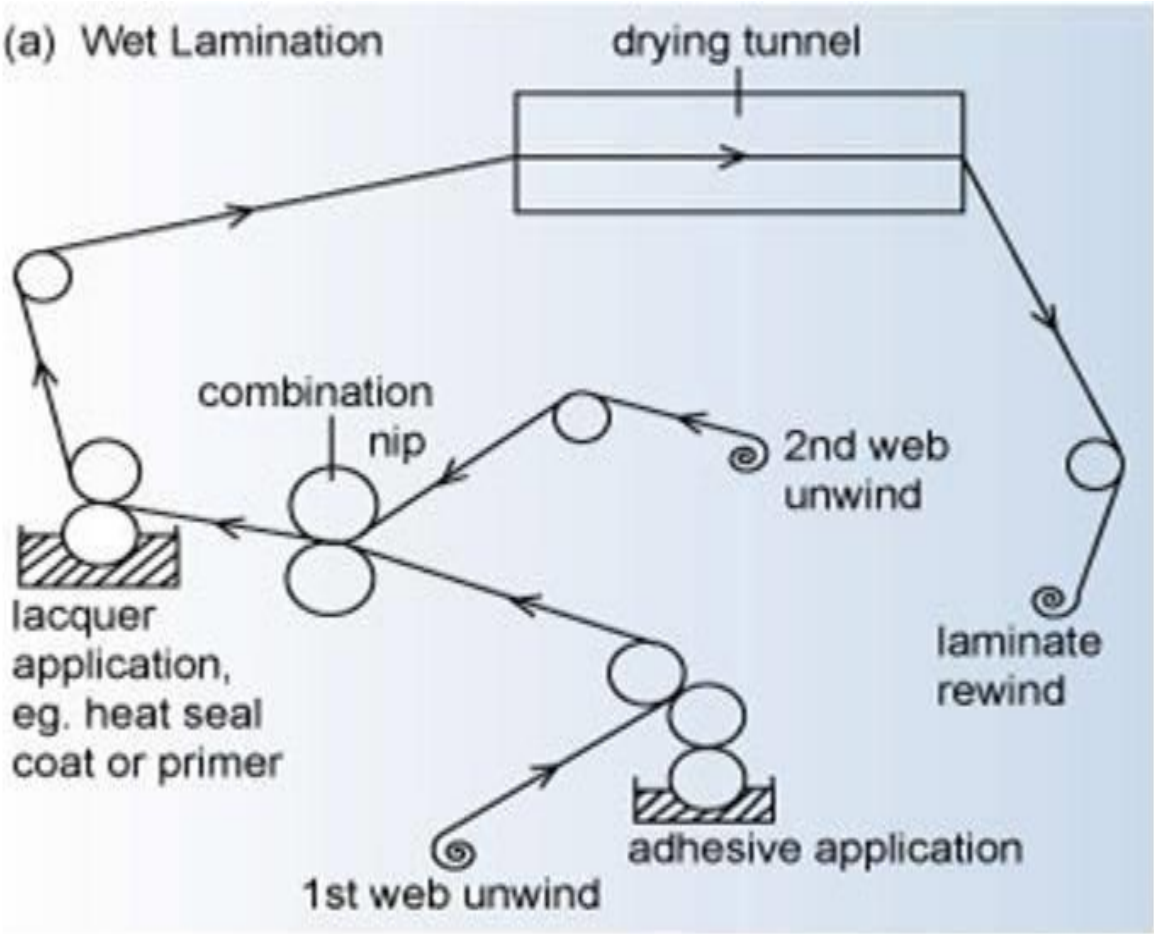
- easy to operate
- short set up
- less waste
- small MOQ
- less operators (1 person)
- can be use as a slittering machine

LAMINATION

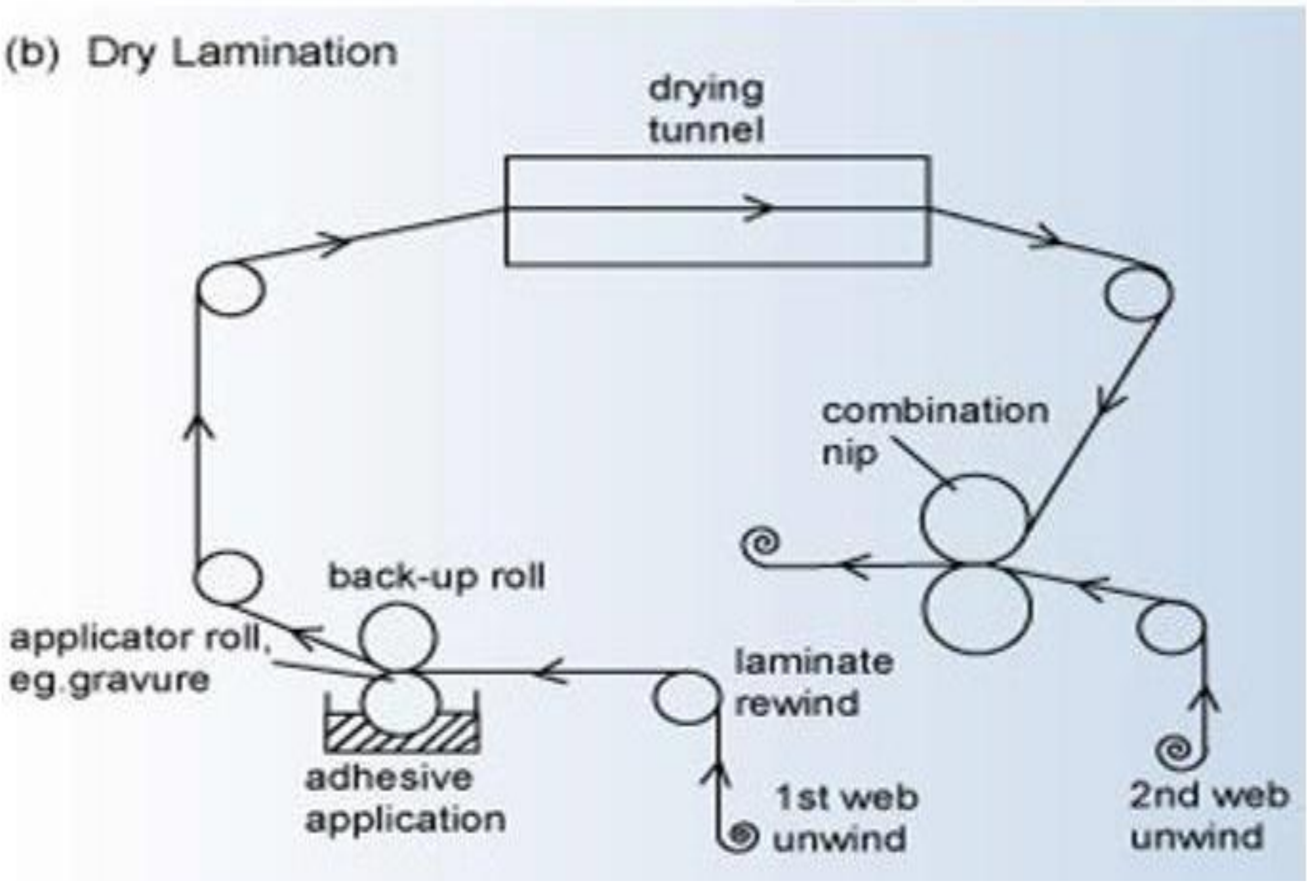
Disadvantages:

- extra cost to produce the roll of the bioplastic (blown extrusion)
- extra cost of adhesives/glue
- the adhesive/glue also has to be un-solvent and biodegradable!
- risk of a wrong adhesion (the paper can take away the glue)
  - finishing time is long (have to dry up)
  - higher thickness for the equal quality

MATERIALS - BIOCOMPOSITES



https://www.bobst.com/baen/products/laminating-flexible-materials/process/



https://www.bobst.com/baen/products/laminating-flexible-materials/process/

EXTRUSION COATING

Extrusion coating and extrusion laminating are converting processes that allow the substrates to be combined to obtain a single compound structure. The materials can be bioplastics, paper, carton board, or aluminum films.

EXTRUSION COATING PROCESS

In the extrusion coating, process an extruder forces melted thermoplastic resin through a horizontal slot-die onto a moving web of substrate. The resulting product is a permanently coated web structure. Extrusion lamination is a similar process to extrusion coating, where the resin is extruded between two substrates and acts as a bonding agent.

EXTRUSION COATING PROCESS

Inside an extrusion coating and laminating line the substrates and melt are nipped at a bonding station. This consists of a large roll, a pressure roll, and a counter-pressure roll cooled by water. The combination of the pressure between the rolls and the temperature permits delivery of the correct adhesion level.

EXTRUSION COATING APPLICATIONS

Extrusion coating and laminating lines are usually custom-built and can be configured for a variety of applications including flexible packaging, industrial wraps.

Extrusion coater laminators deliver a combined substrate, the component elements of which would be very difficult to separate. The combined substrate inherits highly enhanced physical properties and barrier protection performance from its component elements.

EXTRUSION COATING

Advantages:

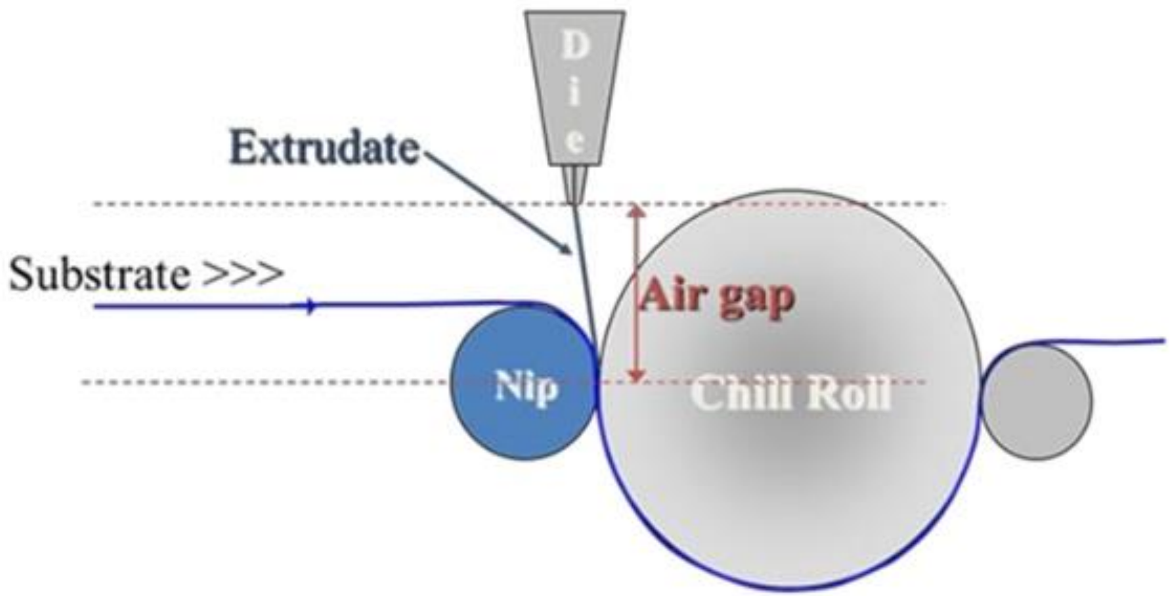
- Big capacity
- Cost effective
- Constant adhesion
- No finishing time
- No glue needed
- Don’t need to extrude the coating material
- Constant and low thickness

EXTRUSION COATING

Disadvantages:

- Extra HR (at least 2 people)
- Long setup
- Special drying system required
- Special screw design required
- Big MOQ

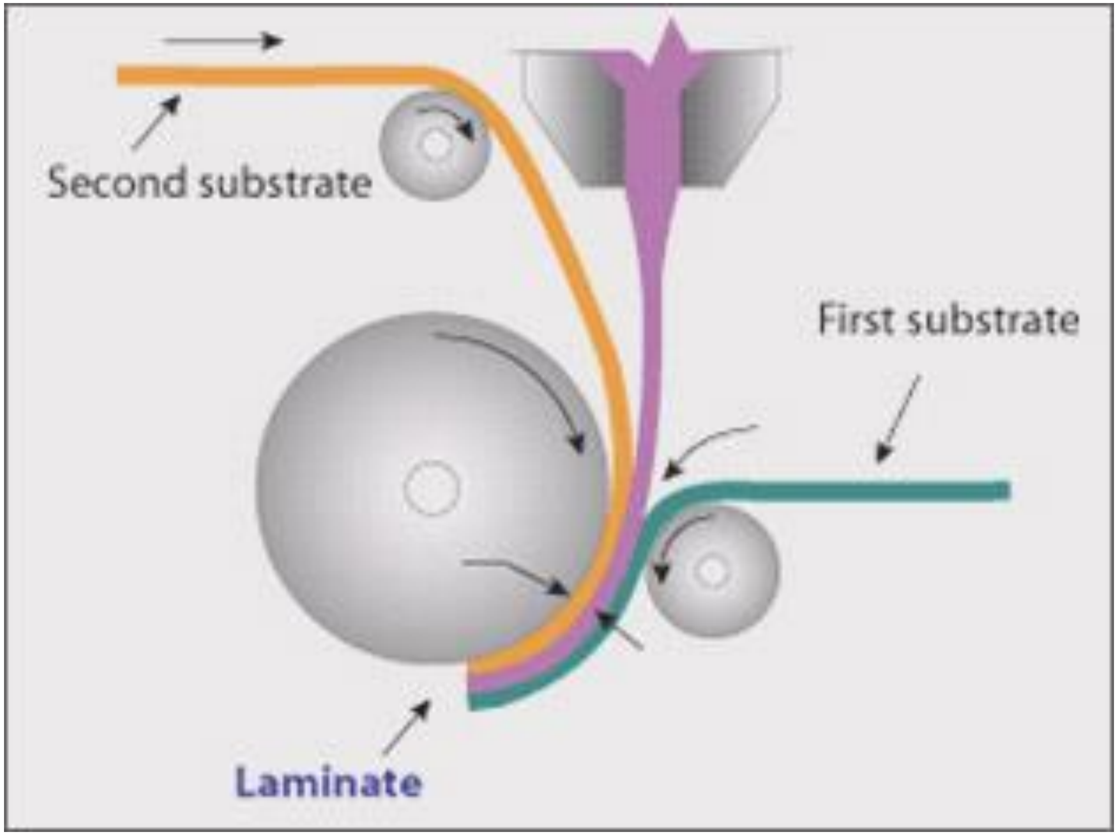
Paperboard Extrusion Coating



https://www.slideshare.net/CCareyYangPhD/yang-biopolymer-extrusion-coating-ppt-flexpackcon-2016

https://www.bobst.com/usen/products/extrusion-coating-laminating/process/

MATERIALS - BIOCOMPOSITES



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https://www.bobst.com/usen/products/extrusion-coating-laminating/process/

THANK YOU!!

THANK YOU!

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