Methods of pollution control and waste management

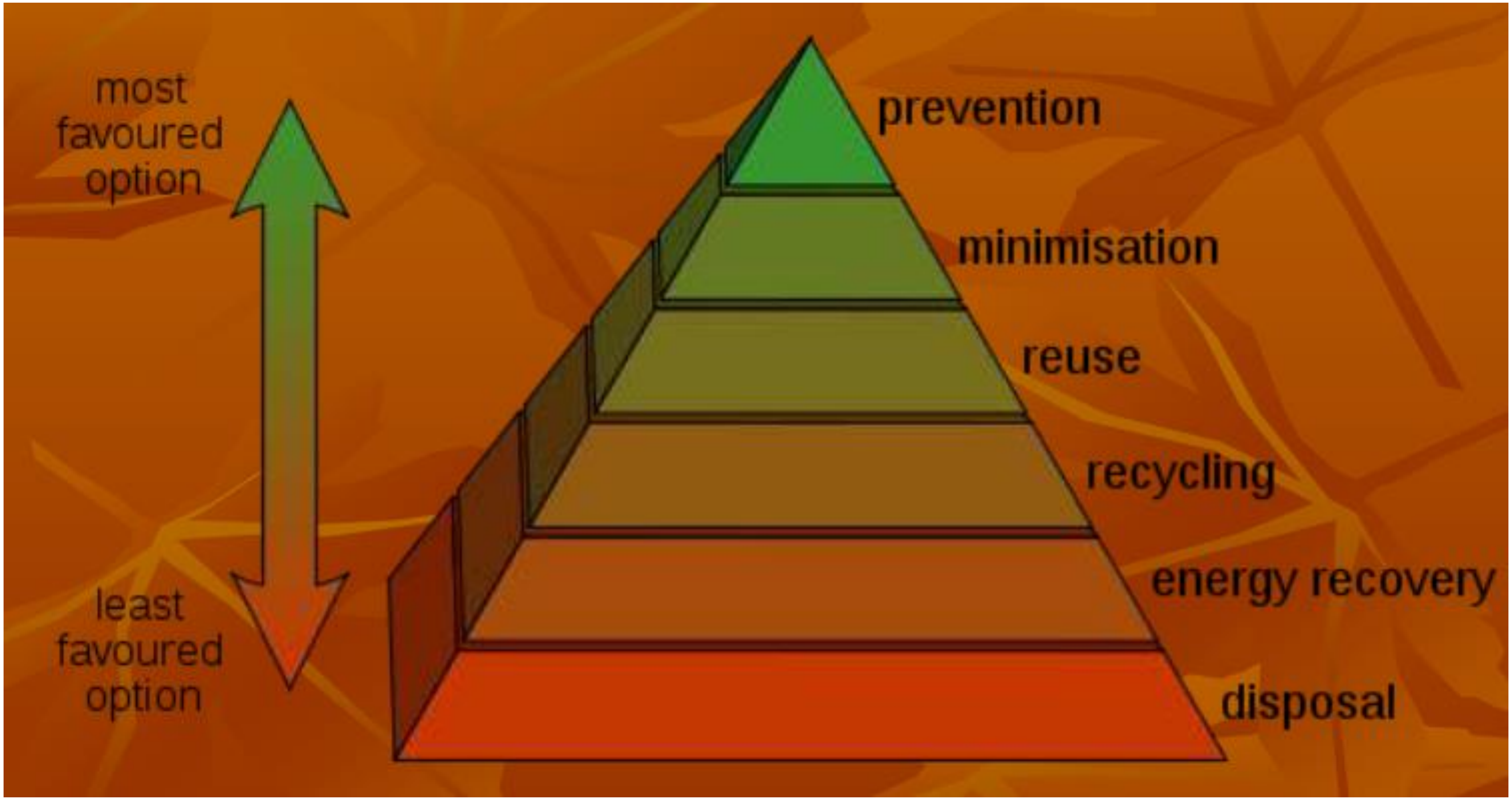
Lecture 10

Solid waste management (SWM)

Methods of plastic recycling

Disposal of radioactive waste

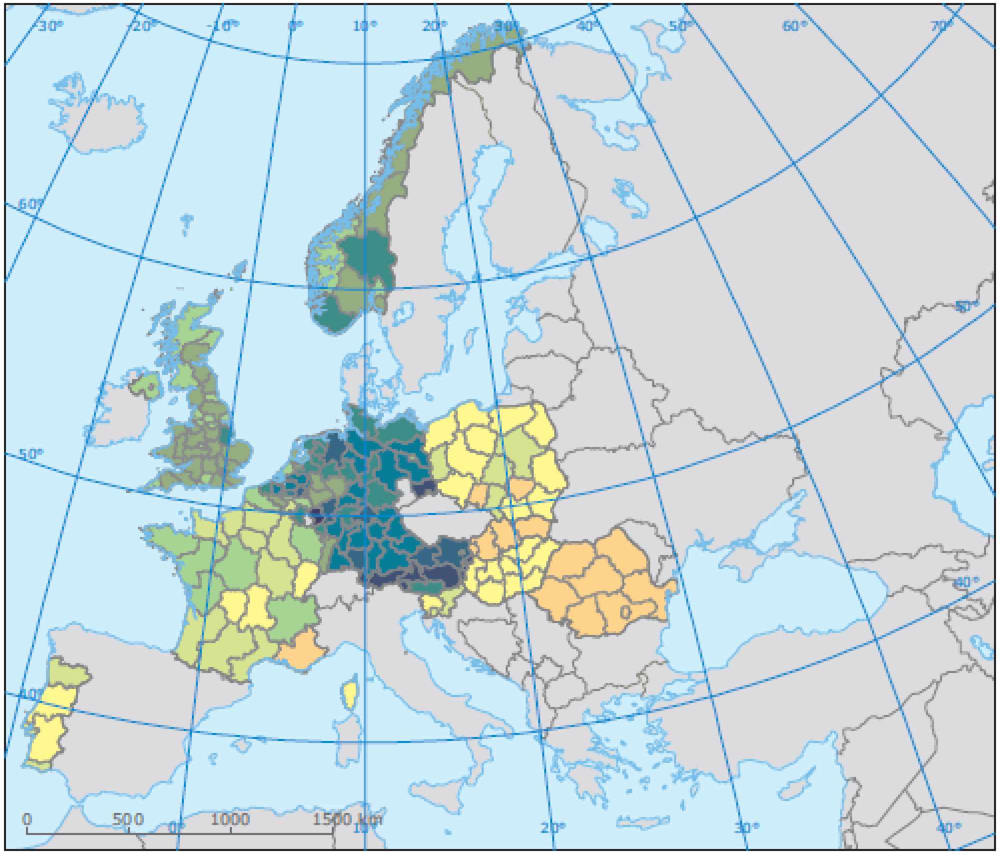
According to the Waste Framework Directive 2008/98/EC, the waste treatment methods are categorized



Management of solid waste (MSW)

- **Recovery and recycling of materials in household waste and industrial waste**
- **Thermal treatment of waste, with energy recovery**
- **Biological treatment of the easy biodegradable part of the organic waste**
- **Landfilling**

Map 2.1 Regional recycling rates for municipal solid waste, 2008/2009



Recycling of municipal waste, 2008/2009

0–< 10 %	30–< 40 %	60–< 70 %	90–100 %
10–< 20 %	40–< 50 %	70–< 80 %	Outside data coverage
20–< 30 %	50–< 60 %	80–< 90 %	

Note: Recycling includes material recycling and composting/digestion. Recycling rates are calculated as a percentage of municipal solid waste generated. 2008 data were used for Belgium, Germany, France, Hungary, Romania and Slovenia. 2009 data were used for the rest of the countries.

Source: Eurostat, 2012a.

Management solid waste (MSW) technologies

The main goal of MSW is to reduce the waste volumes and to protect the health of the population

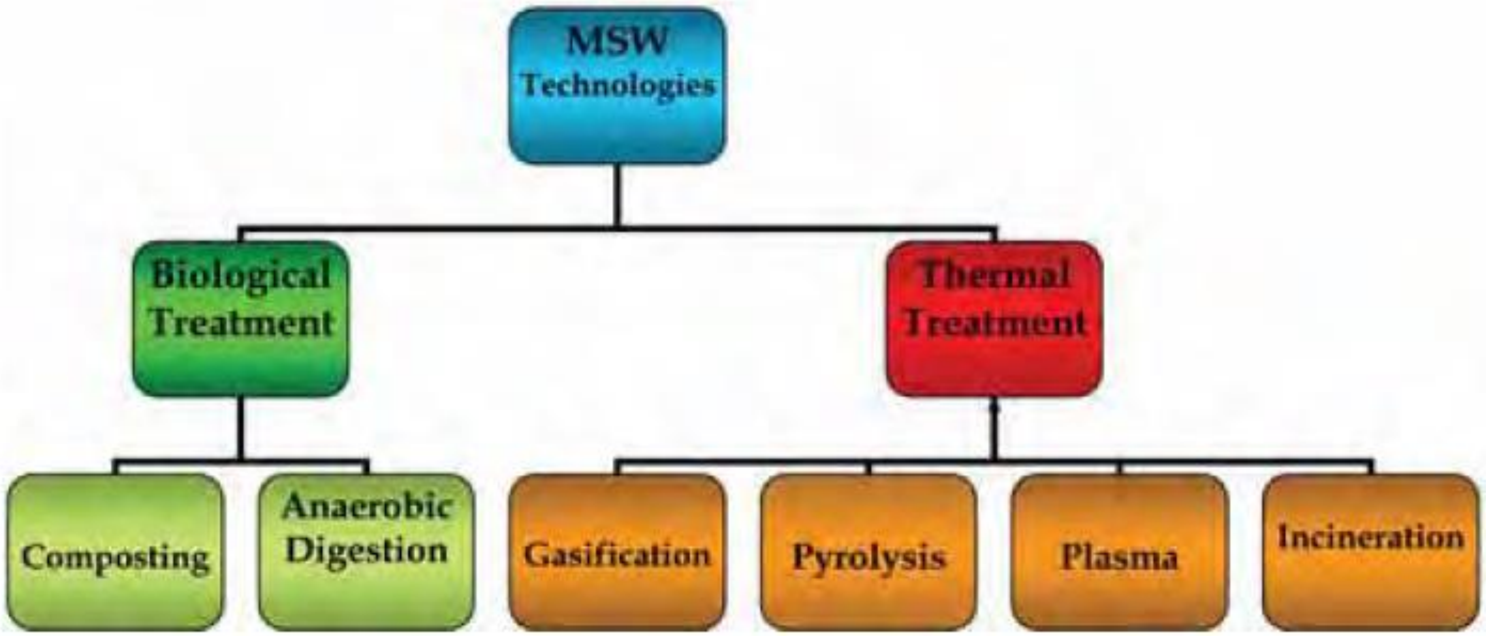


Fig. 1. Different biological and thermal methods for solid waste management

Konstantinos Moustakas and Maria Loizidou *National Technical University of Athens,* Solid Waste Management through the Application of Thermal Methods, INTECH, 2010

Rys. 4. Zakład Unieszkodliwiania Stałych Odpadów Komunalnych w Warszawie [9]

Incineration in Warsaw

Rys. 5. Zakład Termicznego Przekształcania Odpadów Komunalnych w Bydgoszczy [11]

Incineration in Bydgoszcz

Rys. 6. Zakład Termicznego Przekształcania Odpadów Komunalnych w Krakowie [8]

Incineration in Cracow

Rys. 7. Zakład Termicznego Unieszkodliwiania Odpadów Komunalnych w Koninie [13]

Incineration in Konin

Rys. 8. Zakład Unieszkodliwiania Odpadów Komunalnych w Białymstoku [14]

Incineration in Białystok

Rys. 9. Instalacja Termicznego Przekształcania Odpadów Komunalnych w Poznaniu [15]

Incineration in Poznań

The incineration plant in Warsaw planned on 2019
40 000 t/year → 300 000 t/year equipped with modern furnace and system of flue gases purification

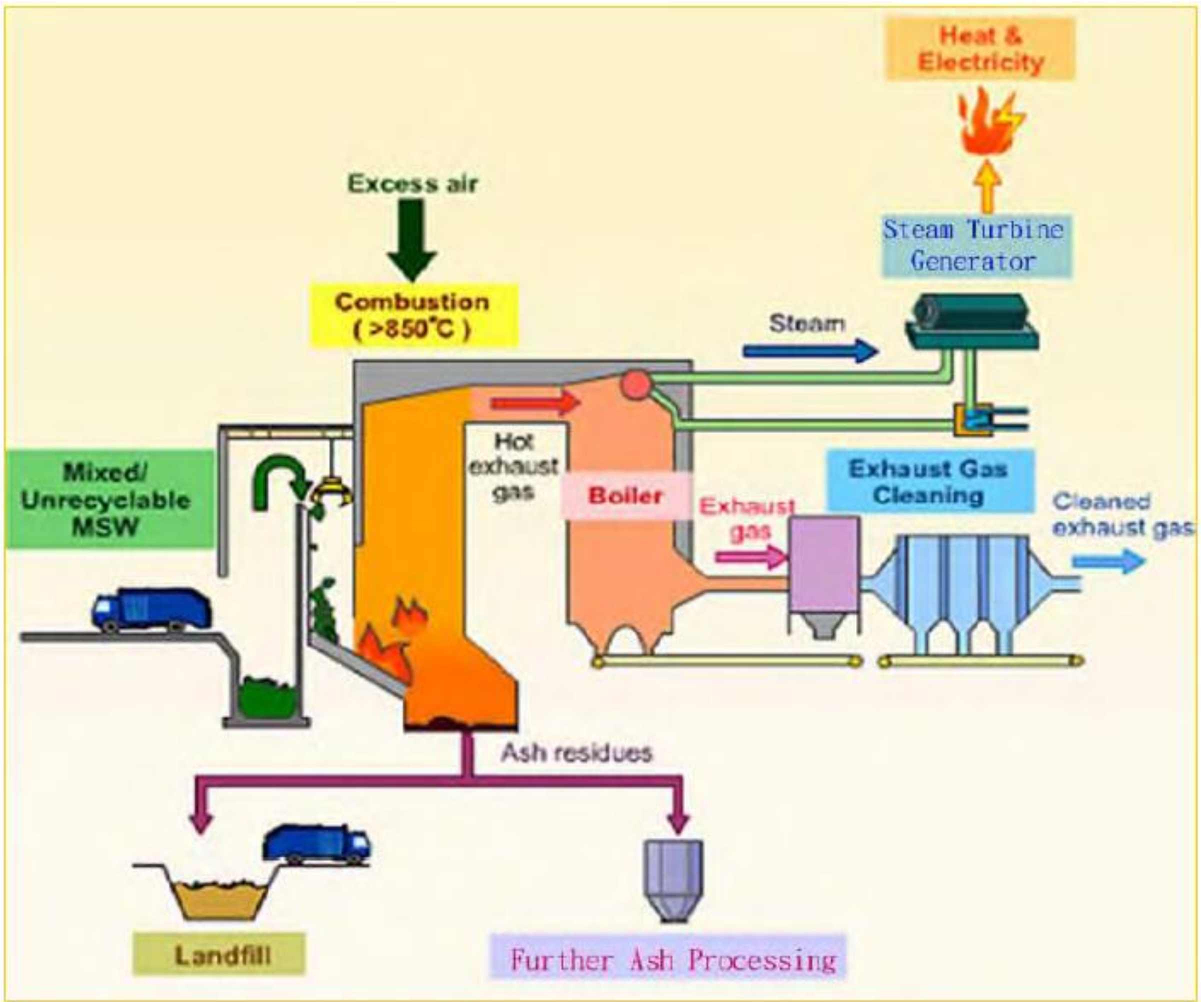
Incineration plant Spittelau in Vienna

The Spittelau incineration plant in Vienna, was built in 1971 rebuilt in 1994, yield: 265 000 t/year (2 x 16,6 t/h)

The Spittelau incineration plant in Vienna designed by Friedensreich Hundertwasser

Incineration plant scheme

The waste are mostly converted into carbon dioxide and water and any noncombustible materials (e.g. metals, glass, stones) remain as a solid, known as incinerator bottom ash (IBA) that always contains a small amount of residual carbon.



'ig. 3. A schematic diagram of incineration process

Integrated Waste Management

Flue Gas Cleaning Systems

- Multi-stage Wet Scrubbers
- SCR - de NOx or SCNR (Catalytic or non-catalytic)
- Electrostatic Precipitators
- Fabric Filters
- Handling of Residues from Waste to Energy

Dioxins and furans emission

- The most important problem dioxins and furans production in combustion process.
- These compounds are extremely toxic and formed when hydrocarbon precursors react with chlorinated compounds during combustion process.
- They are very difficult to burn, combustion dioxin requires temperature above 1200 ^oC
- Difficult to remove from flue gases, so special methods must be used and small amounts of dioxin and furans may be emitted

This is a serious deficiency

- Adsorption on AC can be used for dioxins and furans removal from FG

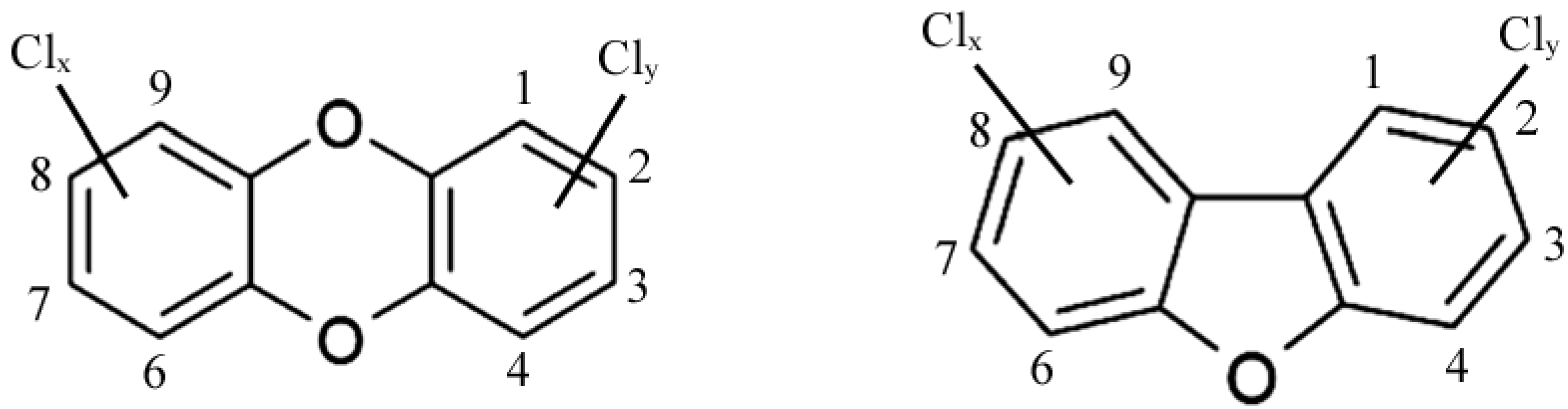


Figure 1 The general structure of dioxins (left) and furans (right)

Pyrolysis (thermal cracking)

$$C_xH_y \rightarrow C_cH_d + C_mH_n$$

Temp. 450 – 750°C in the absence of oxygen

$$C_xH_y \rightarrow C_pH_q + H_2 + \text{coke}$$

$$C + H_2O \longrightarrow CO + H_2 \text{ (in the presence of water)}$$

The majority of the organic substances in waste are subjected to pyrolysis by 75 – 90 % into volatile substances (H_2, CO, CO_2, CH_4, C_xH_y) and by 10 – 25 % to solid residue (coke).

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Pyrolysis

Solid	Carbon that is incorporated into several inert products	-
Gas	Dust particles, CO, CO_2, CH_4, H_2	700 m^3 off-gases / tone of waste
Liquid	CH_3COOH, CH_3COCH_3, CH_3OH, complex oxygenised H/C	

Table 1. Brief description of the solid, liquid and gas products from the operation of a pyrolysis unit

- **Relatively expensive**
- **Permanent operating problem with tar and oils**
- **Problematic disposal of created char residue (toxic)**

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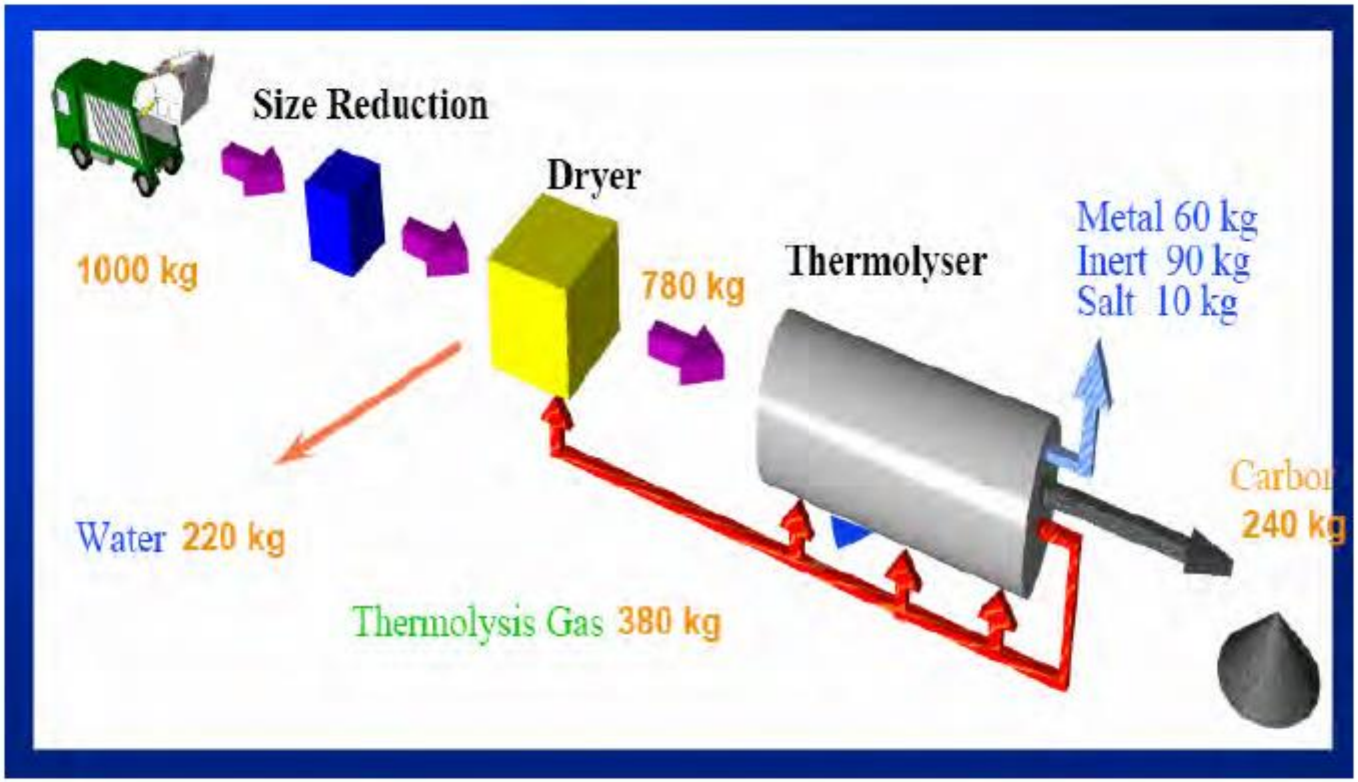
Pyrolysis



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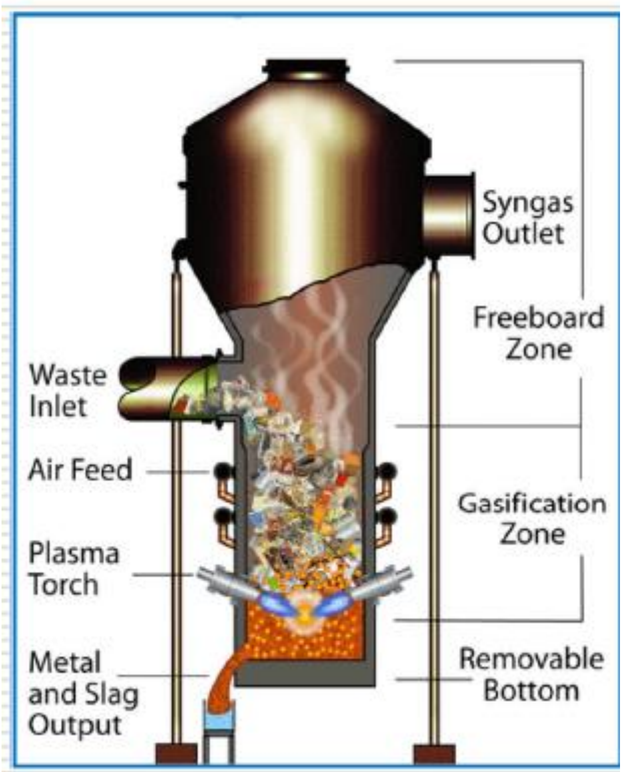
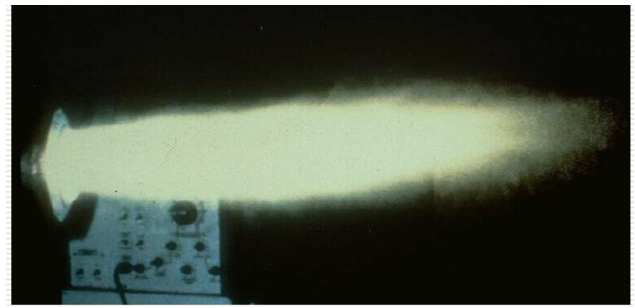
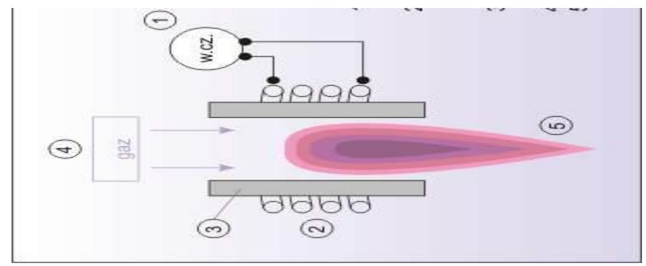
Plasma technology







Plasma torch temp. 4000 – 30 000^0K

- Totally destroys all organics, but shows inefficient energy balance
- Small throughput
- Expensive operation and maintenance, approx. US$ 1000.-/ton

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Location	Waste	Capacity (TPD)	Start Date
Mihama-Mikata, JP	MSW/WWTP Sludge	28	2002
Utashinai, JP	MSW/ASR	300	2002
Kinuura, JP	MSW Ash	50	1995
Kakogawa, JP	MSW Ash	30	2003
Shimonoseki, JP	MSW Ash	41	2002
Imizu, JP	MSW Ash	12	2002
Maizuru, JP	MSW Ash	6	2003
Iizuka, JP	Industrial	10	2004
Osaka, JP	PCBs	4	2006
Taipei, TW	Medical & Batteries	4	2005
Bordeaux, FR	MSW ash	10	1998
Morcenx, FR	Asbestos	22	2001
Bergen, NO	Tannery	15	2001
Landskrona, SW	Fly ash	200	1983
Jonquiere, Canada	Aluminum dross	50	1991
Ottawa, Canada	MSW	85	2007 (demonstration)
Anniston, AL	Catalytic converters	24	1985
Honolulu, HI	Medical	1	2001
Hawthorne, NV	Munitions	10	2006
Alpoca, WV	Ammunition	10	2003

Table 3. Commercial Plasma Waste Processing Facilities (Circeo, 2007)

MSW – Municipal Solid Waste, WWTP Waste Water Treatment Plant, ASR – Auto Shredder Residue, PCBs – Polychlorinated biphenyls

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Parameter	Incineration	Pyrolysis	Gasification
Operation conditions			
Temperature °C	800-1,450	250-700	500-1,600
Pressure (bar)	1	1	1-45
Atmosphere	Air	Inert/Nitrogen	Gasification factor: O_2, H_2O
Stoichiometric relation	>1	0	<1
Products			
Gas Phase	CO_2, H_2O, O_2, N_2	H_2, CO, H_2O, N_2, H/C	H_2, CO, CO_2, CH_4, H_2O, N_2
Solid Phase	Ash, Scoria	Ash, Scoria	Ash, Scoria
Liquid Phase		Pyrolysis Oils & H_2O	

Table 4. Parameters of typical operation conditions & products of the common thermal management practices

Konstantinos Moustakas and Maria Loizidou *National Technical University of Athens,* Solid Waste Management through the Application of Thermal Methods, INTECH, 2010

Biological treatment

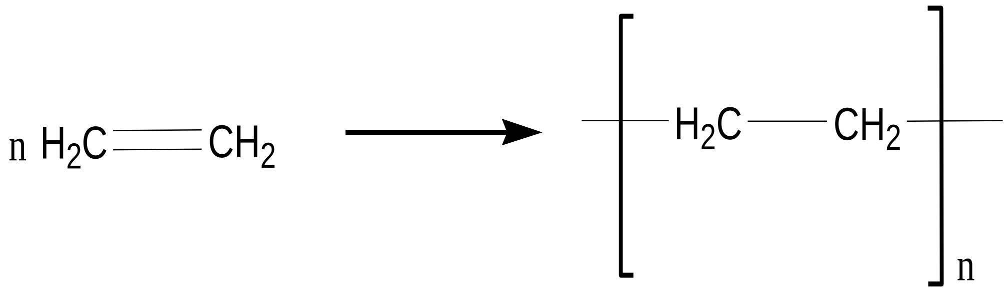
- Composting reactions

Aerobic, analogous to the activated sludge process in wastewater treatment. The microorganisms require water and oxygen and so compost must be kept moist and, at the same time aerated. The temperature should be allowed to rise to 50 – 60 ^{0}C and maintained for several days. The carbon:nitrogen ratio of the raw materials is critical for controlling the rate of composting reactions.

Humus-like material as a product

Plastics

- Most polymers are synthetic organic materials produced by polymerization. They are typically of high molecular mass. **<u>Plastics prepared from polymers</u>** may contain other substances besides polymers to improve performance and/or reduce costs (stabilizers, plasticizers, colorants, extenders and others).

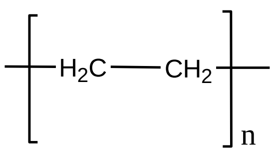


Plastics

- **Thermoplastics** can undergo a softening when heated to a particular temperature, can repeatedly soften and melt if enough heat is applied and hardened on cooling, so that they can be made into new plastics products. Examples are polyethylene, polystyrene and polyvinyl chloride, among others.
- **Thermosets** can melt and take shape only once. They are not suitable for repeated heat treatments; therefore after they have solidified, they stay solid. Examples are phenol formaldehyde and urea formaldehyde resins.

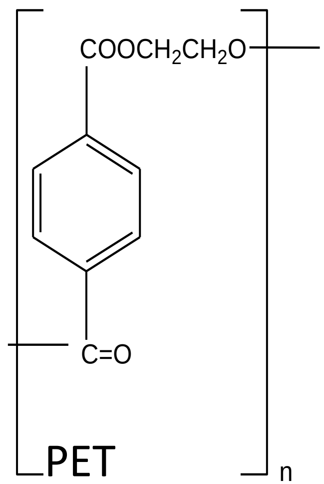
Plastics

- *Thermoplastics make up 80% of the plastics produced today.*



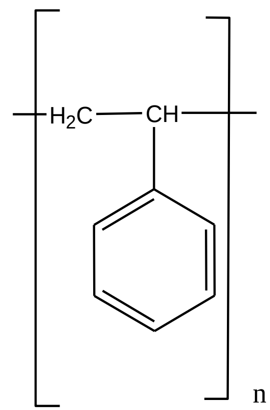
PE (HDPE LDPE)
Polyethylene

piping, automotive fuel tanks, bottles, toys, plastic bags



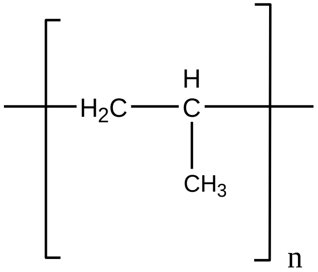
PET
Polyethylene Terephthalate

bottles, carpets, food packaging, synthetic fibers



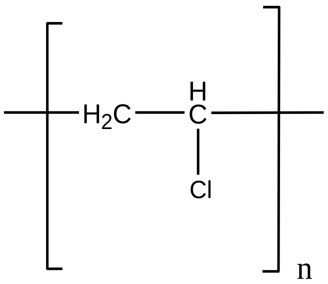
PS
Polystyrene

dairy product containers, cups and plates, packaging for electronics, toys



PP
Polypropylene

automotive parts, food containers, piping, bottle cap



PVC
Polyvinyl chloride

window frames, flooring, bottles, packaging film, cable insulation, credit cards and medical products

„Converting Waste Plastics into a Resource" Compendium of Technologies, UNEP United Nations Environmental Programe Division of Technology, Industry and EconomicsInternational Environmental Technology Centre Osaka/Shiga, Japan, 2009

Europe ranks second in the global plastics production

China remains the leading plastics producer with 23.9%, and the rest of Asia (incl. Japan) accounts for an additional 20.7%.

European production (EU-27+2) accounts for 20.4% of the world's total production.

NAFTA – North American Free Trade Agreement: USA, Canada, Mexico

CIS - Commonwealth of Independent States an alliance of former Soviet republics including Armenia, Azeirbijan, Belarus, Russian Federation, Ukraine, Uzbekistan

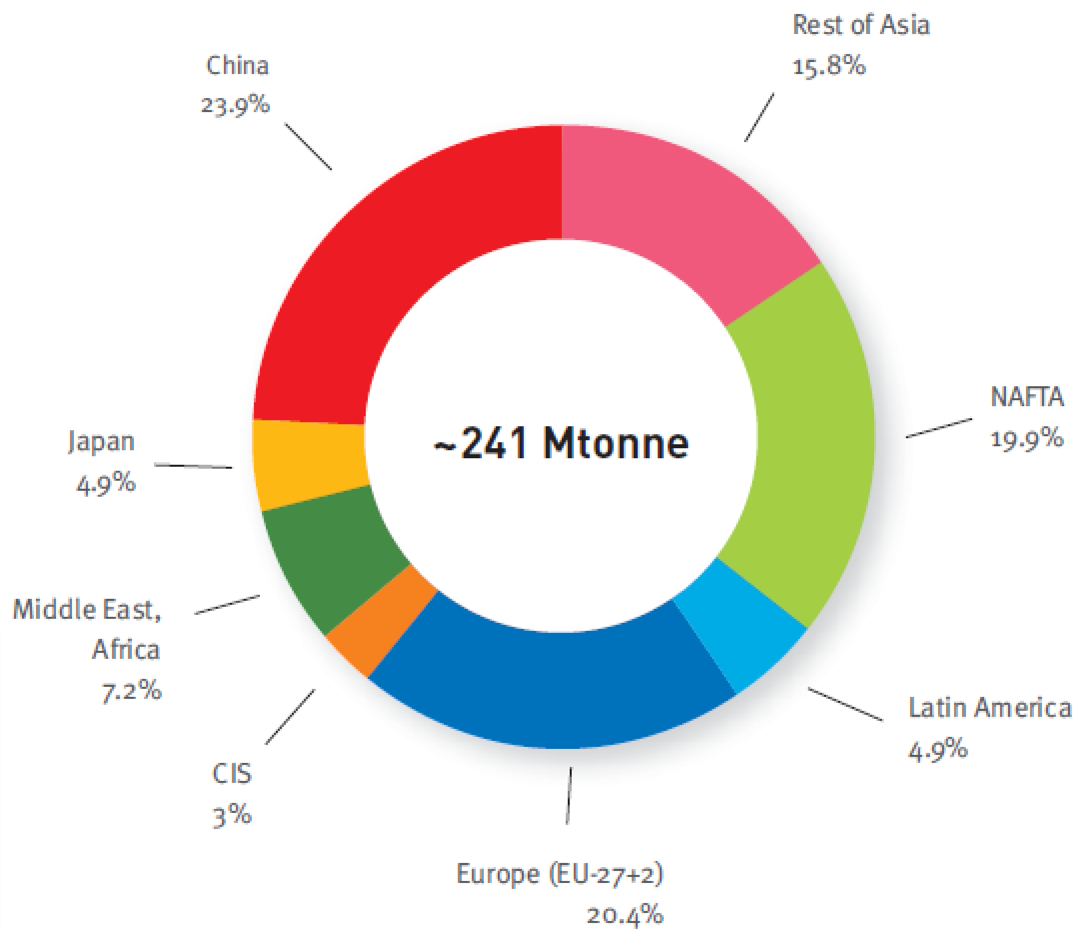


Figure 3: World plastics materials production 2012

Source: Plastics – the Facts 2013 An analysis of European latest plastics production, demand and waste data Plastics Europe (PEMRG) Consultic

Plastics provide for a wide variety of markets

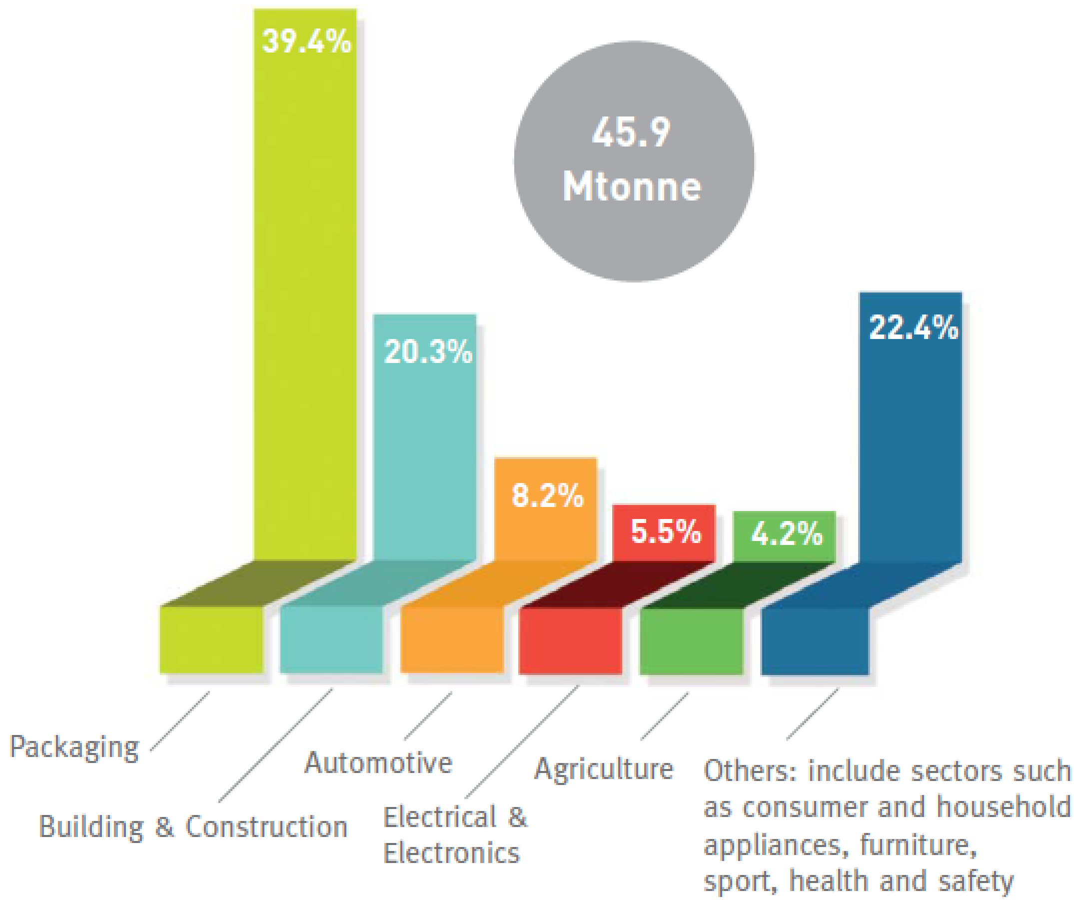
In Europe, packaging applications are the largest application sector for the plastics industry and represent 39.4% of the total plastics demand.

Building and construction is the second largest application sector with 20.3% of the total European demand.

Automotive is the third sector with a share of 8.2% of the total demand.

Electrical and electronic applications represent 5.5% of the plastics demand and are closely followed by agricultural applications which have a share of 4.2%.

Other application sectors such as appliances, household and consumer products, furniture and medical products comprise a total of 22.4% of the European plastics demand.



European plastics demand* by segment 2012 Source: PlasticsEurope (PEMRG) / Consultic

Different plastics for different needs

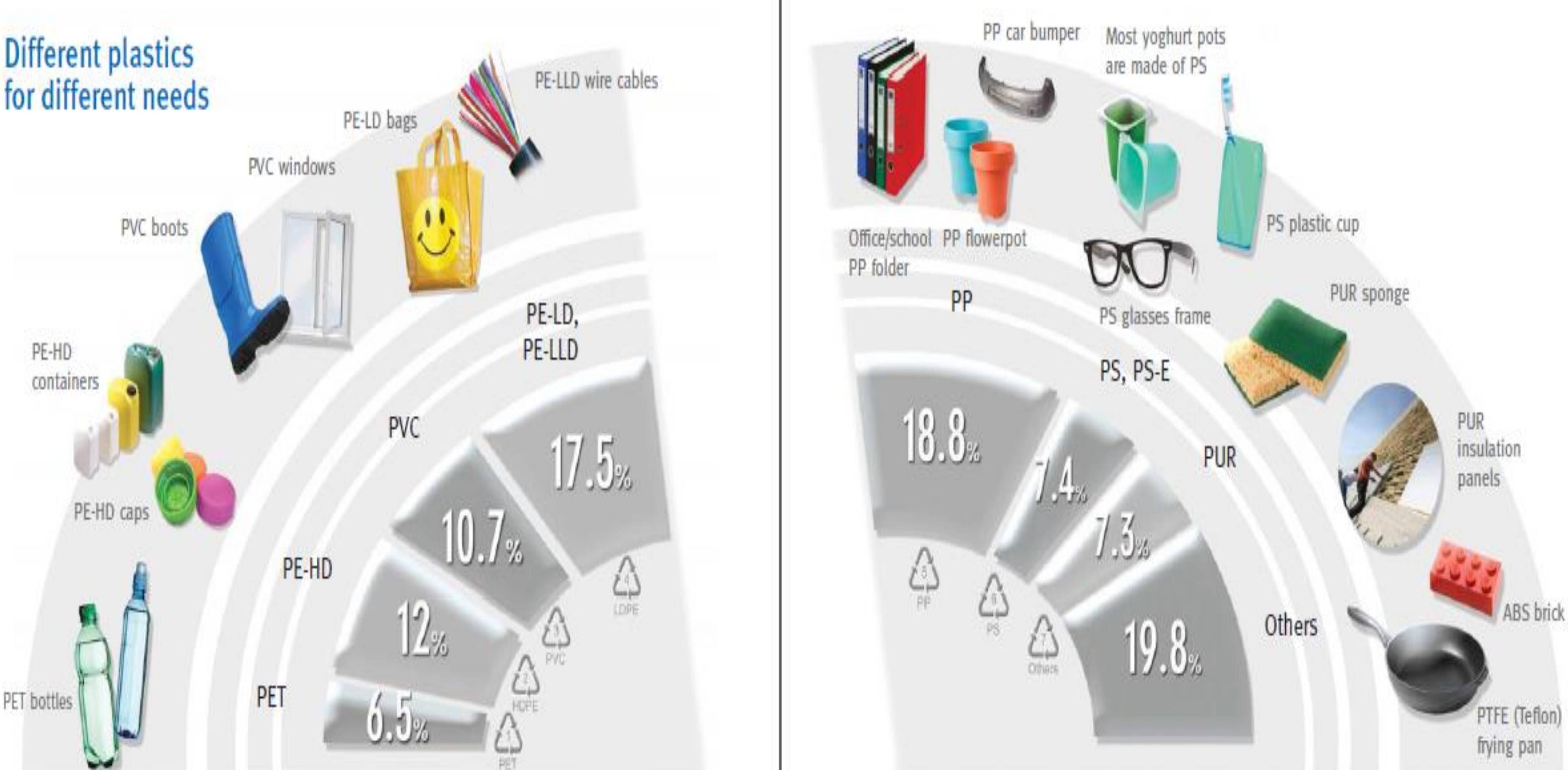


Figure 6: European plastics demand* by resin type 2012

Source: PlasticsEurope (PEMRG) / Consultic / ECEBD

* EU-27+N/CH

Plastic vs. plastic

There are various types of plastics featuring different properties. The international recycling codes (ranging from 1 to 7) which are featured on most plastic products are meant to make (unmixed) separation easy.

Time to act: plastics are too valuable to throw away!

Turning waste into a resource is a goal the European plastics industry is committed to achieve to improve Europe's resource efficiency.

This goal is impossible to achieve with 38% of plastics waste still going to landfill.

As such, landfill is a major hurdle that must be eliminated for such an ambitious goal to be reached.

Recycling and energy recovery are both complementary and necessary to achieve the zero plastics to landfill by 2020 goal.

Since recycling may not always be the most sustainable option for plastics, energy recovery should remain a viable option to realise the full potential of the diverted waste which to generate electricity and heat.

Therefore, the industry is calling for measures to avoid the landfilling of recyclable and high calorific waste.

Recycling of plastics

- **Energy recovery**
- **Mechanical recycling**
- **Feedstock recycling**

Recycling of plastics waste

- Energy recovery by incineration

  Incineration of plastics can also be seen as recovery method, as plastics could replace the application of other oil based fuels

Table 1 Heat capacity of plastics and some other materials (Ylä-Mella 2002).

Material	Heat capacity [MJ/kg]	Material	Heat capacity [MJ/kg]
PVC	18	Heavy fuel oil	41
PE	27	Coal	26
PET	46	Natural gas	36 *
PS	41	Milled peat	10
ABS	35	Paper	17

* Unit MJ/m^3 (0 °C)

Jenni Ylä-Mella, Department of Process and Environmental Engineering, **RECYCLING OF POLYMERS, 480360S Environmental Catalysis (3 cr.), 2005**

Mechanical recycling of polymers

- Separation of plastics by resin type,
- Washing to remove dirt and contaminants,
- Grinding and crushing to reduce the plastics particle size,
- Extrusion by heat and reprocessing into new plastic goods.

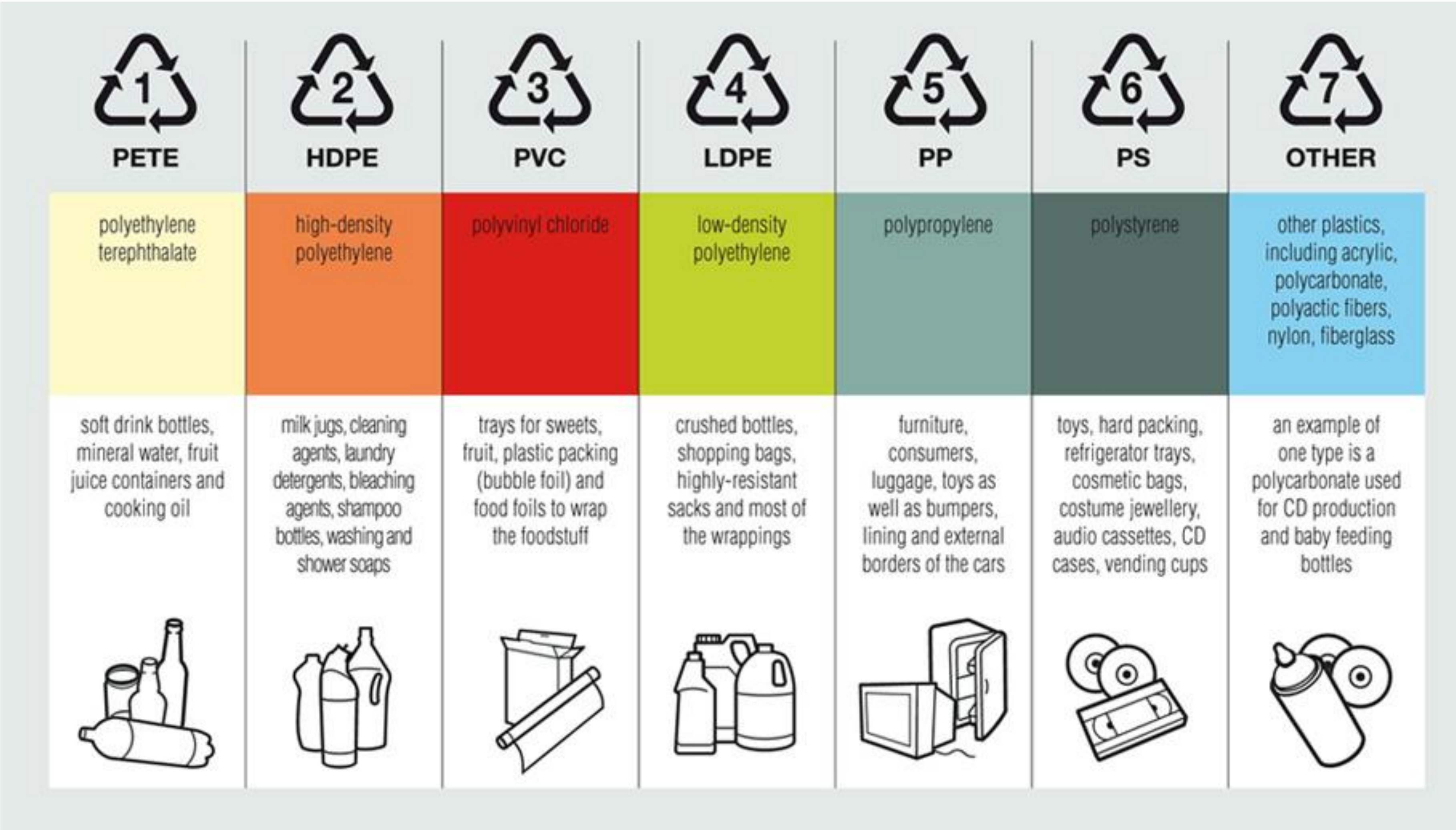
Mechanical recycling of polymers

- This type of recycling is limited to thermoplastics
- Mechanical recycling of plastics is limited by the compatibility between the different types of polymers
- Presence of the other polymers in a matrix of polymer may dramatically change the properties and hinder the possibilities to use it in the conventional applications

  A good example of this is the impacts of polyvinyl chloride (PVC) during polyethylene terephthalate (PET) processing. Only a small amount of PVC in the recycled PET strongly reduces the commercial value of the latter.

- The presence in plastic waste of products made of the same resin but with different color, which usually impart an undesirable grey color to the recycled plastic
- The most polymers suffer certain degradation during their use therefore, recycled polymers exhibit lower properties and performance than the virgin polymers, and are useful only for lesser value applications

To facilitate the mechanical recycling international recycling codes were introduced on the basis of european directive from 1994.



Jose Aguado, David P Serrano, **Feedstock Recycling of Plastic Wastes, Royal Society of Chemistry, Clean Technologies Monographs, 1999**

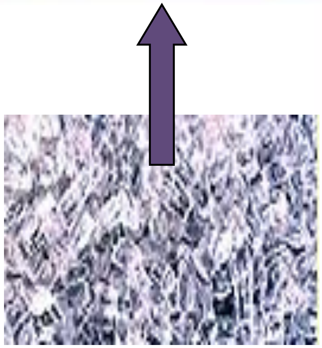
Mechanical recycling

Bottle -to- bottle recycling system for polyethylene terephthalate (PET)

Pre-forms extruded

Conversion using blow molding

Recyclate is obtained



pellets

Feedstock recycling of plastics

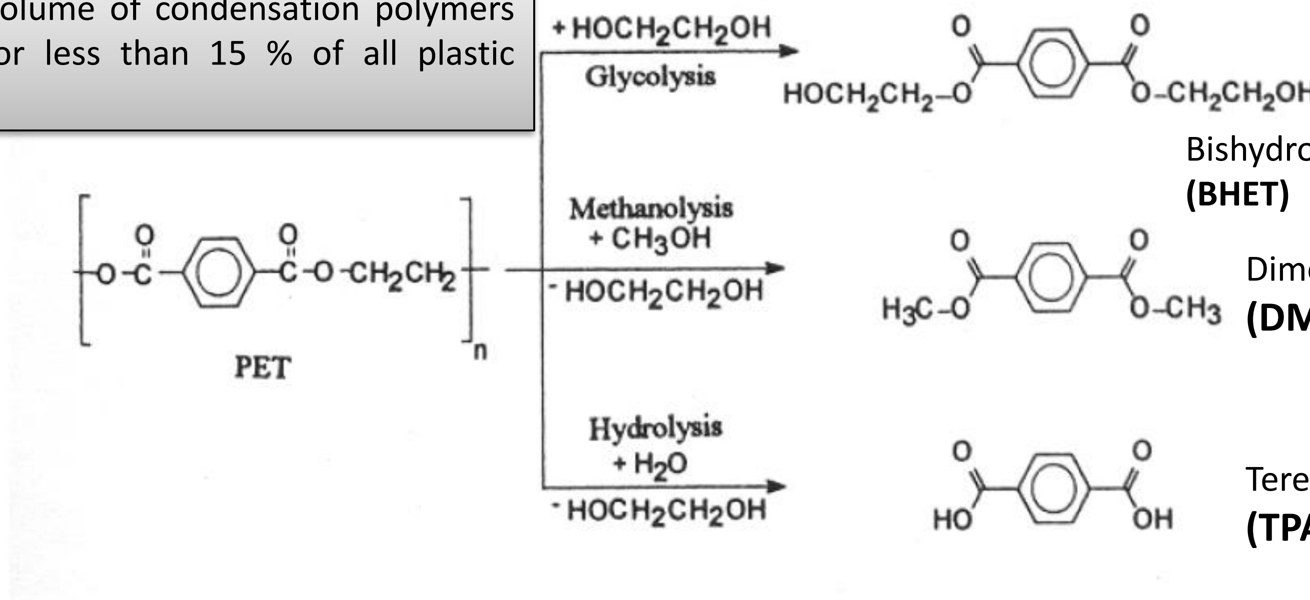
Feedstock recycling of plastics, also referred to as chemical or tertiary recycling is based on the decomposition of polymers by means of heat, chemical, or catalytic agent.

- **Recycling to monomers**
- **Recycling to fuels**
- **Recycling to industrial chemicals**

Chemical depolymerization

<u>Restricted to the recycling of condensation polymers</u>

The total volume of condensation polymers accounts for less than 15 % of all plastic waste



Bishydroxyethylterephthalate **(BHET)**

Dimethylterephthalate **(DMT)**

Terephthalic acid **(TPA)**

Figure 4 Depolymerization of PET into monomers by different solvolysis methods. (Janssen and van Santen (1999)

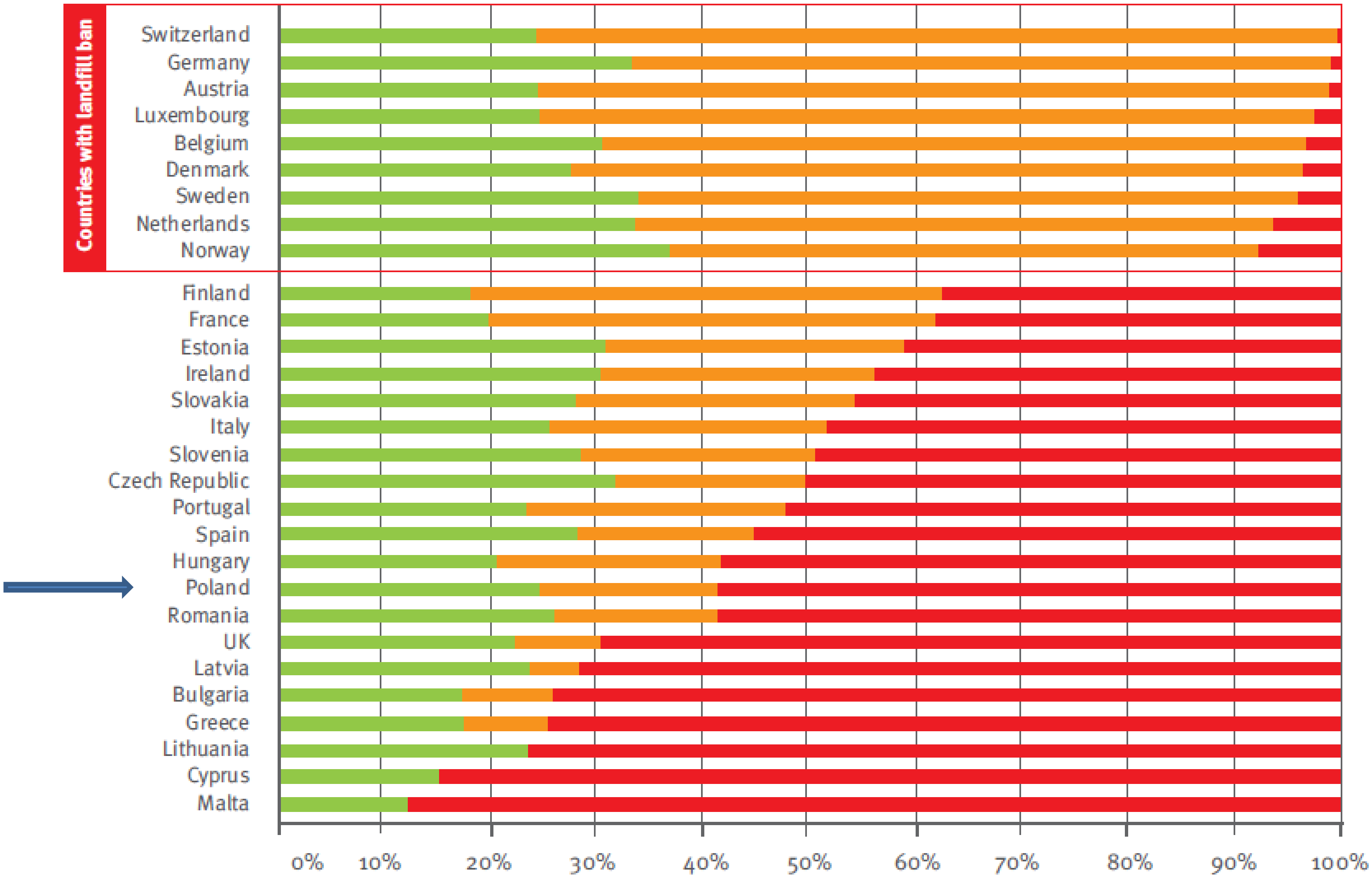


Figure 13: Treatment of post-consumer plastics waste 2012 by EU-27+2

Source: Consultic

Zero plastics to landfill by 2020, a challenging but realistic goal

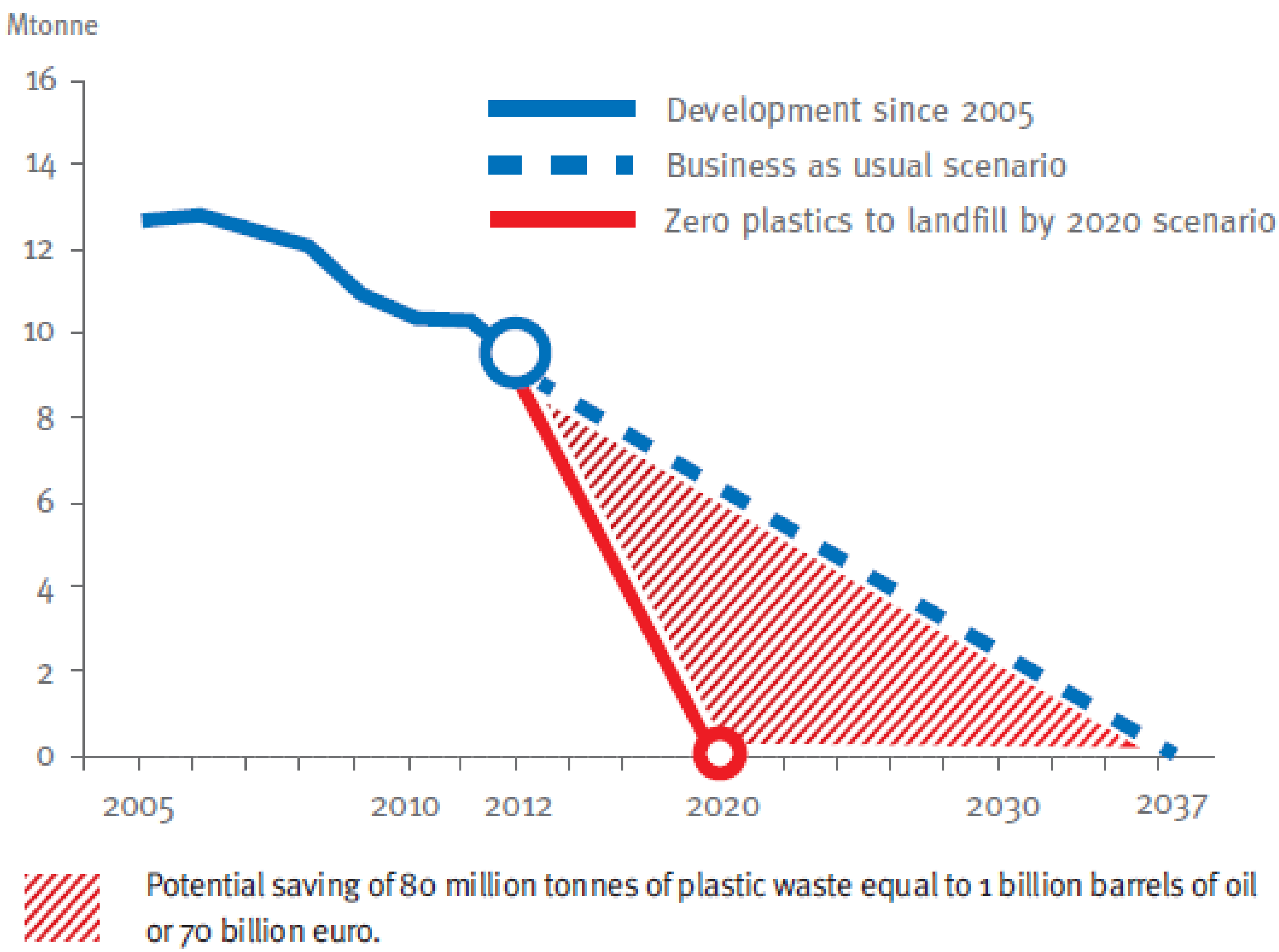
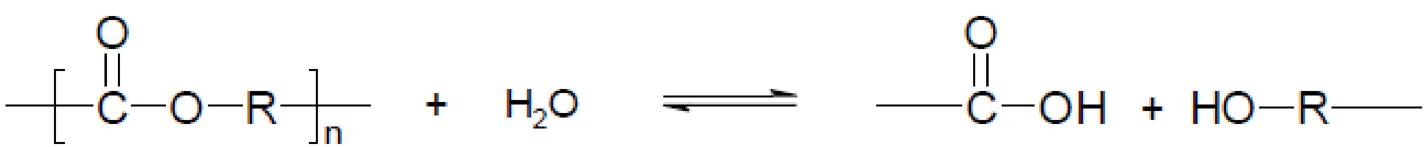


Figure 16: Zero plastics to landfill scenario

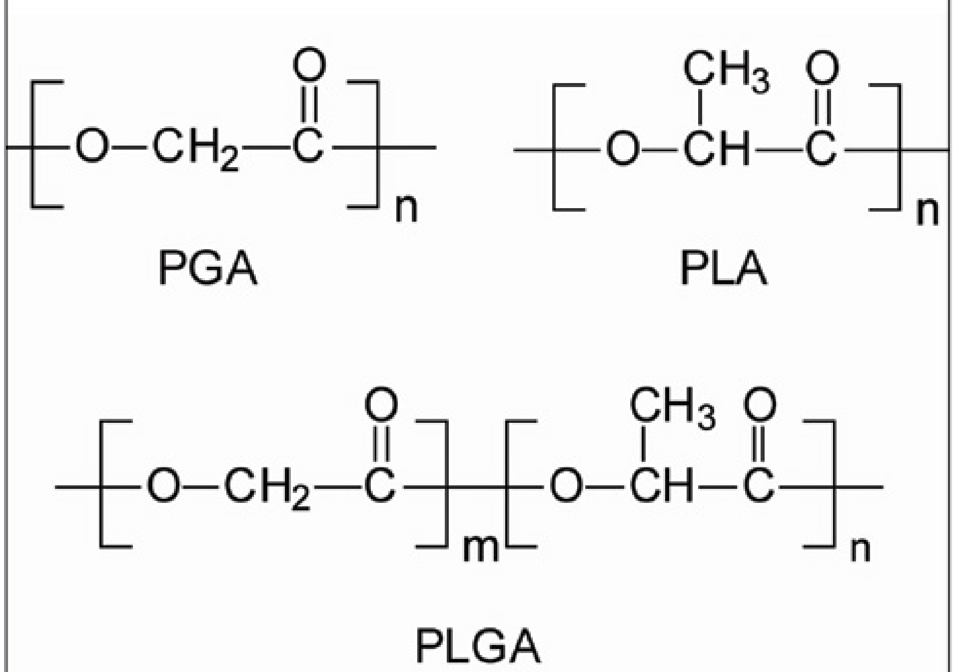
Biodegradable plastics (BPlastics)

- The traditional petroleum-derived plastics are not readily biodegradable they are resistant to microbial degradation, they accumulate in the environment.
- The biodegradable synthetic polymers are produced from feedstocks derived either from petroleum resources (non renewable resources) or from biological resources (renewable resources).
- The most commonly produced Bplastics are aliphatic polyesters that are easy to hydrolyze in the environment.



Biodegradable plastics

Chemical structure of poly(glycolic acid) (PGA), poly(lactic acid) (PLA), and poly(lactic-co-glycolic acid) (PLGA).



Plastics are biodegradable only if were marked this code (symbol of seedling).

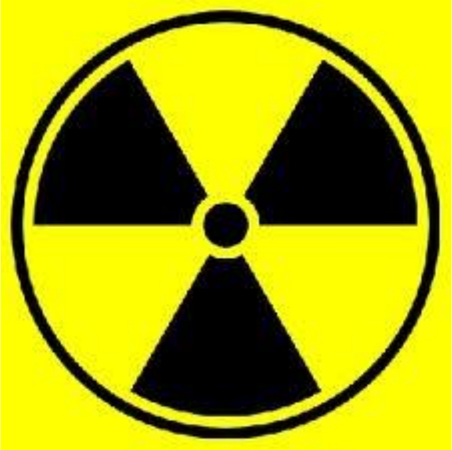
„Mater bi” - thermoplastic starch + polyesters

Biodegradable plastics

Decomposition process of plastic bottle (based on PLA) during 70-80 days

- Cost is a stumbling block for synthetically derived biodegradable plastic materials when they are directly compared with their conventional counterparts
- Mechanical properties currently produced biodegradable plastics are worse.

Radioactive waste



2007 ISO radioactivity danger logo, designed in part for long-term **radioactive waste**

Sources of radioactive waste:

- generation of power in nuclear reactors
- radionuclides from scientific research
- medical isotopes (production and using)
- production of nuclear weapons

Radioactive waste management

In general three options exist for managing:

- <u>Concentration and store</u>
- Dilute and disperse
- Wait to decay

Classification of radioactive wastes

- **High-level Waste (HLW)**

  Highly reactive, generates a significant amount of heat, contains long lived radionuclides. The only disposal option is storage in a deep geologic repository.

- **Intermediate-level Waste (ILW)**

  Require use of special shielding to assure worker safety.

- **Low-level Waste (LLW)**

  Mainly from research laboratory, hospitals and nuclear power plants. The disposal options are near surface burial.

According to guidelines of International Atomic Energy Agency IAEA

Mining and milling

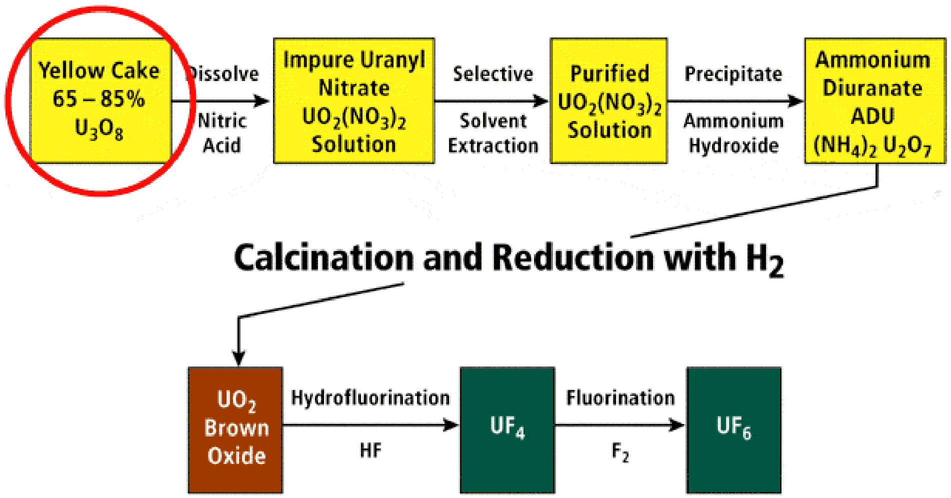
- Uranium is usually mined by either surface or underground mining techniques

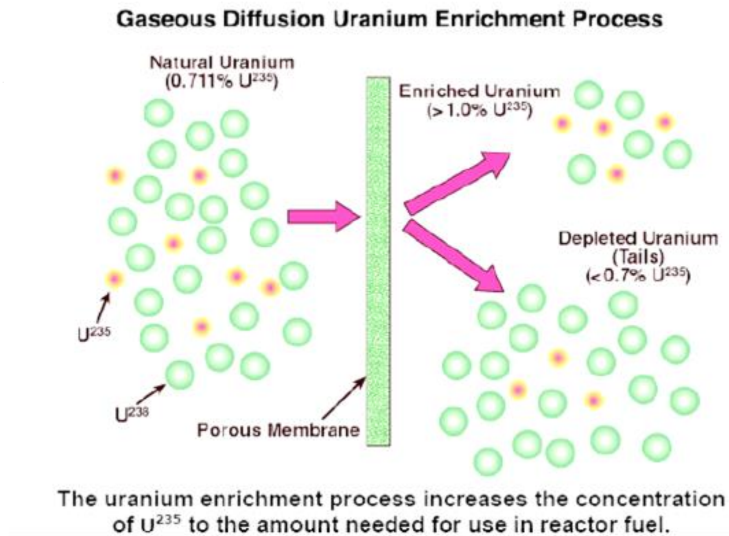
- the mined uranium ore is sent to a mill which is usually located close to the mine. At the mill the ore is crushed and ground to a fine slurry which is leached in sulfuric acid to allow the separation of uranium from the waste rock. It is then recovered from solution and precipitated as uranium oxide concentrate known as « yellow cake »,

70-90%
U_3O_8

Dr. Etienne Y. Vernaz, Nuclear waste and vitrification in France, Director of Research, CEA / Nuclear Energy Division Marcoule Marie Curie Summer School on Knowledge based Material Estremoz , Portugal 2007

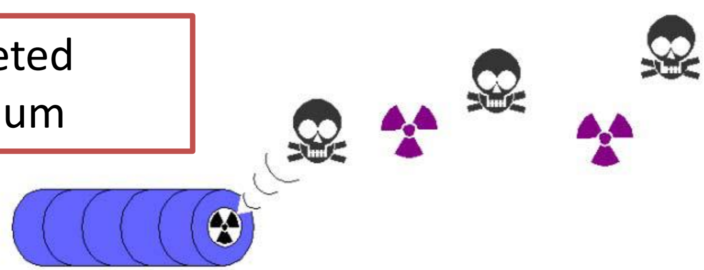
Fabrication of the fuel for nuclear reactor

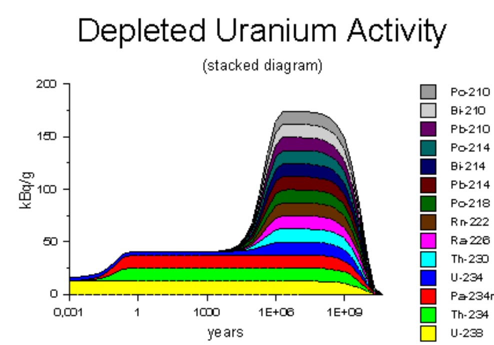




$$UF_6 + 2\,H_2O \rightarrow UO_2F_2 + 4\,HF$$

Depleted Uranium

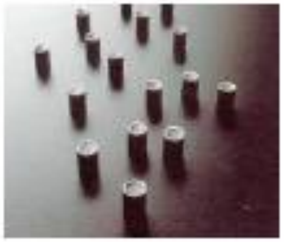




J. Degirmendžic , lecture Wpływ energetyki jądrowej na środowisko, Uniwersytet Łódzki

Fuel fabrication

1. Enriched UF_6 is converted to uranium dioxide (UO_2) and pressed into small « pellets » fritted at 1700°C
2. These ceramic pellets are inserted into thin tubes, of a zirconium alloy (zircalloy) to form « fuel rods »
3. The rods are then sealed and assembled in clusters to form « fuel assemblies »



Assemblage FRAMATOME

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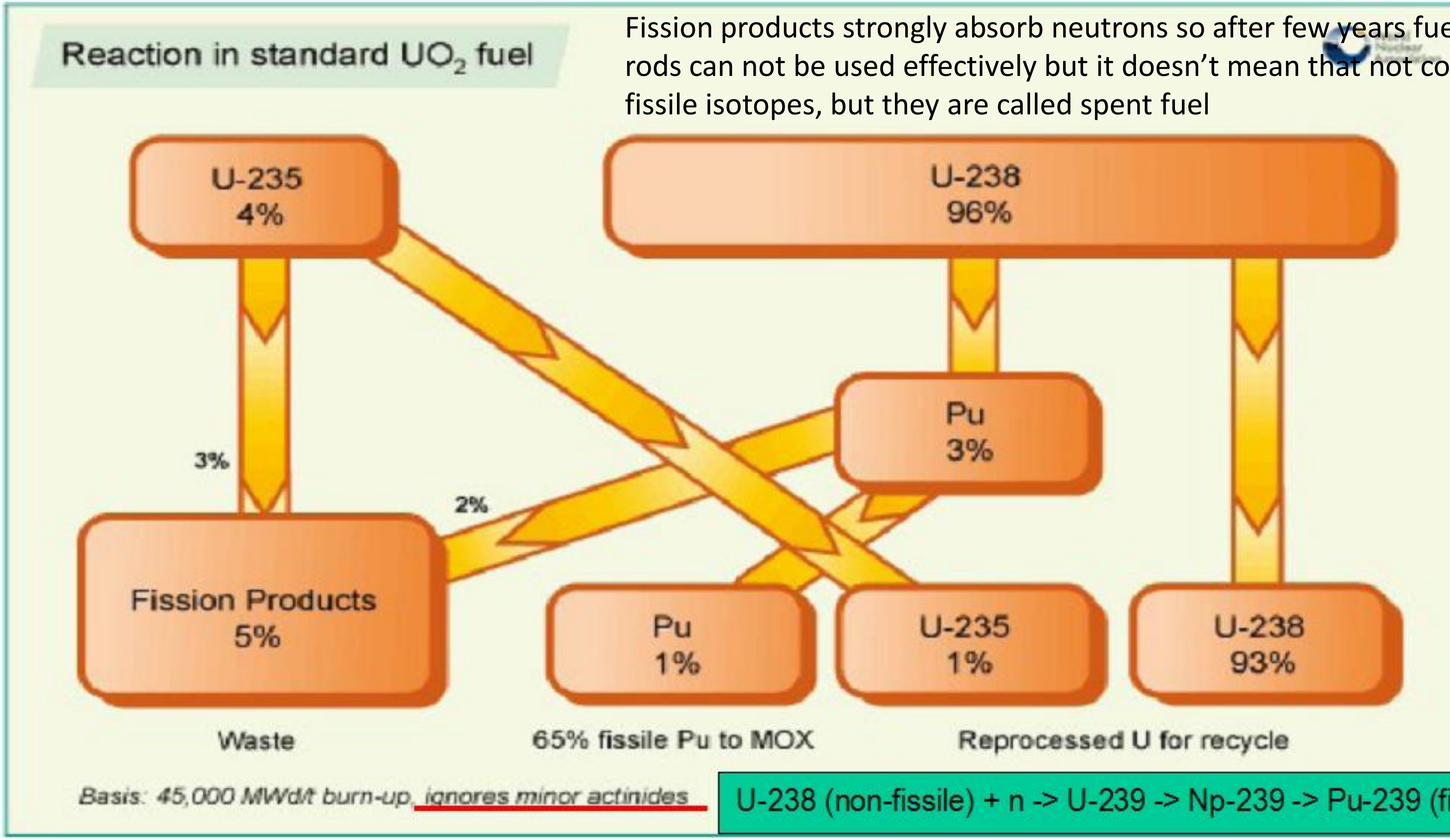
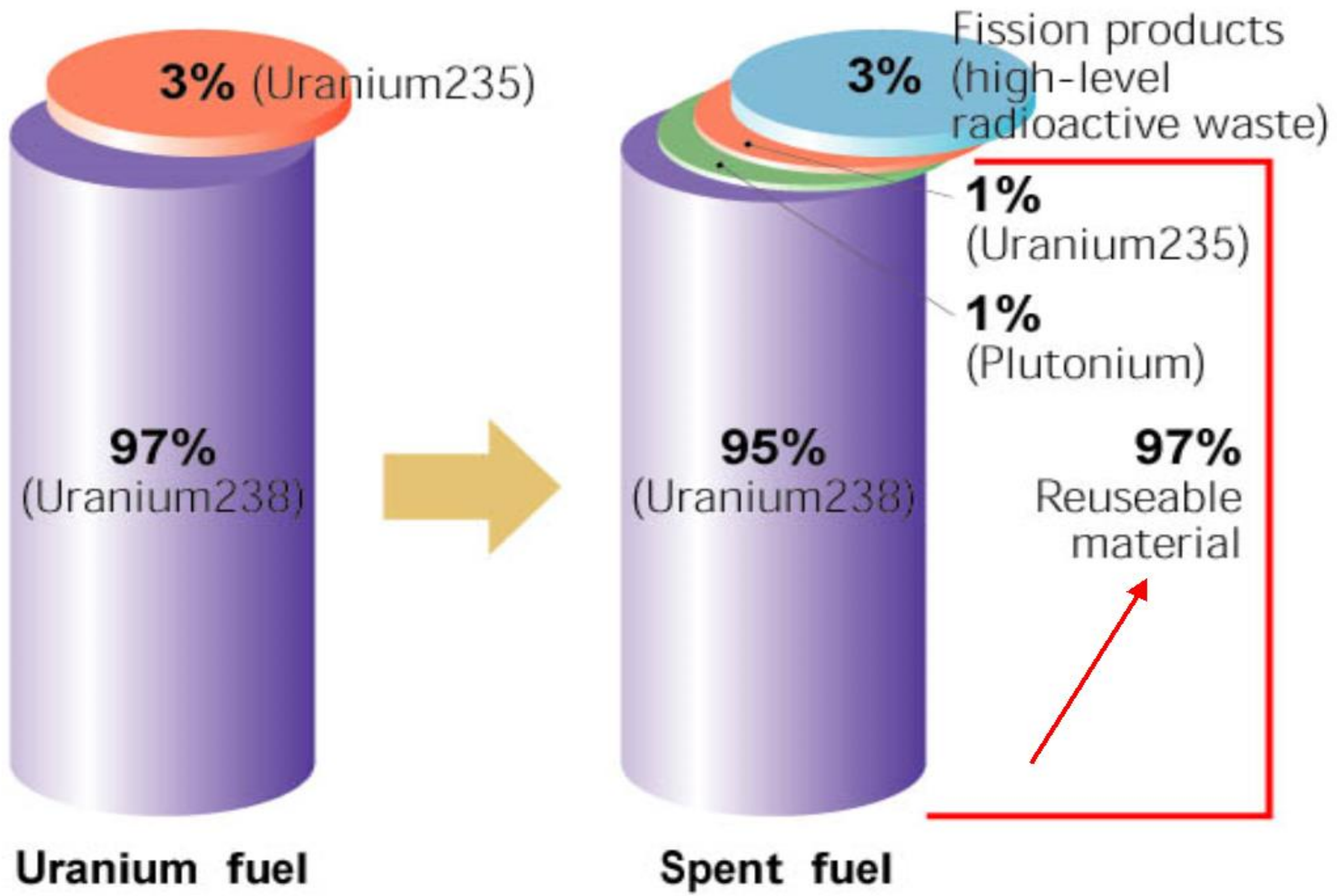
Fission products strongly absorb neutrons so after few years fuel rods can not be used effectively but it doesn't mean that not contain fissile isotopes, but they are called spent fuel



U-238 (non-fissile) + n -> U-239 -> Np-239 -> Pu-239 (fissile

Ok. 1% masy wypalonego paliwa stanowi pluton-239, powstały z konwersji U-238, ok. 96% masy stanowi uran, w przewadze U-238, U-235 jest mniej niż 0.8%. Reszta to inne produkty rozpadu: neptun, ameryk i kiur.

dr. J. Degirmendžicia , lecture „Wpływ energetyki jądrowej na środowisko", Uniwersytet Łódzki



J. Degirmendžic , lecture „Wpływ energetyki jądrowej na środowisko", Uniwersytet Łódzki

The Spent Fuel is store in a pool a few year before processing

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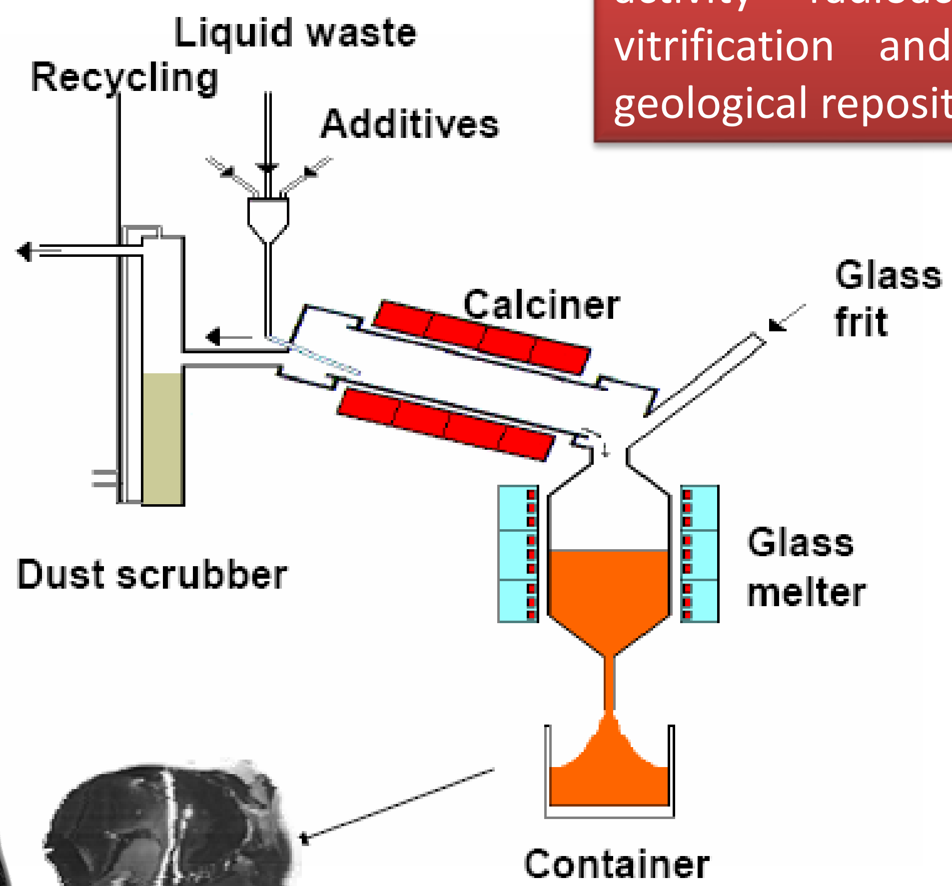
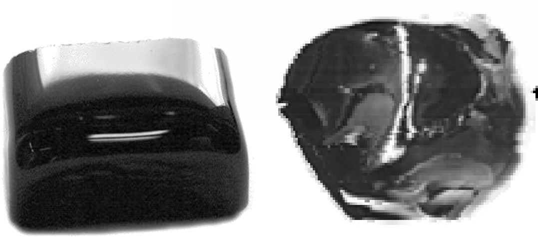
Now the best method of disposal of high level activity radioactive waste method is vitrification and further storage in deep geological repositories.





Two-step calciner / hot crucible vitrification process

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Thank you very much for your attention