INSA INSTITUT NATIONAL DES SCIENCES APPLIQUÉES LYON

deep





Sustainable solid waste management (SWM) framework

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GIRUS (2005-2007)

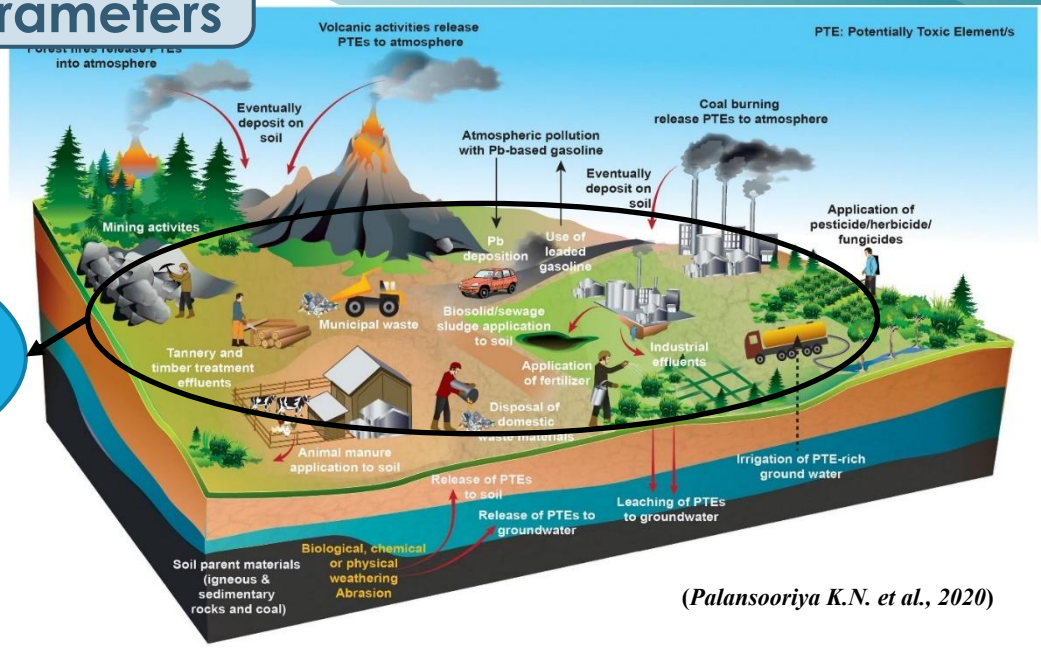
Laboratoire DEEP (Déchets, Eau, Environnement et Pollutions - Wastes Water Environment Pollutions)

Environmental engineering in the age of Anthropocene

≠ scenarios

≠ bio-physico-chemical parameters

Fate and management of complex polluted environments



(*Palansooriya K.N. et al., 2020*)

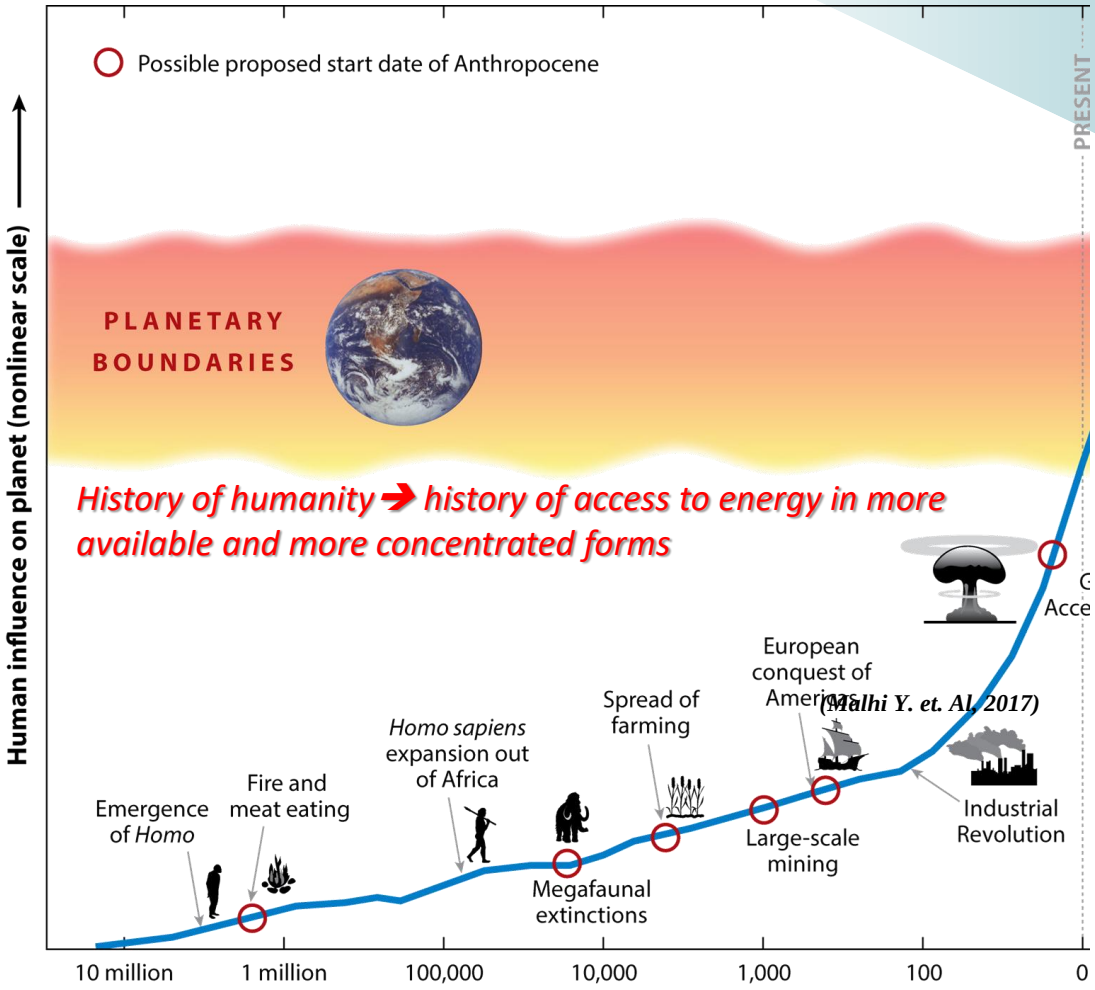
Limiting environmental impact

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PREAMBULE

« ***Anthropocene [...] marks the collision of the planet's history with that of the humanity that occupies it.*** »

[Atlas de l'Anthropocène, p. 11, F. Gemenne, A. Rankovic, atelier de cartographie de Sciences Po, presses de Sciences Po, 2019]



This **increased use of energy** is leading to:

- **Disrupting the Earth's major biogeochemical cycles**;
- **Depleting the various "stocks" of living organisms;**
- **Generate a considerable amount of waste (3.8 Gt of waste/year for OECD countries alone, according to UNEP in 2015)**.

326 Mt de déchets produits en France, en 2017

PREAMBULE



Le Monde ACTUALITÉS ÉCONOMIE VIDÉOS DÉBATS CULTURE LE GOÛT DU MONDE SERVICES S'abonner

DEBATS • LES DESSOUS DES DECHETS

Comment les déchets ont envahi tous les milieux : la folle histoire du « poubellocène »

Par Claire Legros

Publié le 02 février 2024 à 18h15, modifié le 03 février 2024 à 15h06

Lecture 12 min.

Article réservé aux abonnés

Ajouter à vos sélections

ENQUÊTE | **Alors qu'ils n'existaient pas jusqu'à la fin du XIXe siècle, les déchets ont colonisé le vivant. Au-delà des défis techniques qu'ils soulèvent, ils sont devenus un terrain d'enquête pour les sciences humaines, qui s'attachent à éclairer les systèmes et les mythes à la source de leur production.**

How waste has spread to every environment: the crazy story of "wastocene"

PREAMBLE

What do you know about waste and the resources behind it?



Activity: The Waste Fresque



Objective: To uncover the hidden environmental impact of your daily consumption by tracing the journey of the resources and waste we generate.

How it works: In this collaborative workshop, you will work in groups to connect a set of cards representing different stages of a product's life cycle. By establishing cause-effect relationships and mapping material flows, you will collectively build a visual "fresco" that reveals the complete story behind our waste.

Inspired by the "Climate Fresque" methodology.

PREAMBLE

Waste fresque

Lot 1

- **The Systemic Dilemma: Products vs. Consumption**
An analysis of the interdependent relationship between product design and consumer demand in shaping waste streams.

- **End-of-Life Pathways for Common Products**
A review of dominant waste treatment methods (landfill, incineration, recycling), their environmental consequences, and a special focus on composting as a sustainable alternative for organic waste.

- Quantifying the Impact: A Case Study of Incineration









PREAMBLE

Waste fresque

Lot 1

The **incineration of 1 ton of waste** doesn't make it disappear; it transforms it into other forms of waste:

- **Bottom Ash**: ~180 kg (often used for road base or landfilled)
- **Fly Ash** : ~30 kg (a hazardous material requiring special disposal)
- **Recovered Metals**: ~11 kg (a positive output that can be recycled)



PREAMBLE

Waste fresque

Lot 2

- Our consumption decisions determine what becomes waste.

- Distinguishing between composting (aerobic) and anaerobic digestion.

- Packaging represents up to 40% of the average household's waste stream.













PREAMBLE

Waste fresque

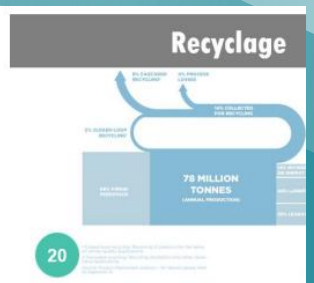
Lot 3

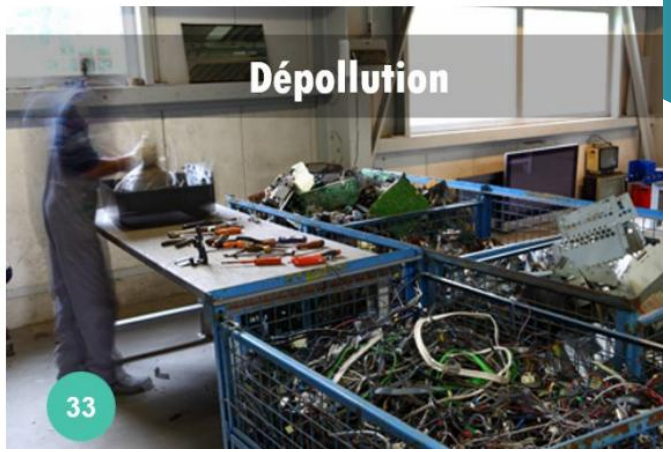
- **Our Waste Breakdown**
51% Residual Waste
29% Recycled Materials (sorted waste)
20% Dedicated Disposal (e.g., hazardous materials)

- **Treatment Pathways**
68% of residual waste is incinerated (often with energy recovery).

- **The Impact of Recycling**
Recycling **saves 23 million tons of CO_2 annually** compared to virgin material production.
Source: CITEO, 2022 (France)







PREAMBLE

Waste fresque

Lot 4

- **The European Plastic Challenge**

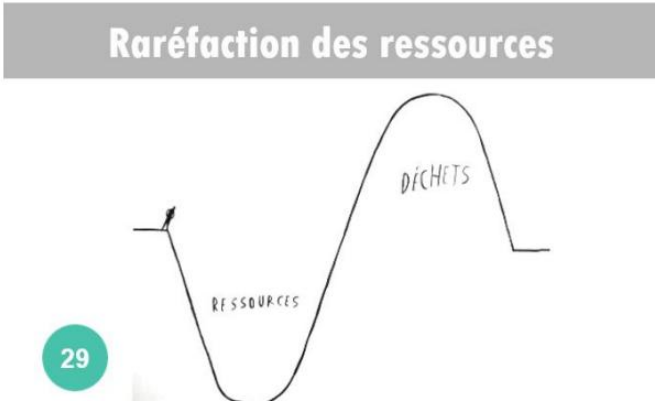
- The EU generates 30 million tons of plastic waste annually.
- Yet, only 17% is recycled—the rest is incinerated, landfilled, or leaks into the environment.





- **The Hidden Material Footprint of Technology**

- Producing a 150g smartphone requires over 70 kg of raw materials.
- That's a material footprint 600 times its final weight.



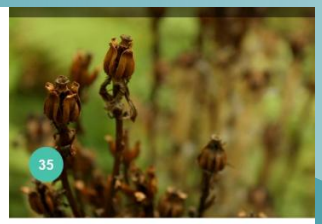
- **Approaching Planetary Boundaries**

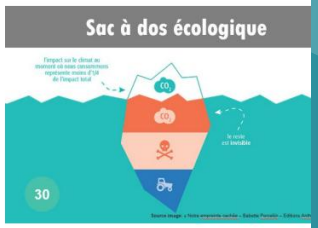
- Growing demand is accelerating resource depletion.
- We are moving closer to a critical threshold for key non-renewable materials.

PREAMBLE

Waste fresque











Lot 5

- **Waste's Contribution to Climate Change**

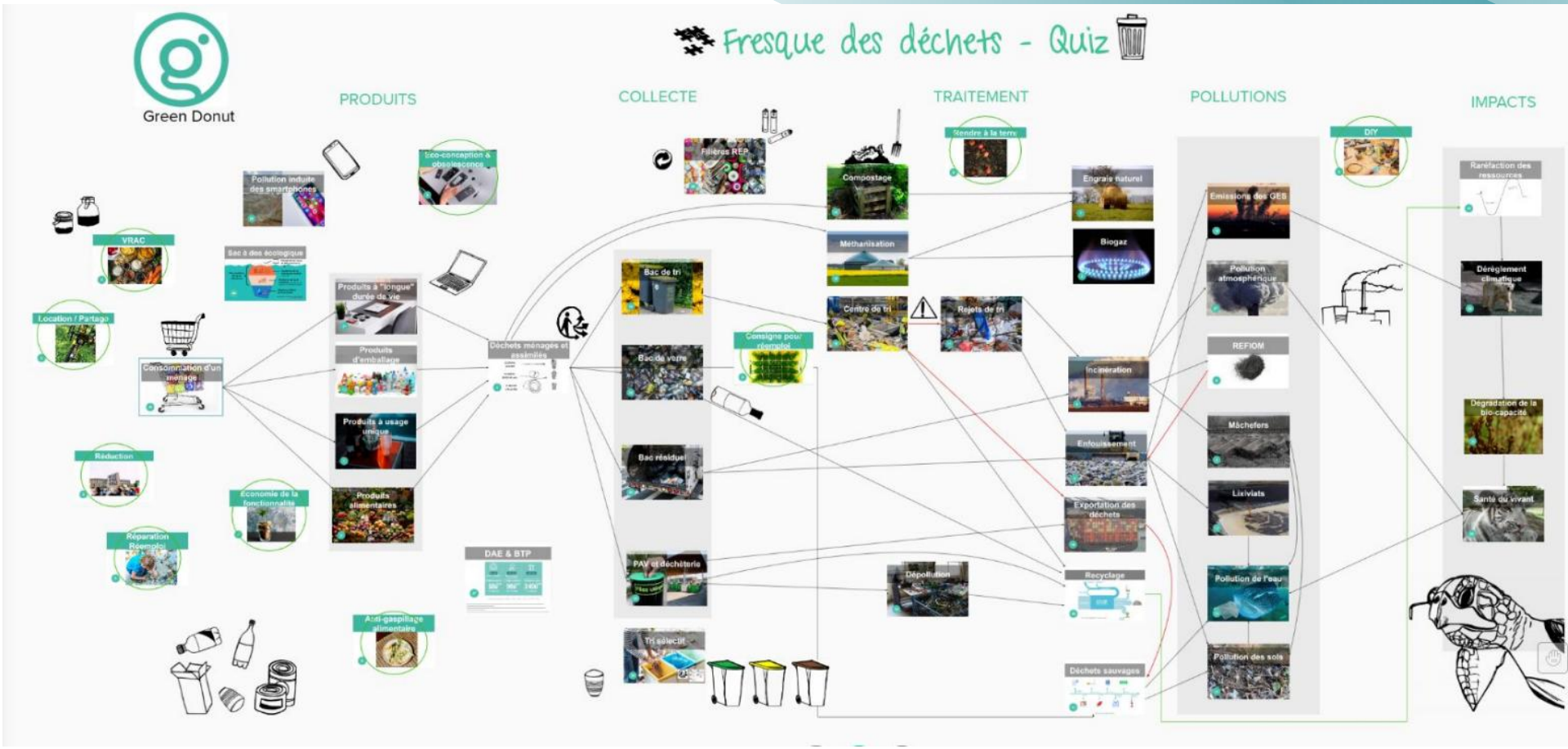
- While not the largest source, waste management is a significant emitter, responsible for 2.5% of France's total GHG emissions.
- The upstream impact of products we throw away—their "ecological backpack"—is often far greater.

- **The Hidden Weight of Consumption: The Ecological Backpack**

The "Ecological Backpack" is the total weight of natural resources (water, soil, minerals) extracted and moved to create a product.
Example: A 5g gold ring has a backpack of over 3 tons of mined ore.
This "hidden" upstream impact is a major, but often overlooked, driver of climate change.

PREAMBLE

Waste fresque



LECTURES OVERVIEW



- **Introduction - Waste system**
- Classification and current legislation
- Sustainable waste management

PREAMBLE



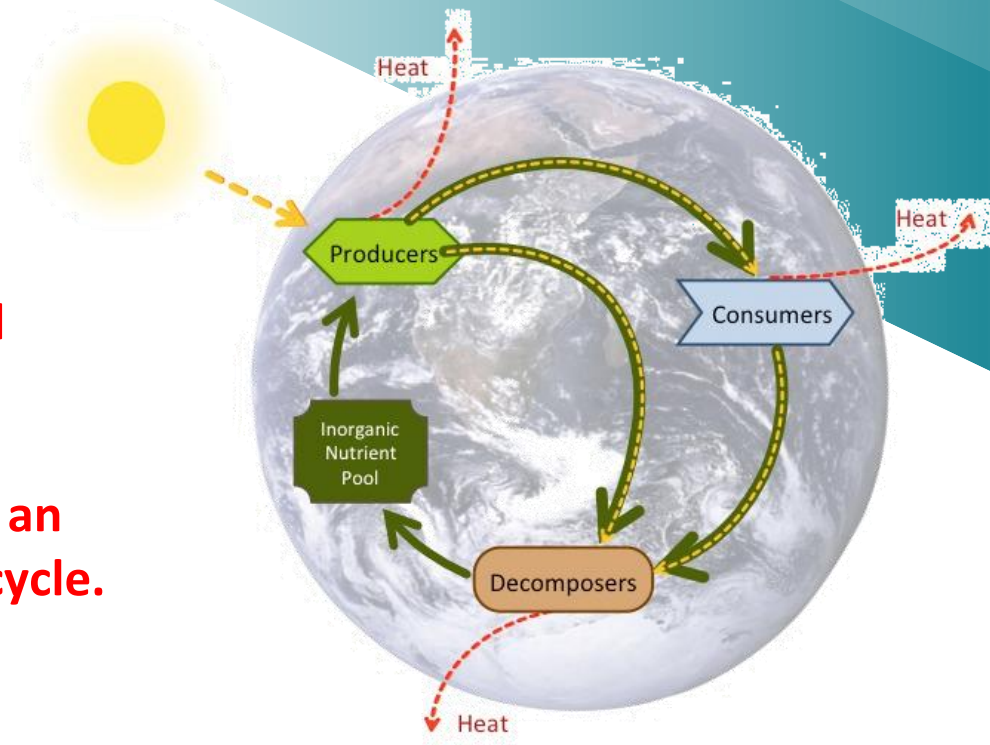
How should Europe manage its waste?

Europe must reduce landfilling and food waste while improving the management and recycling of packaging waste. These are among the main objectives of European waste .

WASTE SYSTEM

ORIGIN OF WASTES

1- Natural reason - existence of major biogeochemical cycles (C, N, S, O…)



A Delicate Balance: The system only functions if producers, consumers, and decomposers are in equilibrium.

Nature's Lesson: Decomposers are not an afterthought—they are a pillar of the cycle.

The Warning: Their decline, like the catastrophic drop in earthworm populations in Brittany, risks a total systemic collapse.

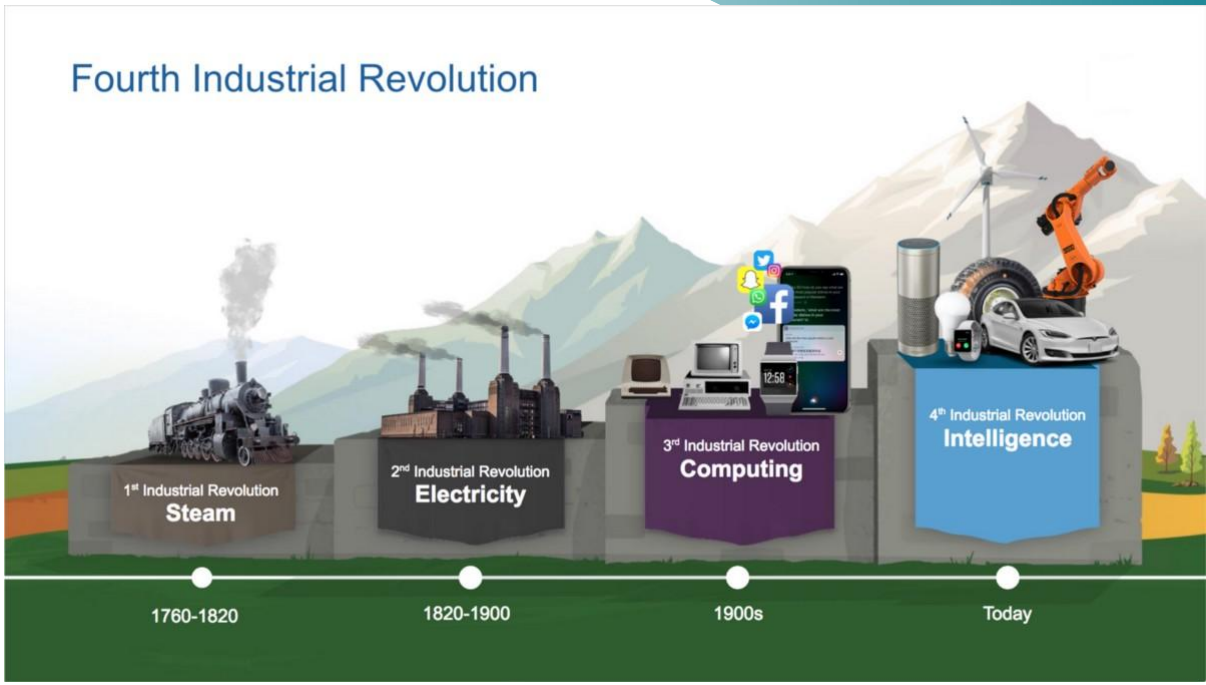
WASTE SYSTEM

ORIGIN OF WASTES

2- Industrial reason – industrial revolutions

- Explosive arrival of energy (first coal, oil; then gas and uranium)

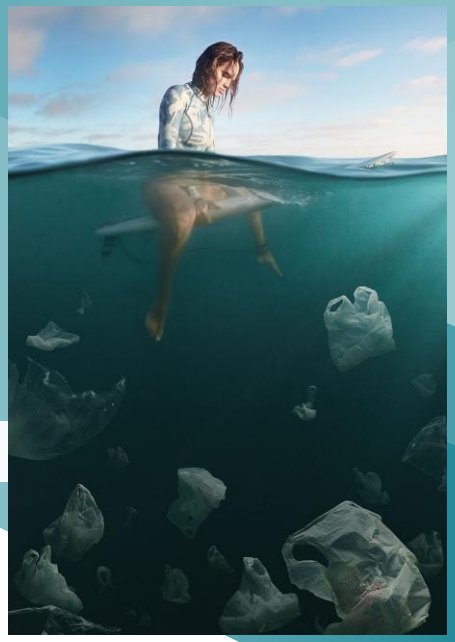
Nothing was a limit to the expansion of production.



Mountain of products that have accumulated everywhere, industrial waste first and then urban waste

WASTE SYSTEM

ORIGIN OF WASTES



3- Chemical reason

- Synthetic chemistry from petroleum but also from plants

➢ **The Petroleum Revolution: A Double-Edged Sword**

From crude oil, we engineered an explosion of new materials: **plastics, synthetic rubbers, textiles, pharmaceuticals, and dyes**.

This created an unprecedented diversity and quantity of novel substances.

➢ **The Fundamental Flaw: A Broken Cycle**

Unlike natural materials, these synthetic products were **foreign to Earth's ecosystems**.

Nature, having never encountered them, **lacks the biological processes to break them down**.

➢ Result: they persist indefinitely as pollution, a legacy of our innovation.

➢ ➔ **The core issue: a catastrophic lack of biodegradability.**

WASTE SYSTEM

ORIGIN OF WASTES



4- Urban development and consumer society

Explosion of products, explosion of materials and correlative explosion of waste

The Drivers of Europe's Waste Generation

☑ **Rising Wealth & Consumption:** Higher living standards drive increased purchasing and waste generation.

🏠 **Demographic Shifts:** More single-person households, which have a higher *per capita* waste output.

🔄 **Changed Consumption Patterns:**

- Proliferation of single-use and disposable products.
- Products designed with **shorter lifespans** (planned obsolescence).
- An overwhelming abundance of consumer choice.

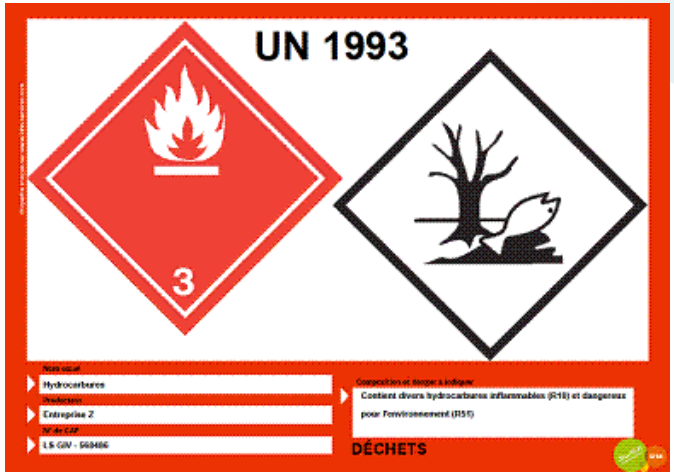
"As Europe has grown wealthier, it has created more and more waste."

WASTE SYSTEM



- **No satisfactory waste definition.**
- **Depending on the actors involved and the context to which we refer, the notion of waste may cover objects of different natures and functions.**
- **Each definition aims to establish, for a given stakeholder group, the set of targets that must be met with particular behavior or attention, but it is ultimately the legal definition that must serve as a reference.**

WASTE SYSTEM



Regulatory approach

Code de l'environnement : Art L 541-1 (15 juillet 1975)

« For the purposes of the present law, "waste" means any residue of a production, transformation or use process, any substance, material, product or, more generally, any movable resource discarded or intended for discarding by its holder ».

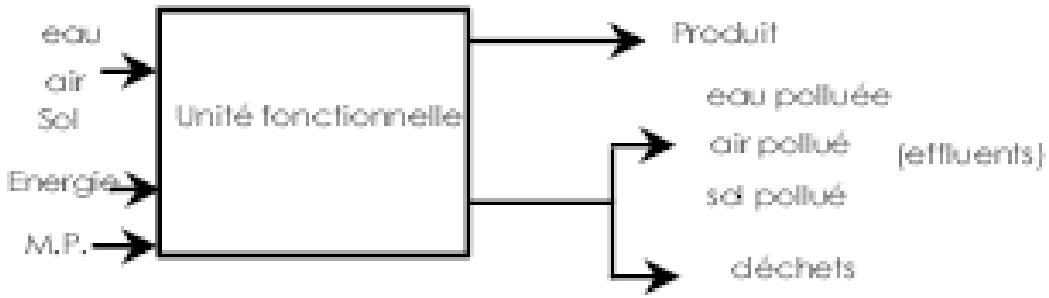
European Directive of March 18, 1991

WASTE SYSTEM



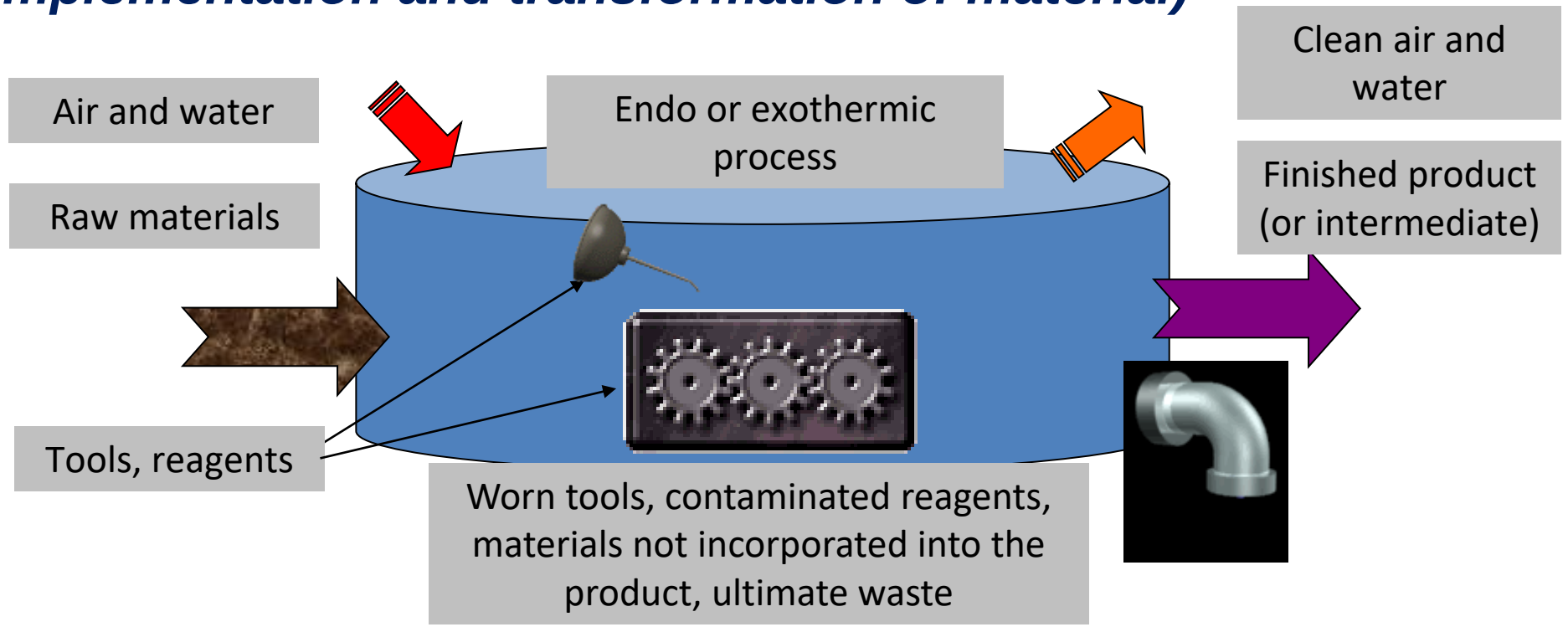
Functional approach

« Waste is then considered as a flow of material from a functional unit, representing an activity or set of activities »



WASTE SYSTEM

Nature of waste : Concept of reactor (unitary operation of implementation and transformation of material)



- **Waste vs Effluents**
  - Effluents : continuous production via a liquid or gaseous outfall (sewer, chimney, etc.)
  - Waste : batch production (solids or liquids, rarely gaseous)
  - Common characteristic: composition and characteristics not voluntarily controlled by the process (difference with co-product)

WASTE SYSTEM

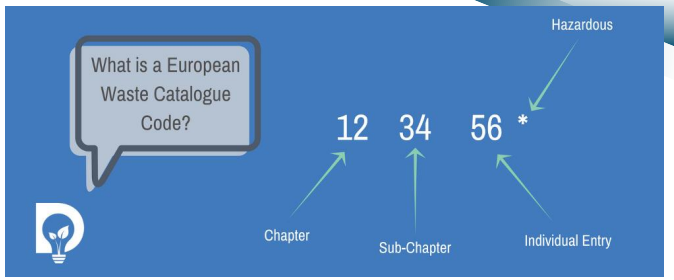
Nature of waste : Concept of reactor (unitary operation of implementation and transformation of material)

Most modern industrial systems are evolving towards an ideal model that prioritizes:

- **Informed material selection.**
- **Energy and material efficiency.**
- **Recycling and circularity.**
- **Minimizing hazardous substances.**

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CLASSIFICATION OF WASTE



A large variety of definitions and classification approaches are used.
Defining waste can at times also be a case-by-case decision.
The national waste regulation is the main reference point in this regard.

Waste can be characterized (and classified) by its nature, but also by its producer, its method of collection, the organization that supports it, or a mix of these concepts.

Classification according to the waste producer

- **"household waste", the initial producer of which is a household**;
- **"waste from economic activities" (DAE), the initial producer of which is not a household.**

CLASSIFICATION OF WASTE

Classification of waste by origin



Source: National Audit Office of Estonia

CLASSIFICATION OF WASTE

Classification according to waste nature

Here are two main categories of waste according to the risk they pose to humans or the environment.

- **hazardous waste** ;

- **non-hazardous waste** (paper, plastics, metals, organic waste…)**.**

In this last category, we also distinguish **inert waste**, which is neither chemically nor biologically reactive and will not decompose or only very slowly.

CLASSIFICATION OF WASTE

Hazardous waste - Particularities

Hazardous waste is generated by many sectors, including industry, healthcare, households and construction; its classification depends on its hazardous properties, not only on its origin.

- **E-waste** : from electric and electronic equipment such as end-of-life computers, phones and home appliances. (PCB, metals…).

- **Medical waste** : from the human and animal healthcare systems (medicines, chemicals, pharmaceuticals…). It could be infectious, toxic or radioactive or contain bacteria and harmful microorganisms.

- **Radioactive waste**, with a special management and regulation.

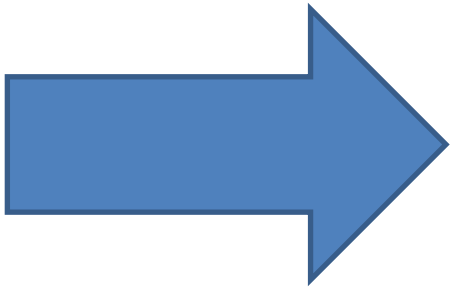
GENERAL STRATEGY OF WASTE MANAGEMENT

Paradigm shift from Waste Management to Resource Management

20th CENTURY

WASTE MANAGEMENT

"How do we get rid of our waste efficiently with minimum damage to public health and the environment?"



21st CENTURY

RESOURCE MANAGEMENT

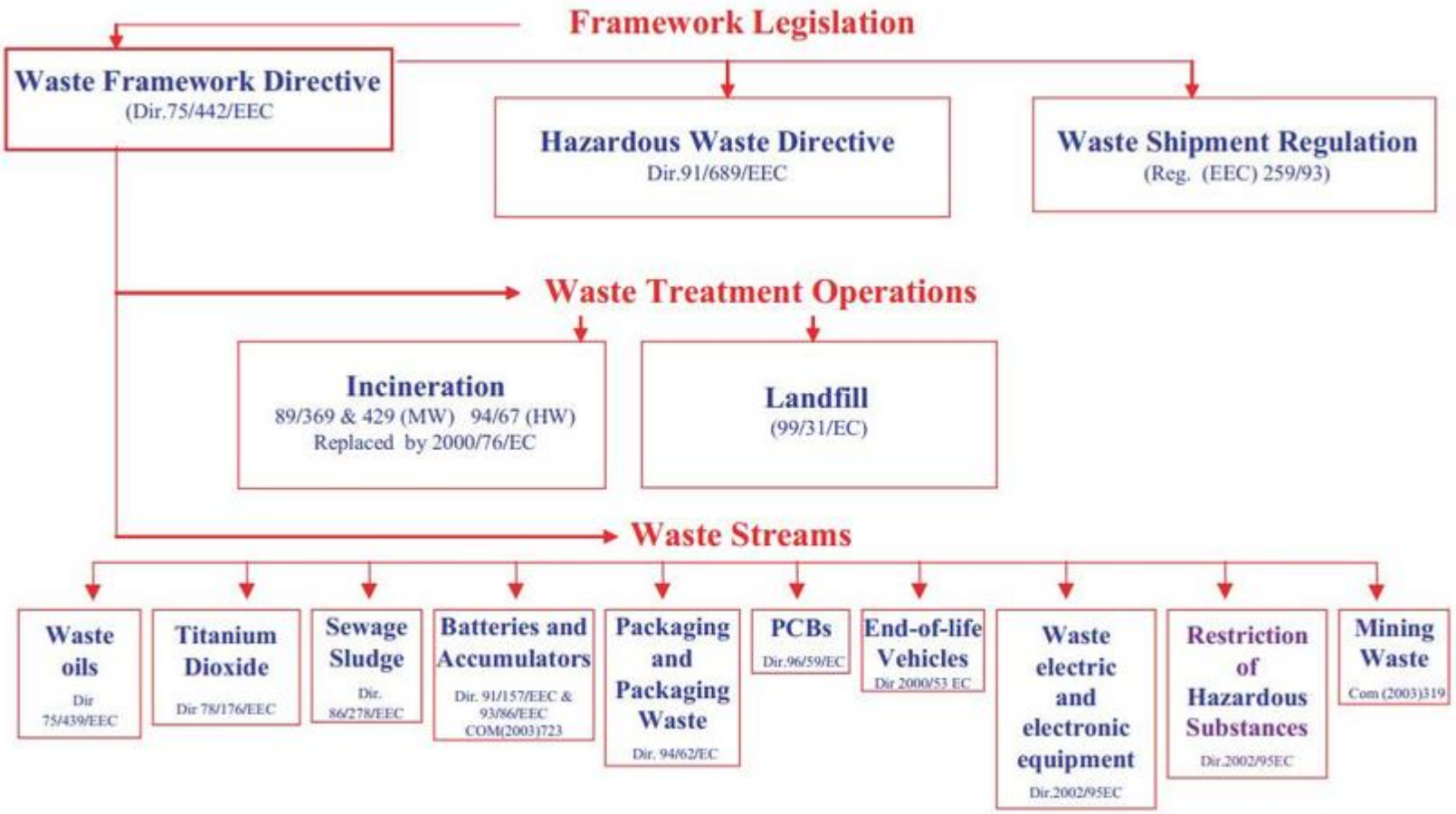
"How do we handle our discarded resources in ways which do not deprive future generations of some, if not all, of their value?"

LECTURES OVERVIEW



- Introduction - Waste system
- **Classification and current legislation**
- Sustainable waste management

EC WASTE LEGISLATION



– **horizontal** legislation;

– legislation on **waste treatment operations**;

– legislation on **specific waste streams**.

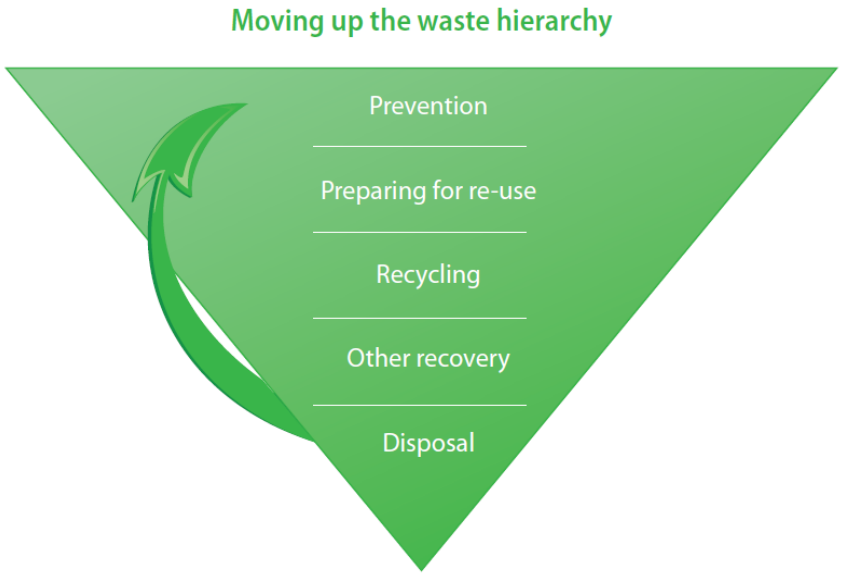
HORIZONTAL LEGISLATION

Horizontal legislation establishes the overall framework for the management of waste.

Council **directive 75/442/EEC of 15 July 1975 on waste** (the "**waste framework directive**" or **WFD**) includes the main definitions and principles concerning waste management. It was comprehensively revised in 1991, 1996 and again in 2008 and finally in 2018 (**Directive (EU) 2018/851**).

https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.150.01.0109.01.ENG

WASTE FRAMEWORK DIRECTIVE



In essence, the WFD requires Member States to give priority to

- **Waste prevention** and to
- **encourage re-use and recovery of waste**.

- Member States must also ensure that waste is recovered and disposed of **without endangering human health** and
- **without using processes or methods which could harm the environment**.

- The directive also requires Member States to draw-up **waste management plans** and to establish a system for the authorization of waste management installations.

WASTE FRAMEWORK DIRECTIVE

The WFD defines : "**Waste means any substance or object that the holder discards, intends to discard, or is required to discard**." Annex I of the WFD lists 16 categories of waste.

In practice, waste classification is based on the European List of Waste, which assigns six-digit codes and identifies hazardous entries with an asterisk.

Finally, the Waste Framework Directive (EU) 2008/98/EC (updated in 2018 - Directive (EU) 2018/851) sets criteria for By-products and End of Waste process

- ✓ *By-product is a substance or object, resulting from a production process, the primary aim of which is not the production of that item. By-products can come from a wide range of business sectors, and can have very different environmental impacts. An incorrect classification could be the cause of environmental damage or unnecessary costs for business.*

Examples: lacto-serum in a cheese factory, beet pulp from the production of sugar, HCl in aqueous solution from the manufacture of lubricant additive, etc.

WASTE FRAMEWORK DIRECTIVE

What are the end-of-waste criteria, and why are they needed?

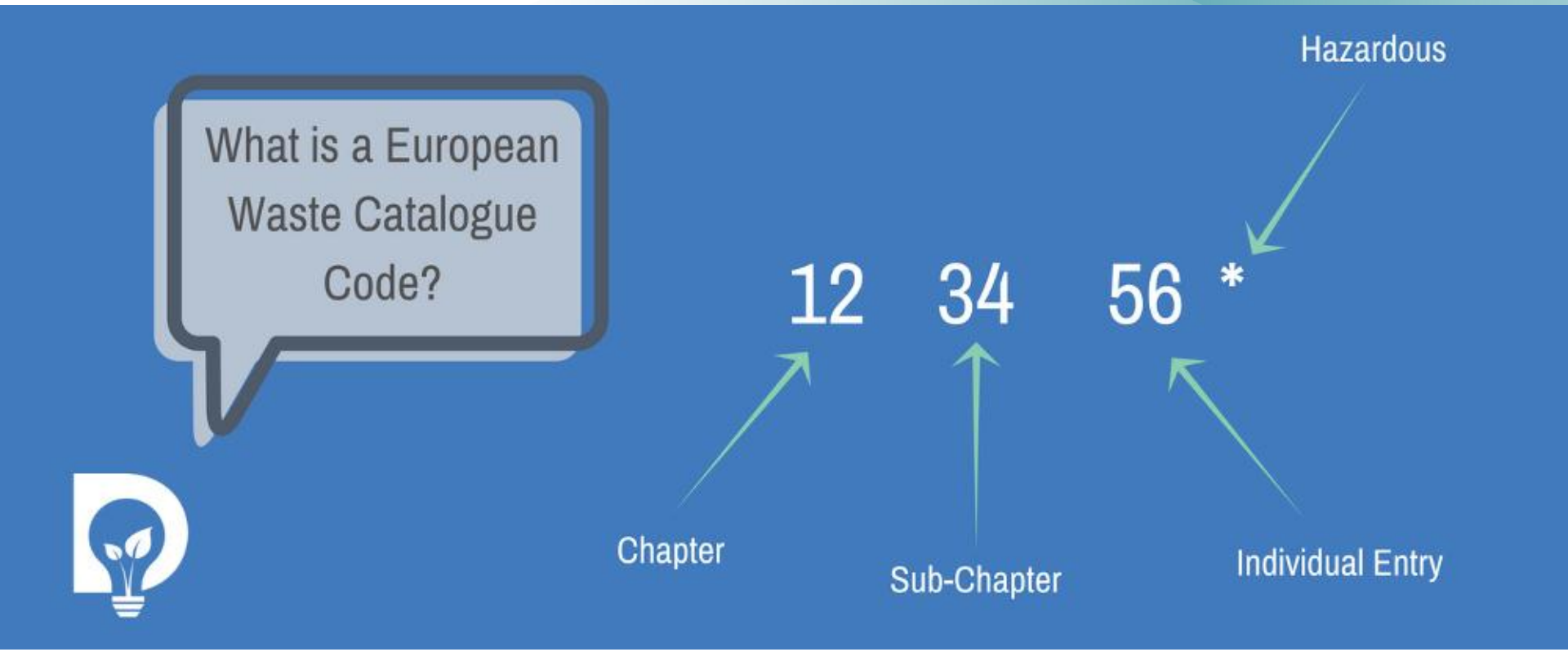
The material must have a specific use, an existing market or demand, comply with applicable technical and legal requirements, and not cause overall adverse environmental or human-health impacts.

According to Article 6 of the WFD 2008/98/EC, certain specified waste shall cease to be waste when it has undergone a recovery (including recycling) operation and complies with specific criteria to be developed in line with certain legal conditions, in particular:

- *the substance or object is commonly used for specific purposes;*
- *there is an existing market or demand for the substance or object;*
- *the use is lawful (substance or object fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products);*
- *the use will not lead to overall adverse environmental or human health impacts.*

Examples: a plywood panel made with a certain percentage of packaging wood chips, a fleece jacket made from waste plastic bottles ...

WASTE FRAMEWORK DIRECTIVE



An EWC Code is a 6-digit code used to identify waste as listed in the EWC. It is formatted as 3 pairs of numbers, for example 12 34 56.
It identifies and classifies waste into categories according to how these wastes have been produced. It adequately describes the waste being transported, handled or treated.

WASTE FRAMEWORK DIRECTIVE

Hazardous Waste Directive & Waste Shipment regulation

Council directive 91/689/EEC of 12 December 1991 on hazardous waste, as amended, complements the WFD for hazardous waste.
Annex III of the directive lists 15 properties of waste which render them hazardous within the meaning of the directive.

The directive also contains substantive requirements concerning, for example :

- ✓ the **permitting of installations handling hazardous waste**.
- ✓ **it contains additional requirements concerning**, for example,
  - **limitations of mixing** of hazardous waste,
  - **record keeping** and the **shipment of waste at national level**, which must be accompanied by a **tracking form**.

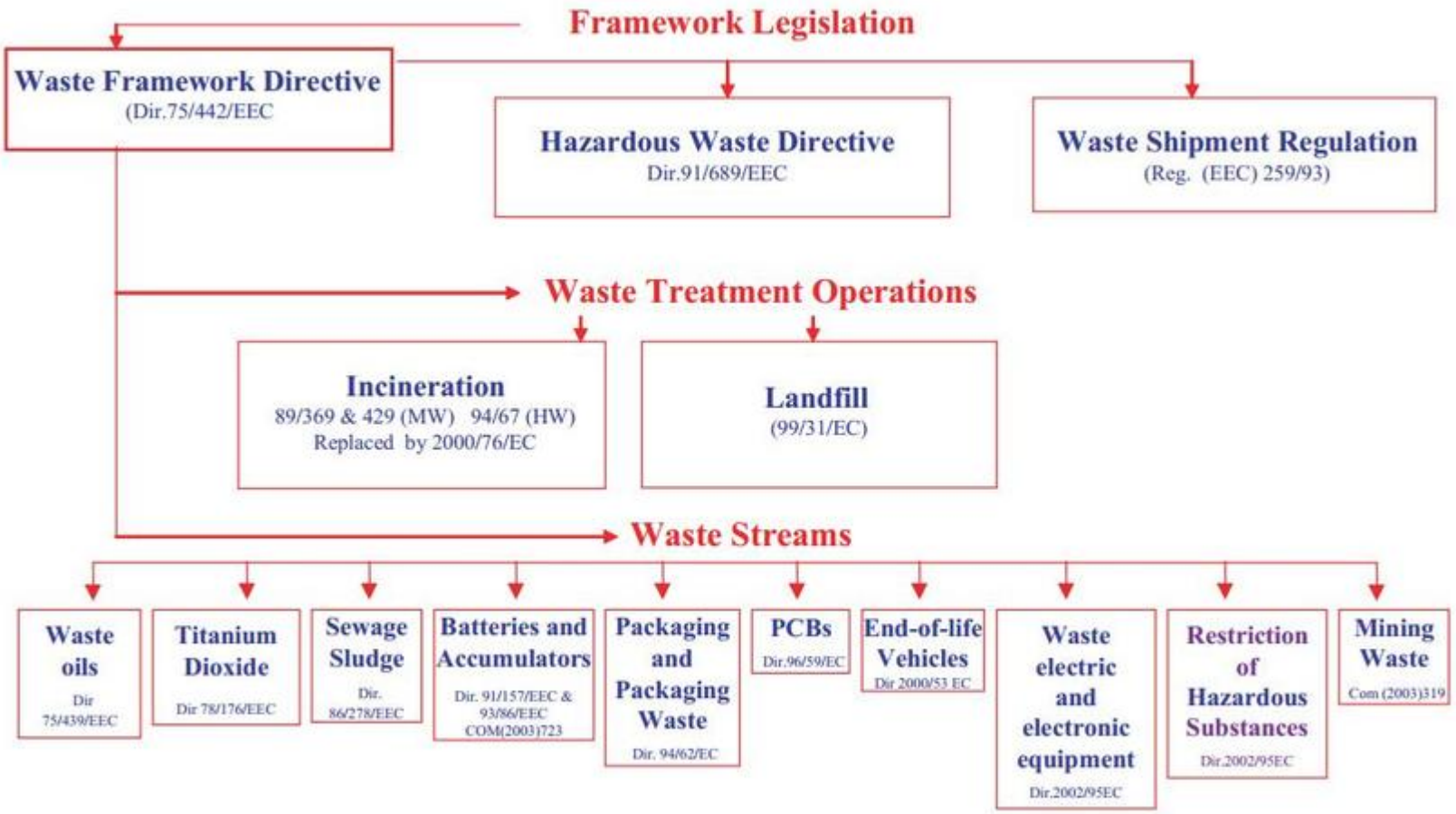
The Community has also adopted legislation concerning the **cross-border shipment of waste.** The main legal instrument in this field is **Council regulation (EEC) No 259/93 of 1 February 1993 on the supervision and control of shipments of waste** within, into and out of the European Community, as amended.

Hazardous waste – List of hazardous properties

H1	"Explosive": substances and preparations which may explode under the effect of flame or which are more sensitive to shocks or friction than dinitrobenzene.
H2	"Oxidising": substances and preparations which exhibit highly exothermic reactions when in contact with other substances, particularly flammable substances.
H3A	"Highly Flammable" - liquid substances and preparations having a flashpoint of below 21°C (including extremely flammable liquids), or - substances and preparations which may become hot and finally catch fire in contact with air at ambient temperature without any application of energy, or - solid substances and preparations which may readily catch fire after brief contact with a source of ignition and which continue to burn or to be consumed after removal of the source of ignition, or - gaseous substances and preparations which are flammable in air at normal pressure, or - substances and preparations which, in contact with water or damp air, evolve highly flammable gases in dangerous quantities.
H3B	"Flammable": liquid substances and preparations having a flashpoint equal to or greater than 21°C and less than or equal to 55°C.
H4	"Irritant": non-corrosive substances and preparations which, through immediate, prolonged or repeated contact with the skin or mucous membrane, can cause inflammation.

H5	"Harmful": substances and preparations which, if they are inhaled or ingested or if they penetrate the skin, may involve limited health risks.
H6	"Toxic": substances and preparations (including very toxic substances and preparations) which, if they are inhaled or ingested or if they penetrate the skin, may involve serious, acute or chronic health risks and even death.
H7	"Carcinogenic": substances and preparations which, if they are inhaled or ingested or if they penetrate the skin, may induce cancer or increase its incidence.
H8	"Corrosive": substances and preparations which may destroy living tissue on contact.
H9	"Infectious": substances containing viable micro-organisms or their toxins which are known or reliably believed to cause disease in man or other living organisms.
H10[2]	"Toxic for reproduction": substances and preparations which, if they are inhaled or ingested or if they penetrate the skin, may produce or increase the incidence of non-heritable adverse effects in the progeny and/or of male or female reproductive functions or capacity.
H11	"Mutagenic": substances and preparations which, if they are inhaled or ingested or if they penetrate the skin, may induce hereditary genetic defects or increase their incidence.
H12	Substances and preparations which release toxic or very toxic gases in contact with water, air or an acid.
H13	Substances and preparations capable by any means, after disposal, of yielding another substance, e.g. a leachate, which possesses any of the characteristics listed above.
H14	"Ecotoxic": substances and preparations which present or may present immediate or delayed risks for one or more sectors of the environment.
HP 15	'Yielding another substance': waste capable of exhibiting a hazardous property listed above not directly displayed by the original waste.

EC WASTE LEGISLATION



– horizontal legislation;

– legislation on waste treatment operations;

– legislation on specific waste streams.

LEGISLATION ON WASTE TREATMENT OPERATIONS

Landfill

Directive 1999/31/EC of 26 April 1999 on the landfill of waste ("the landfill directive") sets out a number of administrative requirements, including:

- **permit conditions**,
- **technical requirements** and **environmental standards** applying to landfills accepting various categories of waste (**inert, non-hazardous and hazardous waste**),
- **reduction of biodegradable waste** disposed of in landfills,
- **banning of the landfilling of certain types of waste**, such as liquid wastes, infectious waste and most tires.

LEGISLATION ON WASTE TREATMENT OPERATIONS

Landfill terminology

Use consistently:

- **landfill** for the general facility;
- **landfill cell** for a specific engineered compartment;
- **leachate** rather than “lixiviate”;
- **landfill gas** or **biogas** depending on the context;
- **hazardous-waste landfill / non-hazardous-waste landfill / inert-waste landfill**.

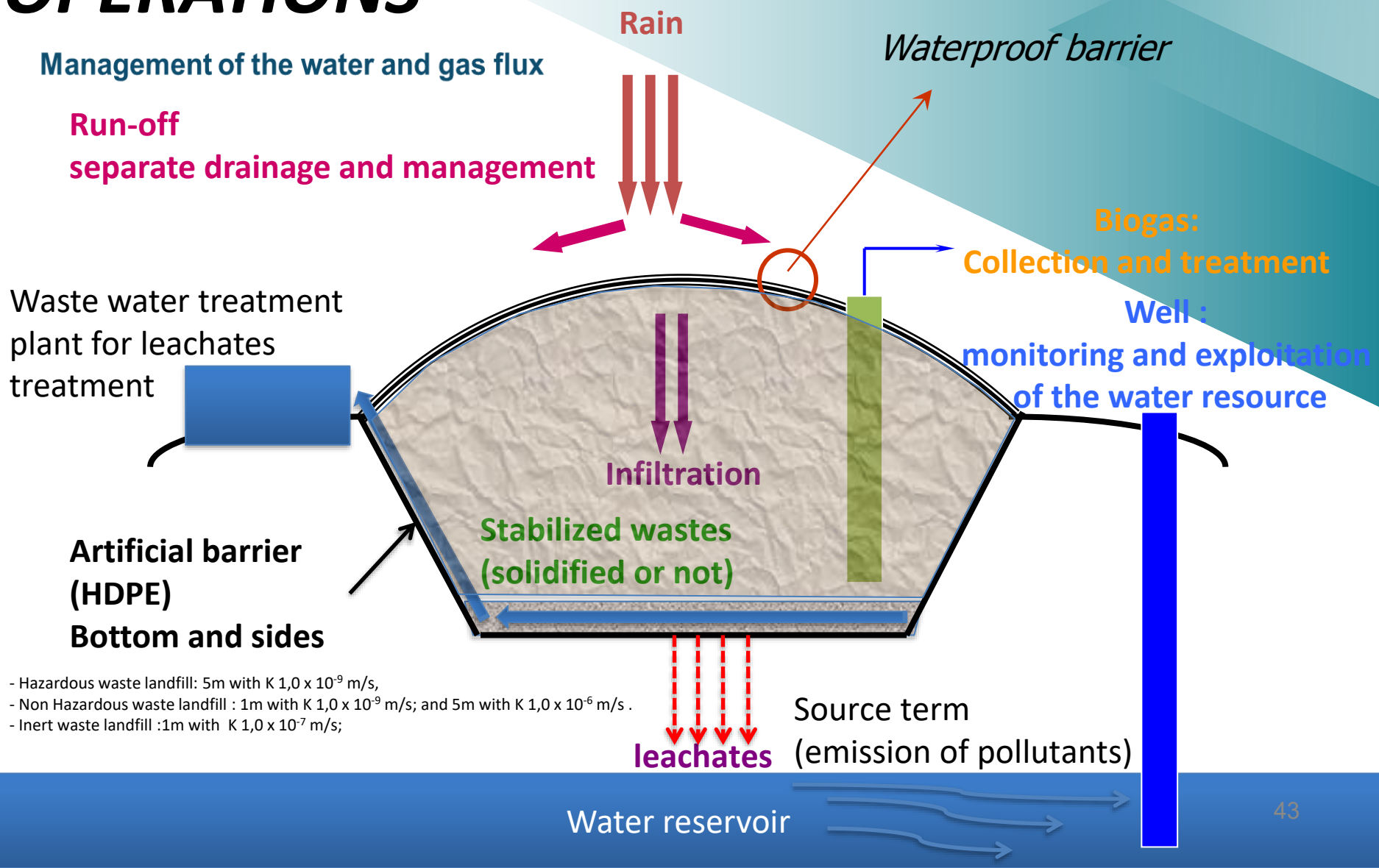
LEGISLATION ON WASTE TREATMENT OPERATIONS

Main principles to ensure environmental protection

The landfill directive also requires **all costs** relating to the **establishment, operation and closure of a landfill** are **internalized into the price charged by the operator**.

Description and illustration of **general criteria** for the Landfill Directive in order to protect the environment

LEGISLATION ON WASTE TREATMENT OPERATIONS



LEGISLATION ON WASTE TREATMENT OPERATIONS

Criteria for the limitation of the source term (via the leaching of waste prior to acceptance)

	L/S=10 l/kg dry matter in mg/kg			C_0 (essai de percolation) mg/l		
	inertes	non dangereux	dangereux	inertes	non dangereux	dangereux
As	0,5	2	25	0,06	0,3	3
Ba	20	100	300	4	20	60
Cd	0,04	1	5	0,02	0,3	1,7
Cr total	0,5	10	70	0,1	2,5	15
Cu	2	50	100	0,6	30	60
Hg	0,01	0,2	2	0,002	0,03	0,3
Mo	0,5	10	30	0,2	3,5	10
Ni	0,4	10	40	0,12	3	12
Pb	0,5	10	50	0,15	3	15
Sb	0,06	0,7	5	0,1	0,15	1
Se	0,1	0,5	7	0,04	0,2	3
Zn	4	50	200	1,2	15	60
Chlorures	800	15 000	25 000	460	8500	15 000
Fluorures	10	150	500	2,5	40	120
Sulfates	1 000,00	20 000	50 000	1500	7000	17 000
Indice phénols	1	-		0,3	-	
COT sur éluat **	500	800	1000	160	250	320
FS (fraction soluble)***	4 000	60 000	10 000	-	-	

10%

LEGISLATION ON WASTE TREATMENT OPERATIONS



The makeover of one of Europe's largest landfills

https://www.youtube.com/watch?v=c36kP3vp_kk

International Finance Corporation

LEGISLATION ON WASTE TREATMENT OPERATIONS

Incineration

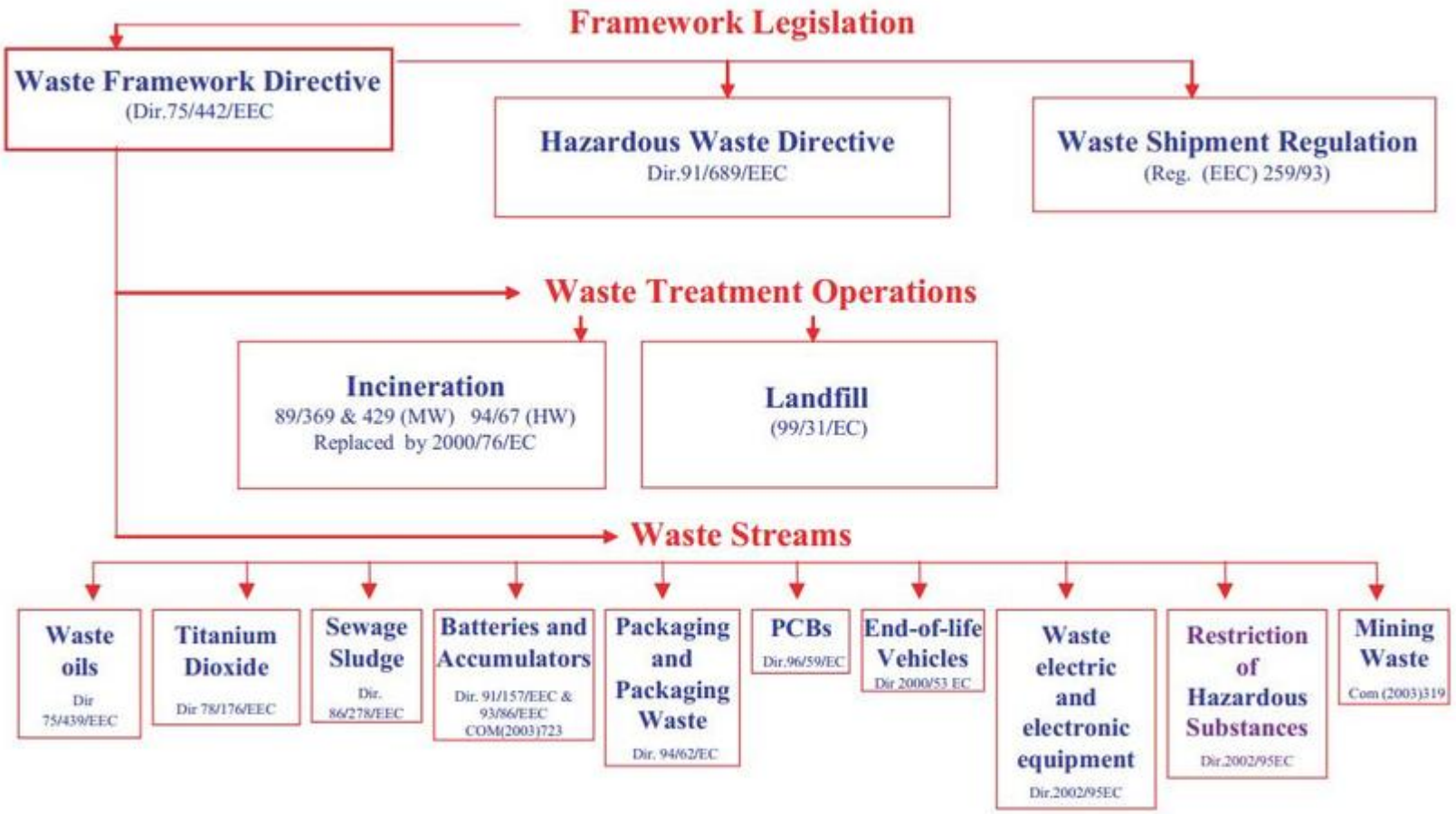
Directive 2000/76/EC was subsequently integrated into the Industrial Emissions Directive 2010/75/EU. Current requirements for waste incineration are based on the IED, its amendments and the applicable BAT conclusions

The directive establishes the **permitting conditions** for incineration plants, including under abnormal operating conditions, as well as limit values in relation to, for example, emissions to air and discharges to water.

The directive includes requirements concerning **waste incineration**, **co-incineration**, **air emissions, water discharges**, and **incineration residues**.

Finally, it also includes requirements on **control, monitoring and measurement**.

EC WASTE LEGISLATION



- horizontal legislation;
- legislation on waste treatment operations;
- legislation on specific waste streams.

SPECIFIC WASTE STREAMS

- **The directive on Waste Electrical and Electronic Equipment (WEEE) adopted in January 2003** contains a number of targets concerning the recovery of WEEE – these are described in Article 6 and must be met since the 31 December 2006. The recycling targets range from 50% to 80% depending on the type of equipment and recovery rates are also set for the different types of equipment. This directive also makes producer responsibility mandatory.

- **…**

SPECIFIC WASTE STREAMS

- **Extended Producer Responsibility (EPR)** is a policy approach under which producers are given responsibility — financial and/or operational — for the management of products when they become waste.

- EPR applies the polluter-pays principle to products placed on the market.
- Producers may comply individually or collectively through an approved producer responsibility organization.
- EPR can finance collection, sorting, reuse, repair, recycling and, in some cases, cleanup of abandoned waste.
- EPR is also intended to encourage eco-design, durability, reparability and recyclability.

SPECIFIC WASTE STREAMS

- **EPR does not mean that all waste-management costs are automatically covered. The level of financial and operational support depends on the scheme, the contract and the applicable rules.**

- **The OECD's guidance identifies principles on the use of EPR, outlines possible options and details the benefits and trade-offs of different approaches. In this way, the OECD helps to harmonize the use of EPR schemes across countries.**

ERP: Basic facts and key principles : https://www.oecd.org/en/publications/extended-producer-responsibility_67587b0b-en.html



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THANK YOU FOR YOUR ATTENTION