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Recycled Materials
« Matériaux Recyclés »

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Preface

The increasing demand for raw materials, combined with the rapid growth of industrial activities and urbanization, has led to significant environmental challenges, including resource depletion, waste accumulation, and greenhouse gas emissions. In this context, the concept of recycled materials has emerged as a key component of sustainable development, aiming to reduce environmental impacts while promoting efficient use of resources.

Recycled materials play a crucial role in modern engineering practices, particularly in civil engineering, where large quantities of materials are required for construction and infrastructure development. The reuse, recycling, and recovery of waste materials not only contribute to reducing landfill volumes but also help conserve natural resources and lower energy consumption. These approaches are strongly aligned with the principles of the circular economy, where waste is transformed into valuable resources.

The present document has been prepared as a course handout for the *Master 2 program, specialty Materials in Civil Engineering*, entitled *Recycled Materials*. It provides both fundamental concepts and advanced knowledge related to waste management, environmental impact assessment, recycling processes, and waste recovery techniques. Particular emphasis is placed on construction and demolition waste, which represents a major source of recyclable materials in the construction sector. To address these objectives, the course handout is organized into five main chapters:

- **Chapter 1:** Waste Management
- **Chapter 2:** Environmental Impact Assessment
- **Chapter 3:** Recycling
- **Chapter 4:** Waste Recovery
- **Chapter 5:** Construction and Demolition Waste

In addition to the theoretical content, this document includes a set of tutorial exercises with detailed solutions, designed to reinforce the understanding of key concepts and to develop the students' ability to apply theoretical knowledge to practical engineering problems.

This document serves as both a theoretical and practical guide for Master's students, as well as a reference for engineers and professionals in civil and environmental engineering. It aims to bridge the gap between academic knowledge and professional practice by presenting clear explanations, real-world applications, and modern methodologies related to recycled materials and sustainable resource management.

Chapter 1: Waste Management

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Chapter 1
Waste Management

Waste is one of the best indicators of the economic vitality and lifestyle of a society.

The growth of production and the increasingly rapid development of consumer goods have profoundly shaped the socio-economic structure of industrialized countries; a wasteful society was born in just half a century. Political authorities are trying to change the way products and waste are perceived by introducing new instruments based on financial incentives. Except for those preserved in museums, all our consumer goods end their lives as waste. There is no doubt that the tendency to consume and waste is closely linked to the purchasing power and prosperity of a society.

1.1. Definition of Waste

What is waste? In the sense of this chapter, waste is any residue from a process of production, transformation, or use, any substance, material, product, or more generally, any movable good that has been abandoned or is intended to be abandoned by its holder.

"Final waste" in the sense of this chapter refers to waste, whether or not resulting from the treatment of other waste, that can no longer be treated under current technical and economic conditions, particularly by extracting the recoverable part or by reducing its polluting or hazardous nature.

Waste is characterized by its origin, the process that generated it, and its use in terms of consumption. Waste is defined as an object or material whose economic value is zero or negative for its holder.

In general, industrial waste is classified into three categories:

- Ordinary industrial waste (OIW)
- Special industrial waste (SIW)
- Inert waste

➢ OIW (Ordinary Industrial Waste)

Ordinary inert waste includes all non-household waste. They are neither hazardous nor inert. This is why they can usually be decomposed or burned. They come from used packaging such as pallets, as well as worn materials like glass, metals, plastics, textiles, or wood.

- SIW (Special Industrial Waste)

Solid or liquid waste specific to industrial activity, containing varying amounts of toxic or hazardous elements, as well as waste from equipment contaminated by these substances.

1.2. Collection, Transport, and Storage

1.2.1. Collection Sites

They must be clear, installed as close as possible to users, adapted to the amount of waste produced, and easily accessible for service providers; they must not cause nuisances and must be cleaned frequently.

1.2.2. On-site Storage Areas

They must be given special attention to prevent them from becoming "a kind of dump" that could cause inconvenience and nuisances:

- For ordinary industrial waste: storage must be enclosed. Reference should be made to the decree of April 2, 1997, relating to general requirements applicable to classified installations for environmental protection, under heading No. 2710. Although establishments are not subject to these obligations, the provisions of this decree serve as good references for setting up and operating a temporary storage site.
- For hazardous waste: temporary storage, prior to recycling or disposal of special waste, must be done on sealed surfaces designed for recovering potential leaks.

I.2.3. Maximum Volumes

Unless otherwise explicitly stated, the volumes of chemical waste stored must comply with the storage capacity of premises designed for this purpose (avoiding stacking, blocking exits, ensuring storage stability, etc.).

1.2.4. Maximum Durations

The maximum storage duration for chemical waste depends on various parameters, such as reactivity, quantity, and storage conditions. In all cases, the maximum storage period must remain under one year. It is necessary to arrange regular removal of waste by an approved company and to plan for removal before summer vacation periods.

1.2.5. Specific Storage Conditions

Chemical waste must be stored under lock and key in premises that comply with current regulations, particularly ventilated, away from heat and ignition sources, and equipped with containment trays.

The storage facility must also be equipped with fire-fighting equipment, absorbent reserves, and a safety shower. The storage area must be marked ("flammable and toxic product storage," "no smoking," etc.) and display visible safety instructions.

1.3. Waste Treatment

1.3.1. Recovery and Recycling

Resource recovery is the process of taking discarded items that are useful for a specific future use. These discarded items are then processed to extract or recover materials and resources or to convert them into energy in the form of heat, electricity, or usable fuel.

Recycling is the process of converting waste into new products to avoid energy consumption and the use of fresh raw materials. Recycling is the third element of the hierarchy: reduce, reuse, and recycle waste. The idea behind recycling is to reduce energy consumption, decrease landfill volume, lower air and water pollution, reduce greenhouse gas emissions, and preserve natural resources for future use.

1.3.2. Composting

Composting (Fig. 1.1) is an easy and natural biodegradation process that takes organic waste—such as plant residues, garden waste, and kitchen scraps—and transforms it into nutrient-rich food for your plants. Composting, normally used in organic farming, occurs by allowing organic matter to remain in one place for months until microbes break it down. Composting is one of the best methods of waste disposal, as it can turn hazardous biological products into safe compost. On the other hand, it is a slow process and requires a lot of space.

Fig. 1.1: Composting.

1.3.3. Technical Landfilling

Final special waste includes those less likely to be treated under current technical and economic conditions, particularly through the extraction of the recoverable part or by reducing their hazardous and polluting nature.

Waste accepted in technical landfill centers (**TLC: Fig 1.2**) is mainly solid, mineral waste with a polluting potential consisting of poorly mobilizable heavy metals. They are very unreactive, very stable, and barely soluble.

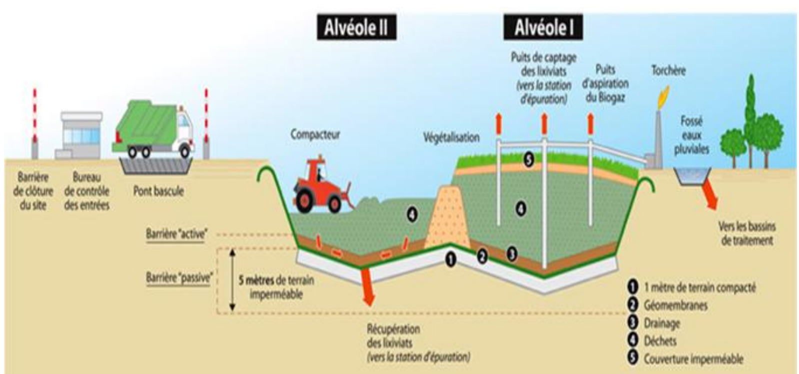

Fig. 1.2: Technical Landfilling.

1.3.4. Incineration / Combustion

Incineration or combustion (Fig. 1.3) is a disposal method in which municipal solid waste is burned at high temperatures in order to convert it into residues and gaseous products. The greatest advantage of this method is that it reduces the volume of solid waste by 20 to 30% of the original volume, decreases the space it occupies, and reduces congestion in landfills.

This process is also known as **thermal treatment**, where solid waste is converted by incinerators into heat, gas, steam, and ash. Incineration is very common in countries where landfill space is no longer available, including Japan.

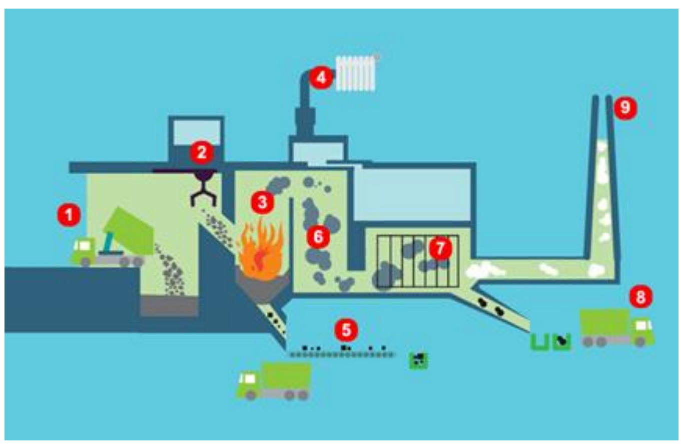

Fig. 1.3: Diagram of the incineration plant.

1.4. Costs in Waste Management

The **economic aspect** plays a very important role in waste management, where the total cost of this process includes not only the contents and the containers, but is also determined by the total weight to be disposed of, particularly in the case of chemical waste.

1.4.1. Waste Treatment Costs

As mentioned above, the **cost of waste treatment** includes four important aspects. All these parameters must be taken into account to evaluate the total cost of waste.

- The recovery of unusable quantities (weight, volumes),
- The type of waste (biodegradable, toxic, radioactive, etc.),
- Transport and storage,
- And treatment methods (recycling, incineration, etc.).

1.4.2. Waste Taxes

There are several taxes related to waste or discharges:

- For collection and treatment of OIW by municipalities.
- For storage and disposal of OIW and SIW.
- For discharges into water.

Chapter 2

Environmental Impact Assessment

The protection of the environment is becoming an increasingly collective concern. The issue of waste is a daily matter that affects every human being, both professionally and personally. As consumers, producers, users of garbage collection services, and sorters of recyclable waste, every citizen and taxpayer can and must take part in better waste management for environmental purposes.

In an integrated vision of sustainable development, the problem of waste cannot be treated as an isolated issue, nor limited to aspects of recovery and disposal. It must be placed within a holistic perspective of risk and resource management that covers the entire life cycle of waste, from its generation to its ultimate treatment. This approach anticipates waste at the project stage, includes source reduction, recovery, and disposal strategies, and aims to control material flows throughout the process leading to waste generation. As much as possible, waste should be avoided at the source by promoting low-waste production processes, long-lasting products, and optimized packaging. The use of polluting substances in both products and processes should be minimized to facilitate later stages of waste treatment and recovery.

2.1. Life Cycle and Sustainable Development

2.1.1. Life Cycle

The **figure 2.1** illustrates the life cycle of materials, starting from raw material extraction and continuing through manufacturing, transport, installation, and use. At each stage, resources and energy are consumed, contributing to environmental impacts such as emissions and waste generation. The end-of-life phase includes disposal, reuse, or recycling, which are essential for reducing resource depletion. Recycling closes the loop by reintroducing materials into the production cycle, supporting a circular economy approach. Overall, this lifecycle perspective highlights the importance of optimizing each stage to improve sustainability and minimize environmental impact.

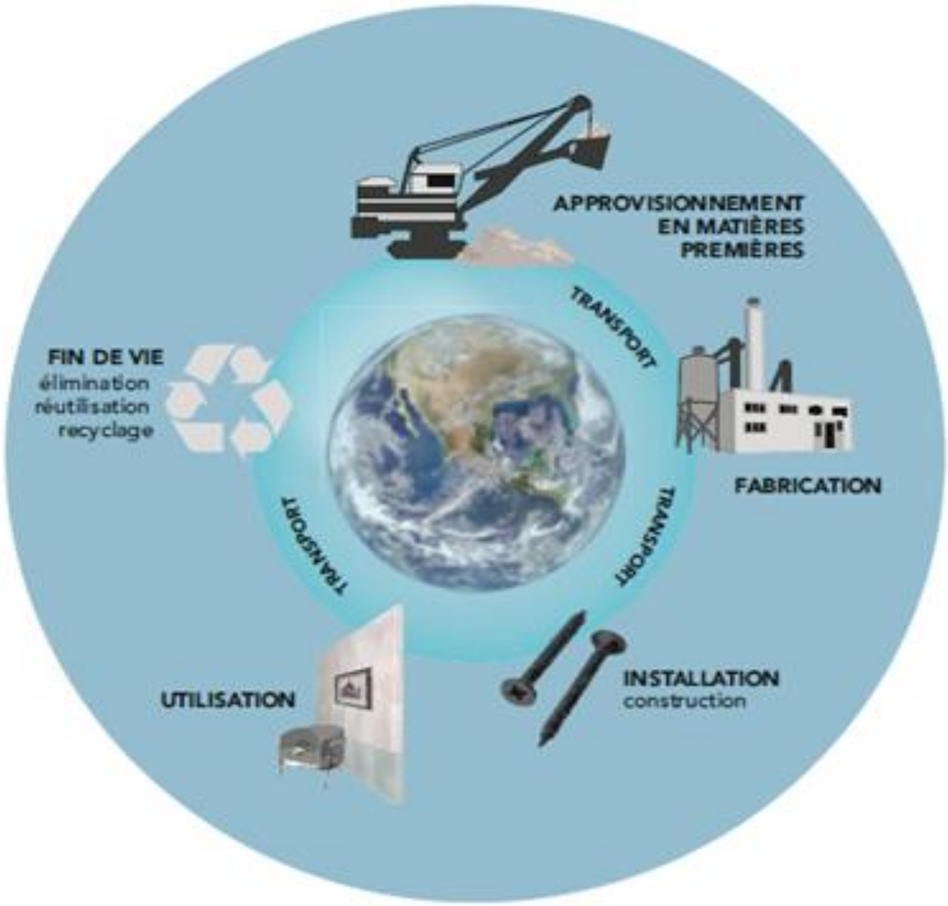

Fig. 2.1: Life Cycle of Materials.

2.1.2. Sustainable Development

Waste recovery should be pursued when it is both ecologically beneficial and economically viable. Recovery is environmentally sound when it generates less pollution than waste disposal or the production of new materials. In the long term, only substances suitable for permanent storage will be placed in landfills.

Waste management begins from the moment of its creation. In an integrated sustainable development approach, the issue of waste should not be treated in isolation. Management anticipates waste at the design stage, integrates reduction, recovery, and elimination strategies, and ensures control of flows throughout the process leading to waste generation.

2.2. Industrial By-products and Their Valorization in Civil Engineering

2.2.1. Demolition Products

Each year, construction and public works activities generate more than 100 million tons of demolition materials and excavated soils, most of which are considered inert waste. The reuse of these materials—after decontamination and recycling—quickly became a priority because it offers at least three major advantages: reduction of landfill use, preservation of natural aggregates, and reduction of transport costs.

In public works, these materials mainly come from building demolitions (residential or industrial), concrete structures, and road pavements. Certain categories that may contain undesirable elements (e.g., plasters that can cause swelling phenomena) are not systematically recovered by public works companies.

Recycling demolition materials, which requires costly installations, is mainly done to replace natural materials for the production of aggregates or fill layers used in earthworks, road construction, railway and airport infrastructures, and industrial platforms.

The recycling of demolition materials thus helps address shortages of natural materials, particularly in or near major urban areas. Therefore, production units are mainly located around large cities or industrial hubs.

2.2.2. Coal Shale (Schistes Houillers)

Coal shale comes from the residues of coal extraction. Coal mining gradually ceased in France, with nearly all mining sites closing by the late 1990s. As a result, many slag heaps composed of shale remain, forming characteristic features of mining regions and part of their heritage.

This section focuses on the exploitation and valorization of the materials contained in these slag heaps. National and regional public authorities encourage the use of these stocks, as it contributes to solving several key challenges:

- Economic challenge: relevant use of these by-products in construction and public works (BTP).

- Environmental challenge: site rehabilitation and landscape integration of slag heaps, including safety and erosion control.
- Sustainability contribution: reducing the need for distant quarries and the associated transport.

Originally, the slag heaps contained around 1 billion tons of coal shale, of which about a quarter has been exploited. Although their use has declined due to the reduced availability of high-quality by-products, coal shale remains used for embankments, subgrades, logistics platforms, and occasionally railway construction.

The use of coal shale is based on the GTR guide: “Réalisation des remblais et des couches de forme” (Construction of embankments and subgrade layers).

2.2.3. Air Lime

The term lime generally refers to calcium and/or magnesium oxides and hydroxides, obtained from the thermal decomposition (calcination) of calcium carbonate (limestone, chalk, shells, etc.) or dolomitic carbonate (dolomite, dolomitic limestone).

Air lime meets this general definition. It is called “air” lime because its hydroxide carbonates upon contact with carbon dioxide in the air, thus contributing to the strength and durability of mortars.

We distinguish between calcium air lime, obtained from pure calcium carbonate, and dolomitic air lime, obtained from mixed calcium–magnesium carbonate. Due to the purity of the source limestones, air limes have no hydraulic properties and must not be confused with hydraulic limes, which are primarily used in mortars and plasters.

The use of air lime in civil engineering must comply with the European Construction Products Directive and the NF EN 459 standard: Building Lime, which defines two categories:

- Calcium lime (CL): containing calcium oxide (CaO) and calcium hydroxide ($Ca(OH)_2$).

- Dolomitic lime (DL): containing calcium and magnesium oxides ($CaO \cdot MgO$) and hydroxides ($Ca(OH)_2 \cdot Mg(OH)_2$).

Air limes have no added hydraulic or pozzolanic components and are available in two main forms: quicklime (Q) and hydrated (slaked) lime (S). Quicklime exists in oxide form and reacts exothermically with water, while hydrated lime is obtained by controlled hydration of the oxide. Hydrated lime can be supplied as a powder or as a suspension in water, forming a paste, slurry, or lime milk, depending on concentration.

2.3. Blast Furnace Slag, Steel Slag, and Fly Ash

2.3.1. Blast Furnace Slag

Topics concerning blast furnace slag are covered in two sections: the present paragraph describes the origin, nature, and properties of these industrial by-products with a view to their use in civil engineering, particularly in road construction techniques.

There are potential uses for these materials depending on technical and environmental requirements, and this section also provides references to their commercialization and application in projects. Blast furnace slags (BFS) are by-products of the steel industry. They are generated during steel production, specifically in the stage where pig iron is produced from iron ore. Depending on the **cooling process** of the molten slag, two main types can be distinguished:

1. **Crystallized Slag (Air-Cooled Slag):**
   - Produced by **slow air cooling** of molten slag separated from pig iron.
   - The slag crystallizes into a **rock-like structure**, usually gray and porous.
   - **Density:** about 3 t/m^3.
   - **Properties:** high mechanical strength and low thermal conductivity.
   - **Main chemical components:** free lime ($CaO \approx 40\%$), silica ($SiO_2 \approx 35\%$), alumina ($Al_2O_3 \approx 11\%$), and magnesia ($MgO \approx 8\%$).
   - **Uses:** road construction, embankments, and fill materials.

2. **Granulated (Vitrified) Slag:**
    - Produced by **rapid water quenching** of molten slag.
    - The sudden cooling prevents crystallization, producing a **glassy (vitreous) structure**.
    - **Properties:** high hydraulic reactivity, improves cement performance and durability.
    - **Uses:** as an additive in cement production (blast-furnace cement) and in concrete manufacturing.

In short:

➡ *Crystallized slag* → slow cooling → crystalline structure → used in roads and fills.
➡ *Granulated slag* → rapid cooling → glassy structure → used in cement and concrete production.

Blast Furnace Slag (BFS)

Blast furnace slag is a **by-product of the iron-making process** in the steel industry. It is formed when impurities in iron ore (silica, alumina, etc.) combine with fluxes (lime and dolomite) during the production of pig iron.

Depending on the **cooling process**, two types are distinguished:

- **Crystallized (Air-Cooled) Slag:** slowly cooled, crystalline, dense, and used in road foundations, embankments, or as aggregate.
- **Granulated (Vitrified) Slag:** rapidly quenched with water, forming a glassy structure; used as a **supplementary cementitious material (SCM)** in cement and concrete.

Advantages:

- Improves concrete durability and sulfate resistance.

- Reduces CO_2 emissions by replacing part of the cement clinker.
- Utilizes an industrial by-product, minimizing waste.

2.3.2. Steel Slag (Basic Oxygen Furnace or Electric Arc Furnace Slag)

Steel slag is produced during the **refining of molten steel**, when impurities (phosphorus, sulfur, and silica) are removed using lime as a flux. The resulting molten slag is separated from the steel and solidified.

Main characteristics:

- Dark, hard, and dense aggregate with high mechanical strength.
- Contains oxides such as **CaO, FeO, SiO_2, and MgO**.
- May contain **free lime (CaO)** and **periclase (MgO)**, which can cause slight expansion if not treated properly.

Applications:

- Used in **road base layers**, **asphalt mixtures**, **cement production**, and **soil stabilization**.
- After aging or treatment, steel slag can also serve as a **replacement for natural aggregates** in concrete.

Environmental benefits:

- Reduces the need for quarry aggregates.
- Reuses a by-product that would otherwise be landfilled.
- When properly processed, it can immobilize heavy metals, contributing to cleaner industrial recycling.

2.3.3. Fly Ash

Fly ash is a **fine powdery residue** collected from flue gases during the **combustion of pulverized coal in thermal power plants**. It consists mainly of **silica (SiO_2), alumina (Al_2O_3), and iron oxide (Fe_2O_3)**, with minor amounts of calcium oxide.

Types:

- **Class F Fly Ash:** low in calcium, obtained from bituminous or anthracite coal; pozzolanic (reacts with lime in the presence of water).
- **Class C Fly Ash:** higher in calcium, obtained from lignite or sub-bituminous coal; both pozzolanic and self-cementing.

Applications:

- Used as a **cement replacement** (15–35%) in concrete to improve workability, durability, and long-term strength.
- Utilized in **geopolymers**, **soil stabilization**, **bricks**, and **lightweight aggregates**.

Advantages:

- Reduces cement production and CO_2 emissions.
- Enhances concrete's resistance to chemical attack and reduces permeability.
- Promotes the reuse of industrial waste in construction materials.

Table 2.1: Summary Table

Material	Origin	Main Composition	Key Uses	Environmental Benefit
Blast Furnace Slag	By-product of ironmaking	CaO, SiO_2, Al_2O_3, MgO	Cement, concrete, roads	Reduces clinker use and landfill waste
Steel Slag	By-product of steel refining	CaO, FeO, SiO_2, MgO	Asphalt, aggregates, cement	Replaces natural aggregates
Fly Ash	Coal combustion residue	SiO_2, Al_2O_3, Fe_2O_3	Cement substitute, geopolymers	Reduces CO_2 and enhances durability

Chapter 3: Recycling

In recent years, the quality of air and soil has deteriorated due to factors such as pollution and the increase in waste. Many countries are therefore seeking alternatives. Within sustainable development, this chapter focuses on recycling, waste recovery, and reuse.

3.1. Definition

"Recycling" (**Fig. 3.1**) is the creation of new materials—or the renewal of initial materials—through waste treatment (including organic recycling but excluding energy recovery). End-of-life products are recycled through specialized collection and processing systems, from collection to the manufacture of new products from waste.

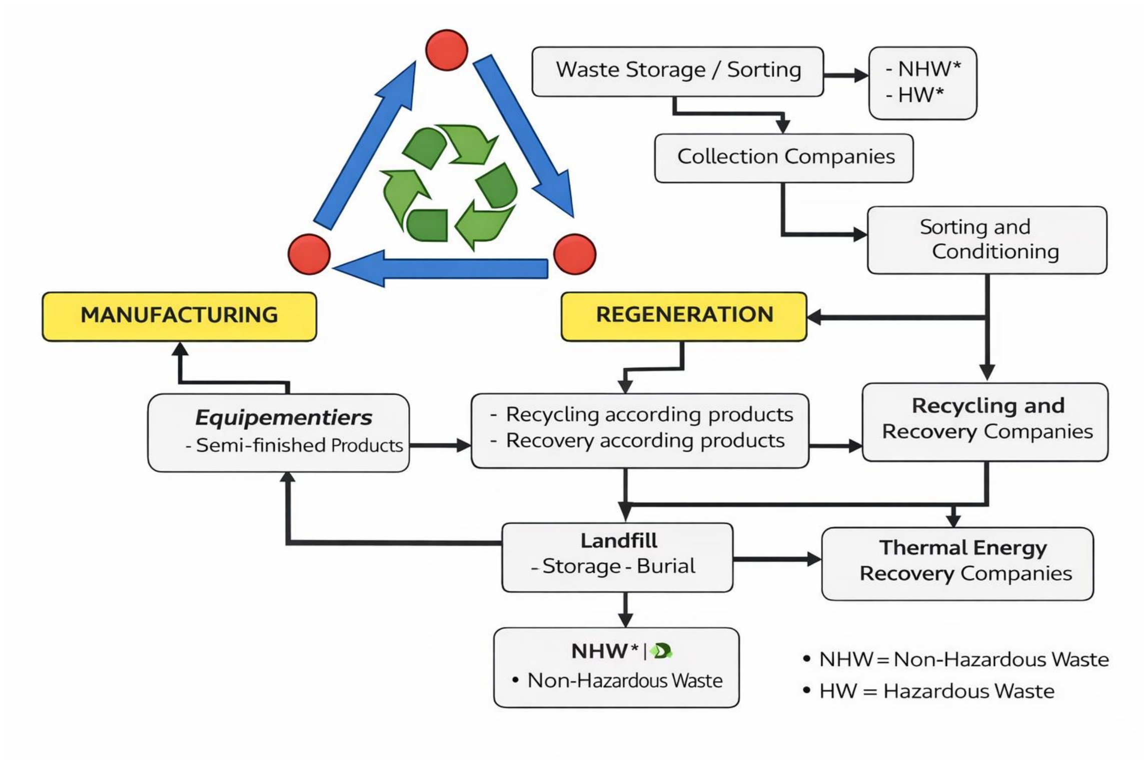

Fig. 3.1: Simplified diagram of the recycling process.

3.1.1. Standards and Process Rules

To prevent pollution problems, the recycling process is governed by precise rules. ISO standards—such as the ISO 14000 family on environmental management—have been deployed to comply with European directives, aiming to reduce waste and promote recovery. These standards can apply to any organization, sector, product, or service.

3.1.2. Categories of Recycling

• Mechanical recycling: yields a homogeneous material that can be remolded.

• Organic recycling (composting): widely used in agriculture.

• Chemical recycling: chemical reactions separate components.

Recyclable materials can be identified by the well-known **Mobius loop (Fig. 3.2)**, the universal logo for such materials since 1970.

Fig. 3.2: Mobius loop symbol used for recyclable materials.

3.2. Challenges

The recycling of materials affects almost every sector (automotive, construction, agriculture, etc.); however, for each recycled substance or material, there are not only benefits but also constraints. This range can be summarized for a few materials as follows:

3.2.1. Advantages

For glass:

- **Lower transport costs:** sand, lime, and soda are not produced on the same site, and traditional manufacturing requires at least three separate transports. In the case of recycling, all components are already available.

- **Lower melting costs:** cullet (crushed recycled glass) melts at a lower temperature than the raw materials, allowing for about **30% energy savings** in glass production.

- **Job creation:** the recycling industry generates employment, with an estimated **10,000 jobs** in this sector.

For paper:

- **Savings in raw materials:** one ton of paper and/or cardboard produces nearly the same quantity of pulp (within a few kilograms), whereas three tons of wood would otherwise be required.
- **Savings in processing costs:** operations such as cutting, grinding, cooking, defibration, washing, and refining—necessary when using wood—are not required in recycling.

3.2.2. Disadvantages

For glass:

- **Requires careful sorting by the public:** the recycling of glass demands special attention from the public when depositing it. The presence of impurities—such as caps, or debris of other materials that resemble glass (ceramics, porcelain)—disrupts the proper functioning of the production line. Automatic sorting systems are used to remove unwanted materials, but this results in additional costs.
- **High weight-to-volume ratio:** this increases the production cost compared with plastic.
- **Lead concentration:** the amount of lead in glass packaging tends to increase with successive recycling cycles.

For paper:

- **Household paper waste:** often mixed with other garbage and contaminated, it can then only be treated by incineration.
- **Tetra Paks:** composed of 95% cardboard, an aluminum film, and an outer plastic film—these three components are difficult to separate and cannot be recycled in the same processing stream. Solutions exist, but they are far more expensive than those for ordinary cardboard.

- **Progressive loss of quality:** after several recycling cycles, the fibers become completely broken down, and the resulting paper becomes increasingly less resistant.

3.3. Alternative Materials

Due to human overconsumption of biodiversity, plant resources (deforestation and vegetation harvesting), petroleum resources, the extinction of species, as well as minerals and raw materials, the risk of resource depletion is far from negligible. This awareness has given rise not only to recycling habits but also to the use of **alternative materials**.

3.3.1. Examples of Alternatives

Construction

- **Wood, straw, and cardboard** — alternative materials to traditional concrete— are becoming increasingly popular. "Straw house construction is booming in France, with more than 500 straw buildings erected each year. Contrary to common belief, straw is a strong material, fire-resistant, an excellent insulator, and, moreover, environmentally friendly."

- **Building with light** — "That's the challenge taken on by an Austro-Hungarian company that created **translucent concrete**, in which light passes through as shadow silhouettes thanks to optical fibers. It's more expensive than ordinary concrete, but just as strong."

- **Cardboard houses** — "Even more surprising are houses made of cardboard. A company has developed a highly innovative material: panels made of cardboard and polystyrene. In the Morbihan region, several houses have been built and have even withstood several storms."

- **Finite: the alternative to desert-sand concrete** — "Building the structures of the future using the sands of the Sahara... That's the vision behind **Finite**, a new alternative construction material made from desert sand—an overabundant resource long neglected by major construction companies. Mainly for technical reasons: desert sand contains 'fine, smooth particles that are difficult to bond together.'"

- **Clay concrete** — "A promising alternative to conventional concrete, **clay concrete**, currently being developed in the Vendée region, is an ecological and high-performance material. Already used on more than twenty construction sites in just three months, clay concrete could revolutionize the construction industry."

3.3.2. Energy Use

The gradual depletion of petroleum resources poses a problem for the future production of polymers. Therefore, it is necessary to seek **alternative solutions**, such as **bioplastics**.

3.4. Deposits and Management

The term **"deposit"** refers to the **quantity of household or industrial waste** produced and collected within a defined area, categorized according to its nature.

3.4.1. Steel and Scrap Iron

Households: justify separate collection; common items include tin cans; recovery via ash processing and pre-treatment sorting; ≈9 kg/person/year of steel in household waste.

Industry: scraps from steelmaking/metalworking and industrial packaging; recovery time varies from weeks (cans) to decades (structures). Scrap is classified into ~20 categories; European specs limit residual impurities.

Distribution of Steel and Scrap Metal Sources (**Fig. 3.3**):

- Scrap from collected end-of-life products (household and industrial packaging waste, mainly end-of-life vehicles) — *largest share (blue section)*
- Scrap from metalworking offcuts — *medium share (light blue section)*
- Scrap from steelmaking plant offcuts — *smallest share (green section)*

Fig. 3.3: Distribution of steel and scrap metal deposits.

The deposit related to **steel and scrap metal** is distributed as follows:

In households:

Steel waste is found in large quantities, which justifies **separate collection**, similar to glass and paper-cardboard. Steel waste comes in various forms, the most common being **tin cans**. Despite the implementation of specific containers and waste collection centers, these materials are still very often mixed with general household waste. As a result, recovery can be carried out in several ways: primarily through **the treatment of incineration bottom ash** (steel accounts for about **10%** of this ash), but also through **waste sorting prior to composting**.

The amount of steel in household waste is estimated at **9 kg per inhabitant per year**. Items such as tin cans, soda cans, and aerosol sprays—once called **“tinplate”**—are made of **thin steel sheets (0.24 mm)**. They are now grouped under the name **“packaging steels”**, whose characteristics must be considered during processing: most are **coated with tin** and, for commercial identification, **covered with varnish**.

In industry:

Industrial steel waste comes from **scraps from the steelmaking and metalworking industries**, as well as **industrial packaging** (drums, barrels, paint cans, car wrecks, etc.). The **recovery time** for steel varies depending on its use—from **a few weeks for cans** to **50 years or more for construction materials**—but even after long periods, steel remains fully recoverable.

Scrap metals are classified into about **twenty different categories**, depending on their size, origin, the quality of the steel, and other criteria. Quality standards are defined by the **European scrap metal reference framework**, which specifies the allowable levels of **residual metallic impurities** (for example, the maximum content for tin is **0.07%**, and **0.5%** for copper).

3.4.2. Non-Ferrous Metals

Recycling is long-established; secondary metals are comparable to primary; cheaper and conserves limited global reserves.

The recycling of **non-ferrous metals** is a long-established industrial activity, mainly justified by the fact that there is **no significant difference** between **primary metal** (refined metal extracted from ore) and **secondary metal** (refined metal obtained from waste).

In addition to being **much less expensive** than refining, recycling also helps **conserve the world's reserves** of these metals, which are relatively scarce and, for most of them, expected to be **depleted within less than a century**.

3.4.3. Inert Waste

Two main sources:

- **Construction and public works:** demolition, construction, and earthwork waste.
- **Extractive mineral industries:** quarries and mines.

3.5. Recycling in Cement Industry

Concrete is mainly sand and gravel with some cement; eco-friendlier than pure cement when aggregates are locally sourced. Cement manufacture (from limestone) requires ~1,450 °C, accounting for ~7–8% of global CO_2 emissions. Modern plants use increasing amounts of alternative waste-derived fuels (e.g., tires, animal by-products).

- **Launch of Projects**
  - Recovery of fines not captured by existing filters in large plants.
  - Environmental protection: joint projects with agronomists to combat desertification near plants.
  - Innovations in packaging of finished cement products.

- **Use of Alternative Fuels**
  - Deployment of alternative fuels to reduce fossil consumption.

- **Modes of Cement Transport**
  - Optimization of transport modes for lower impact.

- **Reduction of CO_2 Emissions: −39%**
  - CO_2-reduction initiatives deliver significant decreases in emissions (−39%).

3.6. Environmental Approach to Concrete Production

3.6.1. Applicable Regulations

Building permits and ICPE (Installations Classified for Environmental Protection). Projects requiring environmental assessment and public inquiry must comply with the Environmental Code: impact study, consultation, specific timelines, consultation of the environmental authority, and public disclosure of decisions.

3.6.2. Regulatory Requirements

Model prescriptions for a concrete production unit (**Fig. 3.4**): environmental integration, optimized withdrawals, annual water-use accounting, stormwater management (recovery/reuse), management of concrete scraps and industrial waste, and transport.

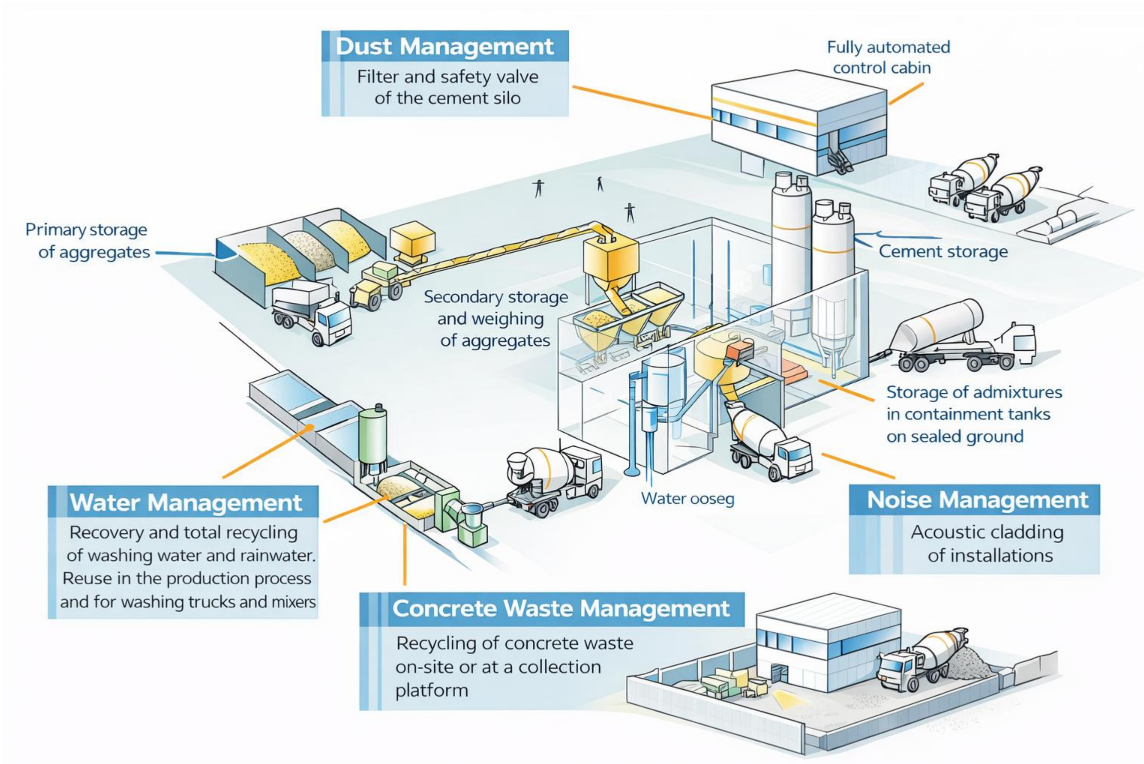

Fig. 3.4: Examples of regulatory requirements.

3.6.3. Use of Concrete (Fig. 3.5)

Use is concentrated in buildings, with complementary use in public works (roads and civil engineering structures).

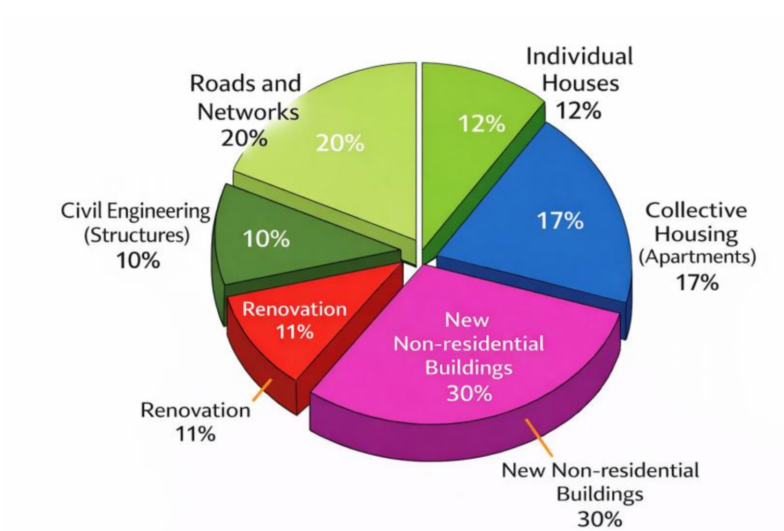

Fig. 3.5: Use of concrete.

3.6.4. Concrete Applications

A one-month study at a Paris-region ready-mix plant tracked material consumption and delivery distances. Two formulations were defined: CEM I with fly ash and CEM III. The SNBPE (*Syndicat National du Béton Prêt à l'Emploi*: French Ready-Mix Concrete Association) BETie tool (software/tool used to calculate the environmental impact of concrete) computed the environmental impact up to site delivery. An average impact for the period was obtained by weighting each mix by its production quantity.

Table 3.1: Data correspond to two main types: CEM I + fly ash (CV) and CEM III.

Category	**Material**	**Dosage (kg)**	**Total Weight (tons)**
Cement	CEM I	219	1,963
Cement	CEM III	320	959
Additions	Fly Ash	92	828
Additions	Filler	112	59
Aggregates	Alluvial	1,714	20,245
Aggregates	Crushed	1,698	232
Admixtures	Total admixtures	1.35	16
Water	Decanted water	—	—
Parameter		**Value**	
Produced Volume		11,945 m³	
Average Distance		25,704 km	
Number of Trips		1,463	

3.6.5. Good Environmental Practice Sheets

Environmental integration; optimize withdrawals; water-use economy; stormwater discharge/recovery; management of concrete scraps and industrial waste; transport.

3.7. Concrete Recycling

Currently, ~80% of demolition concrete is recovered in road applications; ~20% goes to inert-waste storage (ISDI). A key challenge is to demonstrate use in buildings without changing construction methods.

Demolition concrete is crushed into recycled concrete aggregates (RCA). France needs ~435 Mt of aggregates annually; only ~28% is supplied by recycled aggregates. Recycled aggregates and sands are often closer to use sites, reducing transport costs and CO_2.

3.7.1. Valorization Steps

1. Sort debris;
2. Separate concrete from other materials;
3. Crush, remove steel, inspect;
4. Reuse as road sub-base/earthworks or for new concretes.

3.7.2. Recarbonation of Rubble

Rubble can be recarbonated (ambient or accelerated) to reabsorb CO_2, harden, and form better aggregates—improving the carbon balance.

To reduce the carbon footprint of concrete, **recarbonation of demolition rubble** can be used. In this process, **CO_2 from the air is reabsorbed** by the crushed concrete, which **hardens and improves in quality**.

This reaction helps **partially balance the carbon impact** of concrete — especially because the **larger surface area** of the rubble allows **faster CO_2 absorption** than in intact concrete structures.

3.7.3. Property Changes vs Conventional Concrete

Beyond ~10% recycled aggregates: potential drops in compressive strength, Young’s modulus, and splitting tensile strength; altered drying and gas permeability; fresh concrete may be more workable. Hardened concrete: possible thaumasite formation and swelling; little cracking; good steel bond; freeze resistance depends on the source concrete; fire resistance often better due to lower internal temperatures.

3.8. Recycling in Road Pavements

Recycling methods apply to asphalt mixes, sub-bases, and pavement layers.

3.8.1. Source and Condition of Asphalt to Be Recycled

Hot-mix asphalt recycling in a mixing plant, as discussed in this document, concerns only granular mixtures bound with bitumen. They come from the dismantling of existing pavements, whether completely or partially (trenches, purges), or from discarded asphalt mixes.

This applies to all pavement layers: wearing courses, binder courses, base courses, and foundations. These materials are defined under the term "reclaimed asphalt aggregates" in standard NF P 98-149. Experimental standard XP P 98-135 deals with the characterization of reclaimed asphalt aggregates for hot recycling in mixing plants.

The commonly used dismantling methods are:

- Milling, which produces a fragmented material with an apparent diameter ≤ 31.5 mm;
- Jackhammering, mechanical excavator, and loader, which produce blocks weighing from a few kilograms to several hundred kilograms, sometimes forming surface areas up to 1 m^2.

The bituminous materials to be recycled are classified into three broad categories based on their origin (homogeneity) and storage:

1. Single-origin materials;
2. Materials of various origins stored separately;
3. Materials of mixed origins.

Bituminous mixtures of single origin typically come from large construction sites, obtained through milling. They exhibit a certain homogeneity, and their original composition is often known. Under proper milling conditions, these well-identified reclaimed asphalt aggregates are ready for reuse, either immediately after milling or after very short-term storage if storage is required.

Bituminous mixtures from various sources, stored separately, are often derived from medium-sized construction sites.

They have a certain degree of homogeneity, but their original composition is not always known.
Most of the time, they are supplied in the form of milled material (RAP); otherwise, crushing and screening are required for conditioning.

Bituminous mixtures from diverse sources come from small construction sites, manufacturing rejects, and are supplied either as milled material or as blocks. In small quantities, they are usually stored together without distinction. Before use, they must undergo crushing and screening to reduce them to reclaimed asphalt aggregates (RAA) with a maximum size of 31.5 mm. These reclaimed asphalt aggregates are highly heterogeneous in composition.

Currently, this category represents the majority of bituminous materials to be recycled observed in asphalt plant storage areas.

3.8.2. Conditioning

After milling and/or crushing-screening, reclaimed asphalt aggregates must comply with the experimental standard XP P 98-135 concerning asphalt aggregates. The apparent size of the reclaimed aggregate (in any case ≤ 31.5 mm) must be compatible with good disintegration during processing in the mixing plant.

The milling process (advance speed, among other parameters) can influence the nominal aggregate size (D_n) and the fine content of the milled material. The aggregate size forming the reclaimed asphalt must be consistent with the grading curve of the final mixture.

Storage and handling operations should aim to enhance the homogeneity of reclaimed asphalt aggregates — a requirement essential for:

- ensuring representative testing,
- maintaining production regularity, and
- guaranteeing consistent quality performance in use.

3.8.3. Use of Reclaimed Asphalt Aggregates in the Formulation of Hot Bituminous Materials

The standards published in 1999 and after allow the use of a certain percentage of reclaimed aggregates, as specified in **Table 3.2**.

The text in Article 5.4 of these different standards states that, unless otherwise indicated in the contract specifications, the contractor may include reclaimed aggregates up to the percentage specified in **Table 3.2**.

Table 3.2: Admissible Percentage of Reclaimed Asphalt Aggregates

Standard No.	Product	Permissible Percentage of Reclaimed Asphalt Aggregates
NF P 98-130	BBSG	10% in surface course and 20% in binder course
NF P 98-131	BBA	10% in surface course and 20% in binder course
NF P 98-141	BBME	10% in surface course and 20% in binder course
NF P 98-138	GB	40%
NF P 98-140	EME	40%
NF P 98-132	BBM type C	10% in surface course

Legend:

- **BBSG** = Bituminous concrete for semi-coarse surface course (béton bitumineux semi-gros)
- **BBA** = Asphalt concrete (béton bitumineux à module élevé / asphaltic concrete)
- **BBME** = Very thin asphalt concrete (béton bitumineux mince et épais)
- **GB** = Gravel-bitumen mix (grave-bitume)
- **EME** = High modulus asphalt (enrobé à module élevé)
- **BBM type C** = Thin asphalt mix for surface course (béton bitumineux mince type C)

However, regardless of the type of bituminous mixture using reclaimed asphalt aggregates, the mixture must comply with the relevant product standard. This means that mechanical performance and constituents (including the reclaimed aggregates) must meet the requirements of the standard. Therefore, the characterization of reclaimed asphalt aggregates is necessary depending on the percentage used.

Some product standards that have not been recently revised (for example, standard 98-136 for flexible pavement concretes) provide no information on whether reclaimed aggregates may be used. By extension, BBSG (bituminous concrete for surface courses) may accept the same percentages as BBSG base mixes, using the same requirements.

Standards 98-134 (for porous asphalt) and 98-137 (for ultra-thin bituminous concrete) specify in Article 5.4 that the use of reclaimed aggregates is not covered in the current standard.
This means that in traditional cases, reclaimed aggregates are not included in these formulations.
However, for a specific market (for example, recycling old porous asphalt), it is possible to reuse these aggregates, provided that the technical specifications are clearly stated in the contract documents.

The experimental standard XP P 98-135, "Characterization of Reclaimed Asphalt Aggregates for Hot Recycling in Plants," explains how to characterize these materials and provides guidelines for their use in its annex. This characterization is based on binder content, and the properties of both binder and aggregates.

In general, once the aggregate has been clearly identified, it can be incorporated into new asphalt mixtures.

Table 3.3 summarizes and illustrates the different possible uses depending on the level of knowledge about the reclaimed asphalt aggregates.

Table 3.3: Conditions for Reuse Rates of Reclaimed Asphalt Aggregates.

	Type of Layer	**Reuse Rate**
Use in Pavement	**Surface course**	0 – 10% (under condition[1]) – 30% – 40%
	Binder course	10% – 20% – 30% – 40%
	Base course	30% – 40%

In summary

- If the reclaimed aggregates are not characterized or if the characterization parameters are unspecified, recycling is not authorized in surface courses. It may be accepted with a maximum rate of 10% in binder or base layers.
- To recycle reclaimed asphalt aggregates in surface courses, these aggregates must either come from surface course materials, have a binder content of at least 5.5%, or the aggregates must exhibit characteristics consistent with surface course use.
- Recycling at 40% is possible in surface, binder, or base layers if all characterization parameters comply with the values given in **Table 3.3**.

For intermediate recycling rates, refer to the relevant standard.

3.8.4. Suitability of Materials for Recycling of Aggregates

The technology of the equipment plays a significant role in the final quality of the asphalt mix and potential atmospheric pollution. Feeding of reclaimed asphalt aggregates is ensured by a weighing feeder hopper with a low-capacity storage bin designed to allow smooth product flow (steep walls, wide extraction belt, anti-sticking coating). The automation of the asphalt plant must be adapted to account for the specificities of reclaimed aggregates (such as old binder content) and their point of introduction in the production process (synchronization with natural aggregates, preheating delay, etc.).

The recycling efficiency of asphalt plants mainly depends on the nature of the thermal exchanges governing the production process. Depending on the equipment type and the principle of aggregate introduction, **Table 3.4** summarizes the recycling rate possibilities.

Limiting factors are indicated assuming perfectly homogeneous reclaimed asphalt aggregates.

Table 3.4: Recycling Capacity of Asphalt Mixing Plants

Type of Plant	Reintroduction of Reclaimed Asphalt Aggregates	Heat Transfer	Max Recommended Rate	Limiting Factors
Batch plant	Hot elevator foot	Conduction	15%	Steam evacuation and clogging
Batch plant	Recycling dryer	Conduction	25%	Clogging of hot elevator
Batch plant	Specific dryer for reclaimed asphalt aggregates	Convection + conduction	50%	Environmental impact
Parallel flow drum (TSE équicourant)	Middle section of the drum	Convection + conduction	30%	Filter bag clogging
Counterflow drum (TSE contre courant)	Outside gas flow	Conduction	50%	Aggregate overheating, drum temperature, gas temperature

3.8.5. Organization of Preliminary Studies

The compliance of asphalt mixes (including those made with reclaimed asphalt aggregates) with product standards is now a mandatory requirement, except for experimental projects.

Preliminary studies, carried out before construction, make it possible to **characterize the proposed asphalt mix** and to **provide the mixing plant with the composition to follow** according to the intended recycling rate.

Apart from material aspects, the **choice of the recycling rate** depends on the following factors:

- Reuse of all or part of the available reclaimed asphalt aggregates;
- Characteristics of these reclaimed aggregates;
- Final use or purpose of the recycled asphalt.

Whatever the context, these preliminary studies always include, in chronological order:

1. **Identification of the components**;
2. **Development of the mix design**;
3. **Performance verification test (formulation trial)**.

However, two main cases must be considered, which determine the content of the previous points.

➢ **General Case**

❖ **Identification of Components**

- Quantification of the stock of reclaimed asphalt aggregates;
- Characterization of natural aggregates (NF EN 13-043);
- Characterization of reclaimed asphalt aggregates (XP P 98-135):

    - Granulometry before binder removal;
    - Composition after binder extraction:
        - Grain-size distribution (homogeneity);
        - Binder content (average and range);
    - Intrinsic characteristics and angularity of recycled aggregates;
    - Old binder: minimum penetration, maximum softening point (TBA), and range.

❖ **Mix Design Development**

- Determination of the percentages of different components:
    - Conventional weight percentages for formulation study;
    - Weight percentages used as production settings for the mixing plant;
- Selection of the additional binder (conventional or rejuvenating);
- Characterization of the added binder;
- Choice of the recycling rate.

❖ **Formulation Trial**

The formulation trial aims to verify that, for the determined composition, the characteristics of the produced asphalt mix comply with the relevant product standard, at the required performance level and for the selected class.

➢ **Special Case Where the Characterization of Reclaimed Asphalt Aggregates Is Impossible**

When the stock of reclaimed asphalt aggregates consists of highly heterogeneous bituminous materials (in terms of the nature and quantity of recycled aggregates and binders), obtaining a representative sample for proper characterization and determining the range of variation of their properties becomes impossible.

Consequently, the mix design cannot be adjusted based on those variations. This situation leads to reclaimed asphalt aggregates being labeled NS (not specified) in the draft standard XP P 98-135.

In such cases, limiting the recycling rate helps to minimize the impact of heterogeneity in reclaimed asphalt aggregates, and the formulation method includes the following adaptations:

➢ **Identification of Components**

- Characterization of natural aggregates (NF EN 13-043);
- Declaration of average properties of reclaimed asphalt aggregates:
    - Gradation;
    - Binder content;
    - MVRG (mean void ratio in granular mix).

The properties considered for reclaimed asphalt aggregates are **declared values** that replace specified values. They are derived from **previous data** (traceability from past projects, average values representative of local supplies) and not from spot analyses performed on temporary stocks.

➢ **Mix Design Development**

The recycling rates are set at 10% for binder courses and 15% for base courses.

For surface courses, where recycling is normally limited to 10%, it may still be considered if at least one of the following conditions is met:

- The reclaimed asphalt aggregates originate from a surface course;

- There is documented proof that the aggregates of the reclaimed asphalt mixture are at least of Category C;
- The average binder content obtained after conditioning and homogenization of the reclaimed aggregates is greater than 5.5%.

The asphalt designer has full discretion in achieving the performance levels required by the client. The following procedure is generally recommended:

- Start from an existing verified mix design using natural aggregates. This design should not be near the specification limits. It serves as a base that is modified to include reclaimed aggregates;
- Start from an existing and validated design already incorporating reclaimed aggregates;
- In all cases, the final mix design for the recycled asphalt is developed based on standardized test results for natural aggregates and the declared values for reclaimed aggregates.

➢ **Formulation Trial**

Experiments show that for stocks of reclaimed asphalt aggregates from various sources, properly processed (crushed and screened), and for the recycling rates mentioned above, the risk of non-representative sampling does not affect the mechanical performance of recycled asphalt mixes at low recycling levels.

Verification carried out on mixes incorporating reclaimed aggregates confirms that, for the considered recycling rate, the recycled asphalt meets the product standard's required characteristics, performance level, and class.

It should be noted that product standards for "surface courses" include a macrotexture requirement, which naturally applies to asphalt mixtures produced with reclaimed aggregates.

3.9. Environmental Approach to Concrete Production

Concrete is currently the most widely used construction material in the world, with global production estimated at over **10 billion tons per year**. Its popularity stems from its durability, availability, and versatility.
However, this massive production has **significant environmental impacts**: CO_2 emissions, high energy consumption, intensive use of natural resources, and the generation of construction waste.
The environmental approach aims to **reduce these impacts** throughout the concrete life cycle — from raw material extraction to the end-of-life phase of structures.

3.9.1. Main Environmental Impacts of Concrete

3.9.1.1. CO_2 Emissions

The main contributor to greenhouse gas emissions is **cement**, the binding component of concrete.

- The **production of clinker**, the main constituent of Portland cement, requires heating to about **1450°C**, consuming large amounts of fossil fuels.
- In addition, the **decarbonation of limestone ($CaCO_3 \rightarrow CaO + CO_2$)** directly releases carbon dioxide.

💡 **Carbon footprint:**

For each tonne of cement produced, about **850–900 kg of CO_2** are emitted. Cement production alone accounts for nearly **7% of global CO_2 emissions**.

3.9.1.2. Consumption of Natural Resources

- Concrete is made of **aggregates (sand and gravel)**, **water**, and **cement**.
- Extracting these aggregates often causes **ecosystem degradation**, **soil erosion**, and **groundwater disturbance**.
- The use of water in production and curing is also a major issue in arid regions.

3.9.1.3. Waste Generation

Construction sites generate large amounts of **residual concrete, dust, sludge, and rubble**.
Traditionally sent to landfills, these wastes can now be **reused or recycled**, especially as **recycled aggregates**.

3.9.2. Environmental Improvement Strategies

3.9.2.1. Reducing Clinker in Cement

The most effective solution is to **partially replace clinker** with **mineral additions**, such as:

- **Blast furnace slag**,
- **Fly ash**,
- **Silica fume**,
- **Limestone fillers** or **natural pozzolans**.

💡 So-called **CEM II, CEM III, or LC³ (Limestone Calcined Clay Cement)** can reduce CO_2 emissions by **30–50%**, while maintaining similar mechanical performance.

3.9.2.2. Use of Recycled Aggregates

Recycled aggregates, obtained by crushing demolished concrete, make it possible to:

- **Preserve natural resources**,
- **Reduce construction waste**,
- **Limit transportation impacts**.

However, their use requires control and testing:

- Variable moisture content,
- Presence of contaminants,

- Sometimes lower mechanical strength.

Current standards generally allow **20–40% substitution**, depending on the application.

3.9.2.3. Concrete Recarbonation

Recarbonation is a natural process in which atmospheric CO_2 reacts with the free lime in concrete to form calcium carbonate.
Although incomplete, this process helps to:

- **Reabsorb part of the CO_2** emitted during production,
- **Harden recycled aggregates**, improving their quality.

💡 Some innovative technologies accelerate this reaction to **trap carbon permanently** in demolition materials.

3.9.2.4. Eco-Efficient Structural Design

An environmental approach also involves **optimizing structural design**:

- Reducing concrete volume through efficient, high-performance design,
- Using **high-performance concretes (HPC)** to reduce section sizes,
- Integrating **lightweight, fiber-reinforced, or calcined clay-based concretes**, adapted to actual needs.

3.9.3. Life Cycle Assessment (LCA) of Concrete

The **LCA (Life Cycle Assessment)** is an environmental evaluation tool that considers:

1. Raw material extraction and production,
2. Transportation,
3. Implementation,
4. Use and maintenance,

5. End-of-life (demolition, recycling, disposal).

Each stage has its own impact.
LCA helps **quantify global emissions**, identify **improvement levers**, and compare **technical alternatives**.

💡 Example: a slag-based concrete shows a **40% lower carbon footprint** than conventional concrete, but if transported over long distances, this advantage may be offset by higher logistics emissions.

3.9.4. Toward a Circular Economy for Concrete

A circular economy aims to **close material and energy loops**:

- **Reduce:** resource-efficient and optimized design,
- **Reuse:** prefabricated and recoverable elements,
- **Recycle:** aggregates and fines from demolished concrete,
- **Recarbonate:** capture and store CO_2 in rubble.

Pilot projects demonstrate that **100% recycled concrete** (aggregates + mineral additions) is technically feasible, with a **carbon footprint reduced by half** compared to traditional concrete.

3.9.5. Conclusion

The environmental approach to concrete production does not rely on a single action, but on a **combination of strategies**:

- Clinker substitution,
- Material recycling,
- Structural optimization,
- Integration of life cycle assessment tools.

The challenge is to **combine performance, durability, and environmental responsibility**.

The concrete of tomorrow will not only be a building material but also a **key player in ecological transition**, through innovation, research, and circular resource management.

Chapter 4: Waste Recovery

Waste recovery has become a central component of sustainable waste management strategies, aiming to reduce environmental impacts while promoting resource efficiency. In contrast to simple disposal, recovery processes seek to extract value from waste through material reuse, recycling, or energy production.

This chapter explores the main recovery pathways for different types of waste, including wastewater treatment sludge, dredging sediments, and rubber materials. These wastes, often considered problematic due to their volume or contamination, can become valuable resources when appropriate treatment and valorization techniques are applied.

Particular attention is given to treatment processes such as thickening, stabilization, dewatering, and thermal recovery, as well as regulatory frameworks governing waste management practices. The chapter also highlights the environmental and economic benefits of recovery, including reduced landfill use, conservation of natural resources, and energy production.

Finally, this chapter emphasizes the role of waste recovery in the transition toward a circular economy, where waste is no longer seen as a burden but as a potential resource contributing to sustainable development.

4.1. Sludge From Wastewater Treatment Plants

A treatment plant sludge is the main waste produced by a wastewater treatment station. It contains both mineral and organic matter. Its composition may vary depending on the effluent treatment process and on the sector in which the water was used, whether *nuclear* or *food-related*. The treated water may originate from factories, rainwater, or households.

In general, the wastewater entering a treatment plant is referred to as “sludge.” The sludge goes through different stages and takes on various names (primary sludge, secondary sludge, etc.).

More broadly, the term can also refer to all sludges coming from an **industrial purification system**, including residues from **flue gas treatment** or **acid water treatment**, among others.

4.1.1. Types of Wastewater Sludge

4.1.1.1. Primary Sludge

They result from a **primary treatment by sedimentation**. This process lasts about **2 hours** and allows the extraction of materials heavier than water. The principle is simple:

- The water rests in a settling tank, and the heavy impurities fall to the bottom,
- The impurities collected at the bottom of the installation are called **primary sludge** and are composed of **inorganic matter**,
- At this stage, the water is treated at about **40%**, and then continues its path toward the **aeration basin**.

4.1.1.2. Physico-Chemical Sludge

They are formed during **secondary biological treatment**, which takes place after primary treatment. It allows the elimination of organic matter that could not be removed beforehand. These sludges are therefore mainly composed of **organic matter** and contain a **low percentage of inorganic substances**.

4.1.1.3. Mixed Sludge

This is a **mixture** of sludges produced during **primary treatment by sedimentation** and **secondary biological treatment**, that is to say, a combination of **primary** and **physico-chemical sludge**.

4.1.2. Treatment of Wastewater Sludge

The sludge from treatment plants has a **dry matter content** ranging from **1 to 5%**. Therefore, sludge treatment is necessary.

The sludge consists of **free water** and **bound water**. The **free water** is weakly absorbed and can be easily separated using a **dewatering system**. The **bound water**, however, is attached to particles and bacteria and can only be removed by **thermal drying**.

The treatment process aims to **reduce the water volume** and **eliminate various polluting and fermentable substances**. Its main goal is to **prepare the sludge** either for **recycling and recovery** or for **final disposal**.

4.1.3. Sludge Treatment Techniques

There are specific treatment methods depending on the **"configuration"** of the sludge from wastewater treatment plants:

4.1.3.1. Thickening

This step increases the **dry matter content** of the sludge so that it reaches **6 to 8%**. This process is essential for ensuring better treatment quality in the subsequent stages.

4.1.3.2. Stabilization

Stabilization and **sanitization** drastically reduce the water content in the sludge (by up to **80%**), and in some cases, dry it almost completely (with only **5 to 10% residual water**). This step significantly reduces the **volume of waste**, **stabilizes organic matter**, and **eliminates microorganisms or bacteria** that could cause diseases.

4.1.3.3. Dewatering

This technique produces a **pasty or solid sludge** by increasing the **dry matter content** of the original sludge.

4.1.3.4. Drying

This process makes it possible to obtain **solid (dewatered) sludge**, which naturally saves space for **storage and transportation**. This step is becoming increasingly essential today, as the amount of industrial sludge continues to rise. It is a **low-cost operation**, making it **attractive to industries**. In this context, and for maximum efficiency, **innovative techniques** are increasingly being used, particularly **solar drying**.

4.1.4. Reuse of Wastewater Sludge

After these sludges have been treated, the **recycling process** can take place; this procedure can be summarized as follows:

4.1.4.1. Recovery (Valorization)

It is possible to use certain types of sludge in the **agricultural sector**, by **spreading them over fields** as **fertilizer or compost**.

Other sludges, after **dewatering**, can be fed into **thermal furnaces** to **produce energy**. In some cases, it is also possible to reuse the sludge **in industry**, by **reintroducing it into the production circuit**.

4.1.4.2. Disposal (Elimination)

For sludges whose particles are too difficult to manage, the only possible solution is **incineration**. Some types of sludge are **landfilled together with household waste**. Everything depends on the **treatment process applied** and the **sector of origin**. Logically, **sludges derived from wastewater in nuclear or chemical sectors** will always be subject to **disposal** rather than **recovery**. Conversely, **high-quality sludge** coming from the **agri-food sector** would be more appropriately **spread over fields** for reuse.

4.2. Dredging and Desilting Sludge

Dredging or desilting sludge results from the maintenance of canals, estuarine channels, or port waterways.
Dredging is the operation of extracting materials located at the bottom of a water body.

Its purposes may include:

- Carrying out **port engineering works** (such as deepening basins or channels),
- **Maintaining river or maritime channels** used by ships when they become filled with sediments,
- Performing **land reclamation** or **beach nourishment** operations,

- Extracting **marine aggregates** for use in the **construction sector**.

Dredging work is performed by **specialized vessels and equipment**, whose characteristics depend on the **nature of the task** and the **environmental context**:

- Hydraulic or mechanical dredgers,
- Self-propelled ships or stationary pontoons.

The extracted materials are either:

- Stored on board for later transport,
- Placed into adjacent barges, or
- Discharged through pipelines.

Depending on their configuration, dredgers may operate **in motion** or **at a fixed position**.

The **dredged materials** are usually either:

- **Stored on land** at designated disposal sites, or
- **Discharged at sea** (a process known as *clapage*), generally within **controlled zones**.

However, sediments extracted from **industrial or port areas** may be **highly contaminated**, particularly with **heavy metals**.

For these reasons — and to **monitor the environmental impact** of dredging — this activity is **strictly regulated and controlled**.

4.2.1. Types of Dredging Activities

The dredging process consists of **excavating soil or alluvial deposits located underwater** (lakes, rivers, streams, drainage channels, canals, estuaries, marine channels, etc.). It can be performed either **from the shore**, using conventional construction equipment, or **from a specialized vessel or barge** designed for dredging operations.

4.2.2. Evolution of Dredging Sludge

4.2.2.1. Sampling and Analyses

It is important to take samples in the dredged areas using **statistically valid and representative procedures**, meaning that a sufficient number of sampling points must cover the **entire surface and the full depth** to be dredged. Samples from **non-homogeneous areas must not be mixed**.

Analyses must be planned **by sector of use in each basin** so that each pollutant can be geographically located (including at depth, particularly in old ports).

Care must be taken to ensure that the **pollutant fluxes or quantities** that are extrapolated in the reports from the analytical results are expressed **in weight** (and not only in volume, unless concentrations are provided).

4.2.2.2. Location and Indication

In accordance with **Article L218-43 of the Environmental Code**, which reiterates the prohibition of waste immersion under the **London Convention (29/12/1972)**, with exemptions under **Articles L218-44** for dredging spoil and **L214-1, -4, and -10**, dredging materials are classified as **waste**.

Any exemption must be subject to a **permit**.

4.2.3. Handling of Materials

4.2.3.1. Treatment Methods

The purpose of processing is to **minimize or stabilize contamination** with a view to **valorization** and to **reduce the amount of final waste requiring disposal**.

- **Pretreatment:** dewatering and separating the different layers in order to reduce volume, control contamination levels, and orient further processing according to the type of material.
- **Biological treatment:** land spreading or composting while ensuring the watertightness of the facilities.
- **Physico-chemical treatment.**
- **Thermal treatment:** which raises the issue of high energy consumption.
- **Immobilization treatment:** (platforms, in situ settling, drying areas). Several technical research programs are underway to classify and valorize these by-products.

Decontaminated sediments (**mandatory analyses required to confirm decontamination**) must **not** be dumped at sea, even if they may be reclassified as "non-contaminated" according to N1 and N2 thresholds defined in the decree of 9 August 2006.

They must be sent to a **land-based valorization chain**. If a return to the sea is considered, a **comparative economic study** with land valorization must be requested. Currently, there is **no legal reclassification** for treated sediments.

4.2.3.2. Possible Valorization Options

Note that for **marketable sediments**, treatment or transit stations must submit a **declaration (>15,000 m³)** or obtain **authorization (>75,000 m³)** under headings **2517 and 2515** of the ICPE classification (Installations Classified for Environmental Protection).

It should also be noted that commercialization does **not** require a mining procedure **if extraction is limited to the needs of the works**.

4.2.4. Storage

Storage is the **final option** for sediments that cannot be valorized. In this case, there are two regulatory solutions:

- **Non-Hazardous Waste Storage Facility (ISDND)**
- **Hazardous Waste Storage Facility (ISDD)**

Sediments may contain pollutants that are **not accounted for** in the criteria for ISDND facilities (which are normally intended for household and similar waste). Therefore, it is necessary to test the **H14 ecotoxicity criterion**, or — as a precaution — send the sediments to an **ISDD** (intended for toxic waste, but requiring inert materials and involving high costs).

However, the **volumes of sediments are often large** compared to the capacity of these centers.

Storage in a **collective facility** should be limited to what is strictly necessary. New criteria **specific to sediments** are currently pending at the Ministry for classification of sediments as "hazardous" within the framework of the **dredging circular**.

4.2.5. Dumping at Sea (Clapage en mer)

To obtain authorization to dispose of dredged materials at sea by exemption, it must be demonstrated — in a permit application file — that no other solution is possible, and that all measures have been taken to avoid the production and contamination of sediments.

From a chemical and physical perspective, the criteria to be taken into account are listed by the London Convention, but the determination of the list of toxic substances and the critical threshold levels is delegated to the national level.

It is at this stage that the notion of **"low-risk"** with respect to dumping at sea is introduced.

4.3. Rubber

Rubber **C_5H_8** is a natural raw material. It can be obtained either through the transformation of **latex secreted by Hevea trees**, or synthesized from monomers derived from **fossil hydrocarbons**. It belongs to the family of **elastomers**. Natural rubber is a **polyisoprenoid**.

There are therefore two main families of rubber:

- **Natural rubbers**, which come from rubber cultivation (Hevea: the tree that produces latex),
- **Synthetic rubbers**, which are manufactured from petroleum derivatives.

Rubbers are used in many sectors: automotive/transport (tires, braking systems, airbags, sealing...), industrial equipment, building and public works (BTP), medical (condoms, gloves...), food (pacifiers...), adhesives and glues...

Rubber waste comes from four sources:

- Industrial rubber waste (8%),
- Waste from the manufacture of tires and inner tubes (3.5%),
- Used tires (86.6%),
- Recycling residues (powders, shavings) (2%).

4.3.1. Origins

The sources of recycled rubber are the following: used tires (**Fig. 4.1**; 70%), industrial rubber waste (shoe soles, etc.), as well as manufacturing scraps from tire production.

Recycled rubber can be found in all kinds of everyday products; responsible footwear brands in particular are turning to it to manufacture eco-friendly sneaker soles.

Fig. 4.1: Rubber waste (used tires).

4.3.2. Prevention / Reduction

The reuse of rubber scraps within the production process itself helps reduce the generation of waste. The use of natural rubber (latex) is preferable because it is less harmful to the environment, although its carbon footprint is less favorable since it is harvested in intertropical regions.

4.3.3. Management and Collection

Rubber waste must be stored in a closed area, protected from the weather if possible, and in separate piles to avoid any risk of fire; the fumes emitted during a fire being dangerous for both health and the environment. Whenever possible, storage should be limited to small quantities.

Currently, there are few collection channels due to the diffuse nature of this type of waste, although these materials can indeed be recovered.

For large quantities, it is possible to call on a specialized contractor. The transporter must declare its activity to the prefecture if the transported quantity exceeds 500 kg of non-hazardous waste per load.

4.3.4. Recovery (Valorization)

4.3.4.1. Material Recovery

Rubber waste can be used to produce granulates and rubber powders employed in the manufacture of various parts (casters, small components, etc.), sports and road flooring, sealing products, and sound insulation materials, among others.

4.3.4.2. Energy Recovery

Rubber waste can undergo thermal recovery in cement plants. It can also be incinerated together with other waste in non-hazardous waste incineration plants.

4.3.5. Rubber Recycling Processes

4.3.5.1. Micronization

Mechanical grinding of rubber into microparticles as small as 100 microns. The recycled rubber powder can then be reincorporated up to 10% into new rubber.

4.3.5.2. Devulcanization of Rubber

A non-toxic process that consists of breaking the sulfur bonds using an ecological devulcanizing agent (EDV). The resulting material is recycled rubber of good quality, which can be reused at 100% to manufacture new products.

4.3.5.3. Pyrolysis

A process that makes it possible to recover rubber in the form of oil (30 to 50%), carbon black (25 to 40%), and energy (10 to 25%).

4.3.6. Types of Rubber Recycling

- **Non-industrial Recycling:**

The recovery of this material consists of giving it a second life by assigning it a new value, often by adding accessories or transforming it without industrial processing.

4.3.6.1. Old Tires

For example, old tires can be painted in different colors and placed as benches or tables in gardens and public squares (**Figs. 4.2-3**). However, this is not considered a real solution to the problem due to the large number of tires destroyed each year.

Fig. 4.2: Placement of old tires in gardens.

Fig. 4.3: Use of tires as flower pots.

4.3.6.2. Damaged Tires

Damaged tires can also be used in geomaterial applications, such as slope reinforcement (**Fig. 4.4**), reducing the risks of landslides and soil erosion. Together, this system works well to resist soil erosion and prevent shear processes that cause slope failure.

Fig. 4.4: Use of tires as slope-retaining structures.

4.3.6.3. Tires in house construction

In certain regions, tires are used in house construction (**Fig. 4.5**), but their use in this field remains limited and restricted to rare cases.

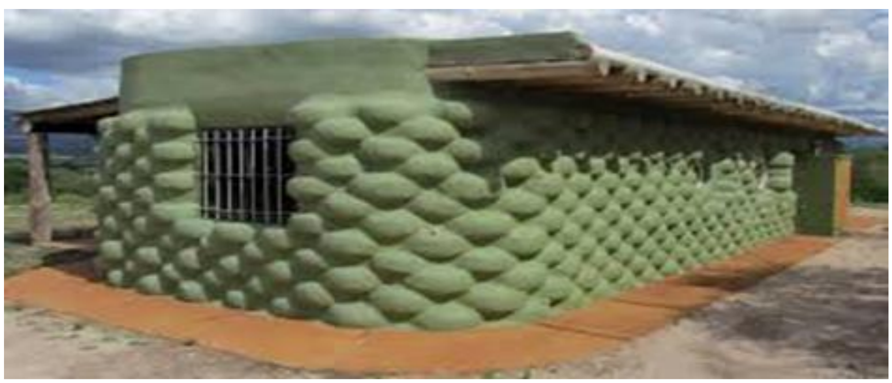

Fig. 4.5: Use of tires for construction.

4.3.6.4. Energy Production

Tires can be melted at very high temperatures in oxygen-free reactors. When the molten material evaporates, it is condensed with water through pipes it passes through, producing useful materials such as:

- Diesel,
- Carbon black,
- Steel.

4.3.6.5. Industrial Recycling

Industrial recycling requires industrial processes to extract raw materials. In the case of tire recycling, tires undergo a manufacturing-type process (**Fig. 4.6**) to extract:

- Rubber,
- Iron,
- Fibers,
- Plastic.

Rubber tires go through several stages before obtaining the raw materials and pure rubber powder.

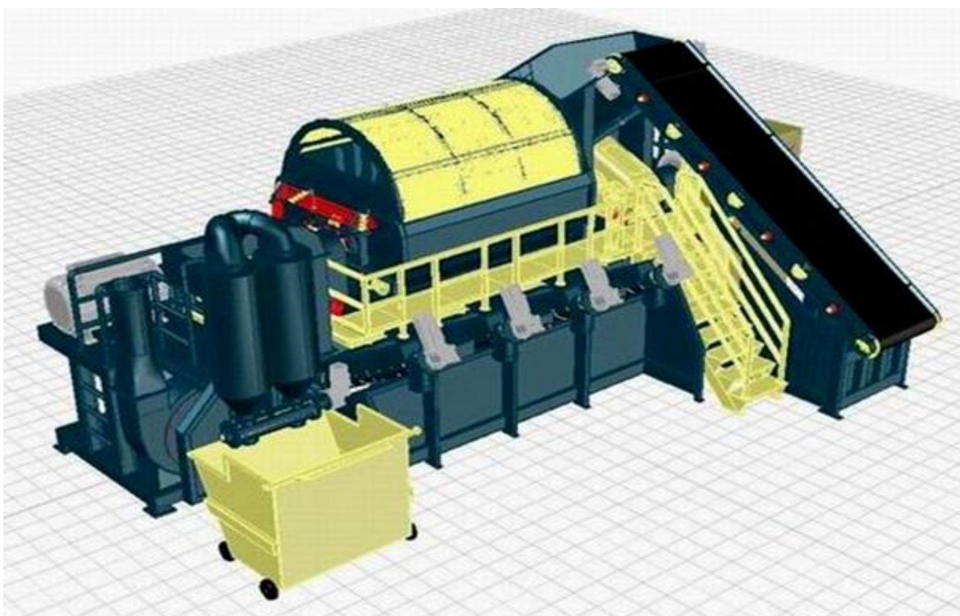

Fig. 4.6: Example of a tire-recycling plant.

Chapter 5: Construction and Demolition Waste (C&D Waste)

Construction and Demolition Waste (C&DW) represents one of the largest waste streams worldwide, accounting for approximately 25–35% of total solid waste in many developed and developing countries. This waste originates from the construction, renovation, and demolition of buildings and infrastructure. Due to its volume, heterogeneity, and environmental impact, effective management of C&DW has become a global priority in the context of sustainable development, resource conservation, and circular economy strategies.

The management of C&DW involves several key steps: identification of waste types, characterization, on-site handling, selective demolition, recycling and recovery processes, and final disposal. Modern approaches aim to reduce the environmental footprint of construction activities by promoting material reuse, recycling technologies, and low-impact resource management.

Construction and demolition waste represents a significant environmental challenge but also a major opportunity for resource recovery. Through selective demolition, recycling technologies, material valorization, and regulatory frameworks, the construction sector can significantly reduce its environmental footprint and contribute to a circular economy.

5.1. Sources and Types of Construction Waste

C&D waste is generated at different stages of the construction life cycle:

5.1.1. Construction Phase

During the construction of buildings and infrastructure, waste is generated due to:

- Material breakage or cutting (wood, concrete, tiles).
- Packaging materials (plastics, cardboard).
- Leftover materials (mortar, concrete).
- Improper planning or over-ordering.

5.1.2. Renovation Phase

Renovations often produce:

- Tiles, ceramics, sanitary fixtures.

- Plaster and gypsum board waste.
- Electrical and plumbing components.
- Insulation materials.

5.1.3. Demolition Phase

Demolition produces the largest volume of C&D waste. Typical materials include:

- Concrete and aggregates.
- Bricks and masonry.
- Metals (steel, aluminum, copper).
- Plastics and composites.
- Glass and window frames.
- Asphalt and bituminous materials.

5.2. Classification of C&D Waste

Construction waste can be categorized according to its composition and recyclability.

5.2.1. Inert Waste

Materials that do not undergo significant physical, chemical, or biological transformations:

- Concrete
- Bricks
- Stones
- Glass
- Ceramics

These materials are ideal candidates for recycling into aggregates.

5.2.2. Non-Inert but Non-Hazardous Waste

Materials that may degrade but are not dangerous:

- Plastics
- Wood
- Paper and cardboard
- Gypsum
- Textiles

5.2.3. Hazardous Waste

These materials pose environmental or health risks:

- Asbestos
- Lead-containing paints
- Solvents and adhesives
- Roofing tar
- Treated wood

Hazardous waste requires specialized handling and disposal.

5.3. Environmental Impacts of Construction Waste

5.3.1. Resource Depletion

Construction relies heavily on natural resources such as gravel, sand, limestone, clay, and metals. Excessive extraction causes:

- Habitat destruction
- Soil erosion
- Reduced availability of raw materials

5.3.2. Greenhouse Gas Emissions

Transport, demolition, and manufacturing processes contribute to:

- CO_2 emissions
- Air pollution (NOx, SO_2)
- Increased carbon footprint

5.3.3. Landfill Pressure

Many countries face limited landfill capacity. C&D waste occupies large volumes, increasing:

- Land use pressure
- Soil and water contamination risks

5.3.4. Pollution and Health Risks

Hazardous materials such as asbestos, treated wood, and paint residues contribute to:

- Respiratory diseases
- Toxic contamination
- Long-term ecological damage

5.4. Sustainable Management of Construction Waste

5.4.1. Waste Prevention

Preventive strategies include:

- Optimizing design to reduce material excess
- Using prefabricated elements
- Implementing Building Information Modelling (BIM)
- Efficient delivery scheduling

5.4.2. Reuse

Many construction materials can be directly reused:

- Doors, windows, frames
- Steel beams
- Bricks and paving stones
- Furniture and fixtures

Reuse reduces energy consumption and avoids new resource extraction.

5.4.3. Selective Demolition

Also known as "deconstruction," selective demolition aims to:

- Separate materials on-site
- Avoid contamination
- Maximize recovery potential
- Minimize landfill disposal

5.5. Recycling of Construction and Demolition Waste

5.5.1. Concrete and Aggregates Recycling

Recycled concrete aggregates (RCA) are produced by crushing and sorting demolition concrete. Applications include:

- Road sub-base layers
- Non-structural concrete
- Backfilling

5.5.2. Metals Recycling

Steel, aluminum, and copper have high recycling value due to:

- High economic return
- Infinite recyclability without quality loss

5.5.3. Wood Recycling

Wood can be:

- Reused in construction
- Processed into particle boards
- Converted into biomass energy

5.5.4. Plastics and Glass

Recycling includes:

- PVC pipes
- Polyethylene films
- Glass windows and panels

5.6. Material Valorization in Civil Engineering

Recycled materials can replace natural aggregates or conventional materials in:

- Road construction (sub-base, embankments)
- Concrete pavement layers
- Asphalt mixtures
- Landscaping projects

Examples include:

- Crushed concrete for road foundations
- Recycled asphalt pavement (RAP)
- Glass sand as a substitute for natural sand

5.7. Regulatory Framework and Standards

Regulations depend on national and international contexts but often cover:

- Selective demolition requirements
- Waste tracking and documentation
- Hazardous material identification
- Recycling standards for aggregates
- Landfill restrictions

European examples include:

- Waste Framework Directive 2008/98/EC
- ISO 14001 Environmental Management Systems

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Tutorials

Tutorial 1

Recycled Materials and Waste Management

Learning Objectives

1. Define and classify different types of waste.

1.1. Definition

Waste is any substance or object that its holder discards, intends to discard, or is required to discard.

It can originate from domestic, industrial, agricultural, or commercial activities.

1.2. Classification of waste

1. Ordinary industrial waste (OIW)
    - Non-hazardous and similar to household waste.
    - Examples: paper, cardboard, plastic packaging, wood scraps.
2. Special industrial waste (SIW)
    - Hazardous or toxic waste that poses risks to health or the environment.
    - Examples: chemical solvents, oils, paints, heavy metals, radioactive waste.
3. Inert waste
    - Stable, non-reactive waste that does not decompose or pollute.
    - Examples: concrete debris, bricks, glass, ceramic fragments.
4. Biodegradable waste
    - Organic matter that can be decomposed naturally by microorganisms.
    - Examples: food scraps, green waste, agricultural residues.

2. Understand the main methods of waste treatment and valorization

Method	Description	Advantages	Limitations
Recovery / Resource valorization	Extraction of useful materials or energy from waste.	Saves natural resources, reduces pollution.	Requires selective sorting and infrastructure.
Recycling	Transformation of waste into new materials or products.	Reduces raw material and energy consumption, cuts CO_2 emissions.	Sorting complexity, cost of collection and treatment.
Composting	Biological degradation of organic waste into natural fertilizer.	Eco-friendly, improves soil fertility.	Slow process, requires control of humidity and temperature.
Incineration	Burning of waste at high temperature to produce heat or energy.	Reduces waste volume (up to 90%), generates energy.	High investment cost, air pollution risk.
Technical landfilling (CET)	Controlled burial of residual waste in sealed sites.	Easy and low-cost for non-recyclable waste.	Risk of soil and groundwater pollution, limited space.

3. Explain the environmental and economic significance of recycling

➢ **Environmental significance:**

- Reduces the extraction and depletion of **natural resources** (minerals, oil, forests).
- Limits **landfill space** and prevents soil and groundwater contamination.
- Decreases **greenhouse gas emissions** and energy use during manufacturing.
- Promotes a **circular economy**, extending the life of materials and products.

- **Economic significance:**
  - Lowers production costs by reusing materials instead of extracting new ones.
  - Creates new **employment sectors** (collection, sorting, processing).
  - Reduces transportation and raw material import costs.
  - Encourages **innovation** in green technologies and material efficiency.

4. Identify examples of industrial by-products used in civil engineering

Material	Origin	Main Properties	Engineering Applications
Blast Furnace Slag (BFS)	By-product of steel manufacturing.	High mechanical strength, good durability, low thermal conductivity.	Cement addition, concrete aggregate, road foundations.
Crystallized Slag	Slow-cooled slag separated from molten iron.	Dense (~3 t/m³), porous, strong, thermally stable.	Road sub-base layers, embankments, fill material.
Coal Shale	Residue from coal mining and washing.	High resistance, local availability.	Embankments, road base.
Fly Ash	Fine residue from coal combustion in power plants.	Pozzolanic properties, improves workability and durability of concrete.	Cement replacement, soil stabilization.
Air Lime	From limestone calcination.	Reacts with CO_2, improves binding in soil.	Mortars, stabilization of fine soils.

5. Apply knowledge of material life cycles and sustainable development principles

- **Life Cycle of a Material:**

1. **Extraction** → Raw materials (minerals, biomass) are extracted.
2. **Manufacturing** → Materials are transformed into products.
3. **Use phase** → Products are utilized by consumers.
4. **End-of-life** → Collection, reuse, recycling, or disposal.
5. **Recycling/Revalorization** → Materials are reintegrated into the economy.

- **Sustainable Development Principles Applied:**

- **Environmental pillar:** Reduce waste and emissions through reuse and recycling.
- **Economic pillar:** Lower costs and resource dependence, create green jobs.
- **Social pillar:** Improve health and living conditions by reducing pollution and promoting responsible consumption.

A material's life cycle approach ensures a **closed-loop system**, where waste becomes a **resource**, promoting **sustainability and circular economy** in civil and environmental engineering.

Part I – Fundamental Concepts

- **Question 1: Define waste according to the document and classify its types.**

Waste is any substance or object that the holder discards, intends to discard, or is required to discard. Types include ordinary industrial waste (non-dangerous), special industrial waste (hazardous), and inert waste (non-reactive).

- **Question 2: Describe the main waste treatment methods and their advantages and limitations.**

Method	Description	Advantages	Limitations
Recovery / Resource valorization	Extraction of useful materials or energy from waste.	Saves natural resources, reduces pollution.	Requires selective sorting and infrastructure.
Recycling	Transformation of waste into new materials or products.	Reduces raw material and energy consumption, cuts CO_2 emissions.	Sorting complexity, cost of collection and treatment.
Composting	Biological degradation of organic waste into natural fertilizer.	Eco-friendly, improves soil fertility.	Slow process, requires control of humidity and temperature.
Incineration	Burning of waste at high temperature to produce heat or energy.	Reduces waste volume (up to 90%), generates energy.	High investment cost, air pollution risk.
Technical landfilling (CET)	Controlled burial of residual waste in sealed sites.	Easy and low-cost for non-recyclable waste.	Risk of soil and groundwater pollution, limited space.

Part II – Recycling and Environmental Impact

➢ **Question 3: Explain recycling principles and its role in reducing greenhouse gases.**

Recycling transforms waste into new products, reducing raw material use, energy demand, and greenhouse gas emissions.

➢ **Question 4: Discuss the main economic parameters influencing waste treatment.**

Economic parameters include recovery quantities, type of waste, transport, storage, and treatment methods.

Part III – Valorization of Industrial By-Products

➢ **Question 5: Summarize the main by-products, their origin, properties, and civil engineering applications.**

Material	Origin	Properties	Applications
Blast Furnace Slag	By-product of steelmaking	High strength, low thermal conductivity	Concrete, road layers
Crystallized Slag	Slow-cooled blast furnace slag	Porous, dense (~3 t/m^3)	Fill materials, aggregates
Air Lime	Limestone calcination	Reacts with CO_2	Mortars, soil stabilization
Coal Shale	Coal mining residue	Durable, locally available	Embankments, subgrades

Part IV – Sustainable Development and Life Cycle

➢ **Question 6: Define and explain the life cycle approach for recycled materials.**

The life cycle includes extraction, production, use, end-of-life, and recycling/reuse.

❖ Main stages of a material's life cycle:

1. Extraction: acquisition of natural resources (minerals, water, energy).
2. Manufacturing: transformation into usable materials or products.
3. Distribution and transport: energy consumption and emissions due to logistics.
4. Use phase: performance, maintenance, and energy consumption during service life.
5. End-of-life: options include reuse, recycling, recovery, or disposal (landfilling or incineration).
6. Reintegration: recycled materials are reintroduced into production systems.

❖ Application to recycled materials:

- For recycled products (e.g., recycled concrete, blast furnace slag, fly ash), the life cycle focuses on reducing extraction and manufacturing impacts by reusing existing materials.
- It helps identify where environmental gains (CO_2 savings, energy reduction) are greatest.
- Encourages circular economy models, where waste from one process becomes the raw material for another.

It supports circular economy principles, reducing waste and environmental footprint.

➢ **Question 7: Discuss the environmental and social benefits of recycling industrial by-products.**

🌿 **Environmental Benefits**

1. **Resource conservation:** Recycling industrial by-products (slag, fly ash, etc.) reduces the need for new raw materials such as limestone, sand, and gravel.
2. **Waste reduction:** By reusing industrial residues, the volume of waste sent to landfills is significantly reduced, prolonging landfill lifespan.
3. **Pollution prevention:** Limits air, soil, and water pollution by avoiding open dumping and reducing the extraction and transport of new materials.
4. **Energy savings and CO_2 reduction:** Recycling requires less energy than producing materials from virgin resources, leading to lower greenhouse gas emissions.
5. **Circular economy promotion:** Encourages closed material loops where by-products are transformed into secondary raw materials instead of waste.

👥 **Social and Economic Benefits**

1. **Job creation:** The recycling and valorization sectors generate **local employment** in waste collection, sorting, processing, and research.
2. **Economic competitiveness:** Industries save on material costs, transport, and landfill fees, while developing **new market opportunities** for eco-materials.

3. **Improved public health and living conditions:** Cleaner environments, less pollution, and reduced exposure to toxic substances improve **quality of life** for communities.

4. **Awareness and education:** Promotes sustainable behavior, environmental awareness, and civic responsibility in citizens and industries.

Part V – Application Exercise

A road construction project uses crystallized slag instead of natural aggregates.

Given: density = 3 t/m^3, cost reduction = 25%, CO_2 emission reduction = 30%.

1. Estimate CO_2 savings if 10,000 t of aggregates are replaced.
2. Discuss other economic and ecological benefits.

Solution:

1. CO_2 savings: 10,000 × 30% = 3,000 t CO_2 avoided.
2. Qualitative benefits: reduced transport emissions, lower costs, and improved sustainability.

Tutorial 2

Recycling and Valorization of Waste Materials

Objectives

By the end of this session, students should be able to:

- Analyze real cases of waste management and valorization.
- Evaluate the environmental and economic impacts of recycling.
- Propose sustainable engineering solutions using recycled materials.

Part I – Comprehension and Analysis

➢ **Exercise 1: Classification Practice**

The following materials are extracted from different industrial activities. Classify them into one of the three categories: **inert waste**, **ordinary industrial waste**, or **special industrial waste.**

Material	Type of waste	Justification
Glass bottles		
Used engine oil		
Concrete rubble		
Contaminated soil		
Plastic packaging		

👉 *Explain your reasoning briefly for each item.*

Answer:

Material	Type of waste	Justification
Glass bottles	Inert waste	Chemically stable, non-reactive, recyclable without pollution.
Used engine oil	Special industrial waste	Toxic, polluting, requires special treatment.
Concrete rubble	Inert waste	Non-biodegradable, stable, used in recycling for aggregates.
Contaminated soil	Special industrial waste	Contains pollutants and heavy metals.
Plastic packaging	Ordinary industrial waste	Non-toxic but non-biodegradable, suitable for recycling.

Summary:

Inert waste = stable (no reaction).

Ordinary industrial = non-hazardous.

Special industrial = hazardous/toxic.

➢ **Exercise 2: Environmental Impact Comparison**

Compare **two waste treatment methods** — *incineration* and *recycling* — according to the following criteria:

Criterion	Incineration	Recycling
CO_2 emissions		
Energy consumption		
Waste reduction efficiency		
Long-term sustainability		

👉 *Which method would you recommend for urban waste management? Why?*

Answer:

Criterion	**Incineration**	**Recycling**
CO_2 emissions	High due to combustion gases	Low (reduces need for new materials)
Energy consumption	High (requires heat)	Lower (energy recovered from reprocessing)
Waste reduction efficiency	70–90% volume reduction	Variable (depends on type of waste)
Long-term sustainability	Moderate (produces ash and gases)	Excellent (supports circular economy)

Recommendation:

For **urban waste**, recycling is more sustainable and economical long-term. Incineration can complement recycling for non-recyclable waste, but it produces greenhouse gases.

Part II – Application and Problem Solving

➢ **Exercise 3: Energy and Cost Savings**

A municipality decides to recycle **12,000 tons of glass waste per year.** Data:

- Energy saving = **30%** compared to manufacturing from raw materials.
- Average cost of energy for new glass production = **500 MJ/ton**.
- Recycling cost = **30 €/ton = 4500 DZD/ton**, raw material cost = **45 €/ton = 6750 DZD/ton**.

Questions:

1. Calculate the **total energy saved** per year (in MJ).
2. Calculate the **total cost savings** per year (in € and DZD).
3. Discuss additional environmental benefits of glass recycling.

Solution:

Given:

- 12,000 tons of glass/year
- 500 MJ/ton (new production energy)
- Energy saving = 30%
- Cost of raw material = 45 € or 6750 DZD/t → recycling = 30 € or 4500 dZD/t

1. **Energy saved:**

$$12{,}000 \times 500 \times 0.30 = 1{,}800{,}000 \text{ MJ/year}$$

2. **Cost savings:**
   Cost difference = 45 - 30 = 15 €/t = 6750 – 4500 = 2250 DZD/t
   Total = $12{,}000 \times 15 = 180{,}000$ € saved per year
   Total = $12{,}000 \times 2250 = 27\ 000\ 000\ DZD$ saved per year
3. **Environmental benefits:**

- Less CO_2 released from furnace operations.
- Reduced extraction of raw materials (sand, lime, soda).
- Lower landfill volumes and transportation emissions.

➢ **Exercise 4: Civil Engineering Application**

A local construction company wants to replace natural aggregates with **crystallized blast furnace slag** in a road sub-base layer.

Given:

- Density of slag = 3 t/m^3.
- Reduction in CO_2 emissions = 28%.
- Reduction in transport cost = 20%.
- Initial quantity of natural aggregates = 5,000 tons.

Questions:

1. Estimate the **CO_2 reduction (in tons)** achieved by this substitution.

2. Estimate the **percentage of cost reduction** in transport.

3. Discuss **two technical advantages** and **one limitation** of using slag instead of natural aggregates.

Solution:

Given:

- 5,000 t aggregates replaced
- CO_2 reduction = 28%
- Transport cost reduction = 20%

1. CO_2 reduction:

$$5{,}000 \times 0.28 = 1{,}400 \text{ tons of } CO_2 \text{ saved}$$

2. Transport cost reduction:

20% reduction from baseline cost → if baseline = 100%, new cost = 80% (savings = 20%).

3. Technical advantages:

- Excellent mechanical strength and stability.
- Lower thermal conductivity (improves pavement performance).
- **Limitation:** Possible variability in composition or expansion (requires aging).

Part III – Discussion and Critical Thinking

➢ **Exercise 5: Life Cycle Reflection**

Explain how a **life cycle assessment (LCA)** contributes to the sustainable use of materials in civil engineering.

Illustrate your answer with an example of a recycled material from your chapters (e.g., fly ash, steel slag, or lime).

Answer:

Life Cycle Assessment (LCA):

Evaluates the environmental impacts of a material from **extraction → production → use → end-of-life → recycling**.

Example (Fly Ash):

- Collected from power plant emissions.
- Replaces 20–30% of cement → reduces clinker and CO_2 emissions.
- Improves durability and workability of concrete.

Conclusion:

The life cycle approach ensures a **closed material loop**, minimizing waste and promoting sustainable construction practices.

➢ **Exercise 6: Debate**

In groups, discuss the following statement:

"Recycling is always the best solution for waste management."

👉 Each group should prepare **3 arguments for** and **3 arguments against** this statement. Then, propose a balanced conclusion from an environmental and economic perspective.

Answer:

Arguments For:

1. Preserves natural resources.
2. Reduces pollution and landfill volume.
3. Creates jobs and supports circular economy.

Arguments Against:

1. Some materials degrade after multiple recycling cycles.
2. Energy and transport can offset benefits.

3. Sorting and processing costs can be high.

Balanced conclusion:
Recycling is **essential** but **not always optimal**.
The best approach is **integrated waste management** combining *reduction*, *reuse*, *recycling*, and *energy recovery*.

Bonus – Open Question "Low-Carbon Construction Project"

Imagine you are an engineer in charge of designing a **low-carbon construction project**. Which recycled or alternative materials would you use, and why?

Describe briefly their origin, advantages, and environmental benefits.

Answer:

Proposed materials:

- **Blast furnace slag** → replaces cement clinker, reduces CO_2 by ~40%.
- **Fly ash** → improves concrete performance and reduces cost.
- **Recycled aggregates** → reduce quarry extraction.
- **Lime and clay-based binders** → lower energy consumption.

Environmental benefits:

- Lower carbon footprint.
- Reduced waste production.
- Promotion of circular economy and local materials.

Tutorial 3

Sustainable Construction and Carbon Footprint Reduction

Objectives

By the end of this session, students should be able to:

- Understand the role of materials in achieving carbon neutrality.
- Evaluate CO_2 emissions in construction processes.
- Analyze the potential of recycling, recarbonation, and alternative binders.
- Propose practical engineering solutions for low-carbon construction.

Part I – Comprehension and Analysis

➢ **Exercise 1 – Key Concepts**

Define the following terms in your own words:

1. Carbon footprint
2. Carbon neutrality
3. Recarbonation
4. Life Cycle Assessment (LCA)
5. Circular economy

Answer:

1. **Carbon footprint**: Total amount of greenhouse gases (expressed as CO_2e) emitted across a product's or activity's life cycle (materials, transport, use, end-of-life).
2. **Carbon neutrality**: A balance where remaining emissions are **fully counterbalanced** by removals/offsets (or avoided via circular strategies), yielding **net-zero**.

3. **Recarbonation**: Natural or accelerated **CO_2 uptake** by alkaline demolition rubble (e.g., crushed concrete), which **re-hardens** and forms better aggregates while **partially offsetting** prior emissions.

4. **Life Cycle Assessment (LCA)**: A **cradle-to-grave / cradle-to-cradle** method that quantifies environmental impacts from raw material extraction through end-of-life (including recycling).

5. **Circular economy**: An economic model that **keeps materials in use** (reduce, reuse, recycle), **minimizes waste**, and **recovers value** from by-products.

➢ **Exercise 2 – Comparative Analysis**

Complete the table comparing the main environmental indicators for three materials used in construction.

Material	**CO_2 Emissions (kg CO_2/ton)**	**Durability**	**Recyclability**	**Remarks**
Ordinary Portland Cement				
Blast Furnace Slag Cement				
Clay or Limestone-based Eco-Cement				

👉 *Explain which material you would recommend for a sustainable infrastructure project and why.*

Answer:

Material	CO_2 Emissions (kg CO_2/ton)*	Durability	Recyclability	Remarks
Ordinary Portland Cement (OPC)	**High** (reference)	High (with proper design)	Moderate (downcycling of concrete)	Baseline binder with high clinker content.
Blast Furnace Slag Cement	**Lower** than OPC	Very good sulfate/chloride resistance	Good (enables industrial by-product use)	Replaces clinker; improves durability & lowers CO_2.
Clay/Limestone Eco-Cement (e.g., LC^3)	**Lower** than OPC	Good (mix-design dependent)	Good	Reduces clinker via calcined clay + limestone.

*Keep this table **relative** unless local LCA data are available.

Recommendation (sample answer): For sustainable infrastructure, choose **Blast Furnace Slag Cement** or **Clay/Limestone Eco-Cement**. Both **cut CO_2** versus OPC and can **improve durability** (especially slag in aggressive environments). Select based on **local availability**, **specifications**, and **exposure class**.

Part II – Calculation and Application

➢ **Exercise 3 – CO_2 Emission Reduction**

A company plans to replace 40% of the clinker in its cement with blast furnace slag. Given:

- 1 ton of clinker emits 850 kg CO_2.
- 1 ton of slag emits 90 kg CO_2 (including processing).

- Annual production = 50,000 tons of cement.

  1. Calculate the CO_2 emissions before and after substitution.
  2. Determine the percentage reduction in total emissions.
  3. Discuss other benefits of using slag-based cement.

Solution:

Given:

- Replace **40% clinker** with **slag**.
- Emission factors: **Clinker = 850 kg CO_2/t**, **Slag = 90 kg CO_2/t**.
- Annual cement production = **50,000 t**.

1) Total CO_2 before substitution (assume 100% clinker baseline)

Per ton: 850 kg CO_2:

Total: $50{,}000 \times 850 = 42{,}500{,}000$kg CO_2 = **42,500 t CO_2**

2) Total CO_2 after substitution (60% clinker, 40% slag)

Per ton: $0.6 \times 850 + 0.4 \times 90 = 510 + 36 = 546$kg CO_2

Total: $50{,}000 \times 546 = 27{,}300{,}000$kg CO_2 = **27,300 t CO_2**

Reduction (absolute and %)

Absolute: $42{,}500 - 27{,}300 = 15{,}200$t CO_2

Percentage: $15{,}200/42{,}500 \approx 0.3576$→ ≈ **35.8% reduction**

3) Other benefits (brief)

- **Clinker factor down → lower fuel & process CO_2**.
- Better **durability** (sulfate/chloride resistance), potential **service-life extension**.

Industrial symbiosis: valorizes slag, reduces landfill.

➢ Exercise 4 – Recarbonation of Demolition Rubble

During demolition, 10,000 tons of concrete rubble are left to recarbonate naturally.

- The recarbonation process captures 80 kg of CO_2 per ton of rubble.

    1. Calculate the total CO_2 absorbed.
    2. If the initial concrete emitted 350 kg CO_2 per ton during production, estimate the percentage of emissions compensated through recarbonation.
    3. Explain how this process contributes to carbon neutrality.

Solution:

Given:

- Rubble: **10,000 t**
- Recarbonation capture: **80 kg CO_2/t**
- Original concrete footprint: **350 kg CO_2/t**

1) Total CO_2 absorbed

$10{,}000 \times 80 = 800{,}000$kg CO_2 = **800 t CO_2**

2) % of original emissions compensated

Original emissions: $10{,}000 \times 350 = 3{,}500{,}000$kg = **3,500 t CO_2**

Compensation: $800/3{,}500 \approx 0.2286$→ **≈ 22.9% compensated**

3) Contribution to carbon neutrality (brief)

Recarbonation **partly offsets** embodied CO_2 and produces **harder, better aggregates**, aiding circularity; it **doesn't** by itself reach net-zero but **meaningfully reduces** net impact.

Part III – Critical Thinking

➢ **Exercise 5 – Strategies for Low-Carbon Construction**

List four strategies that engineers can adopt to reduce the carbon footprint of buildings and infrastructure, focusing on:

- Materials
- Energy efficiency
- Waste management
- Construction methods

Answer:

- **Materials:** lower-clinker cements (slag/LC^3), **fly ash**, **recycled aggregates**, optimized mix designs, low-carbon binders (lime/clay).
- **Energy efficiency:** passive design, high-performance envelopes, efficient MEP, on-site renewables.
- **Waste management:** design for disassembly, modularity, on-site sorting, **reuse/recycling** plans, use of industrial by-products.
- **Construction methods:** optimize logistics, local sourcing, off-site prefabrication, lean scheduling to cut idle time and waste.

➢ **Exercise 6 – Discussion**

"Sustainable construction is not only about reducing emissions, but also about creating a circular material cycle."

Discuss this statement in 10–15 lines, using examples from industrial by-products (slag, fly ash, lime, etc.).

Answer:

Sustainable construction goes beyond emission cuts; it **closes material loops**. By integrating **industrial by-products** (e.g., blast furnace slag, fly ash) into binders and aggregates, projects **reduce clinker demand**, **lower CO_2**, and **extend service life** through improved durability. Recycled aggregates and **recarbonated rubble** keep mineral resources in circulation and shrink landfill use. LCA helps **quantify trade-offs** and prevent burden-shifting across stages. While recycling and substitution are pivotal, they must be combined with **demand reduction** (efficient design), **reuse**, and **smart construction** (prefab, logistics). The most resilient approach is a **circular system** that maintains value, reduces extraction, and **improves socio-economic outcomes** (local jobs, lower costs). Thus, sustainability is a **systems question**: materials, methods, and management working together.

Bonus – Applied Research Question

Imagine you are tasked with designing a carbon-neutral housing project. Describe briefly which materials, technologies, and design principles you would select to minimize the environmental footprint of the building.

Answer:

For a **carbon-neutral housing project**:

- **Binders & concrete:** use **slag- or LC^3-based cements**, **fly ash**, and **recycled aggregates**; design mixes for **lower clinker** and **target durability**.
- **Envelope & energy:** passive solar design, high-R insulation, airtightness, **heat pumps**, PV + battery, smart controls.
- **Circular design:** modular components, design for disassembly, **material passports** for future reuse.
- **Site & water:** low-impact foundations, permeable surfaces, **rainwater harvesting**, greywater reuse.
- **Verification:** LCA from early design; **commissioning** and post-occupancy monitoring.

Outcome: **lower embodied and operational CO_2**, high durability, and a **replicable** low-carbon model.

Tutorial 4

Recycling in Road Pavements (RAP)

➢ **Exercise 1 — Sources & Categories (concept)**

Q. Name the three categories used to classify bituminous materials to be recycled and give one typical characteristic of each.

Answer:

- **Single-origin materials**: usually from large jobs, obtained by **milling**, relatively **homogeneous**; often **ready to reuse** immediately or after short storage.
- **Various origins stored separately**: often from medium-sized works; **composition not always known**; typically supplied as **milled RAP**; may require **crushing/screening** first.
- **Mixed origins**: small jobs & manufacturing rejects; supplied as **milled material or blocks**; **highly heterogeneous** and therefore **crushing/screening to ≤ 31.5 mm** is required before use.

➢ **Exercise 2 — Conditioning & sizing (quick checks)**

Q1. A RAP stock contains many 45 mm chunks. Is it acceptable for hot recycling as is?
Q2. Why does the milling process (e.g., advance speed) matter for RAP quality?

Answer:

- **A1. No**. Apparent size must be **≤ 31.5 mm** to ensure good disintegration in the plant; oversized RAP must be crushed/screened.
- **A2.** Milling parameters affect **nominal size (D_n)** and **fine content** of RAP, which must be compatible with the **target gradation** of the final mixture.

➢ **Exercise 3 — Standards: maximum RAP contents by product/layer**

Q. Using the 1999+ standards, give the **permissible RAP percentages** for these products/layers when nothing else is specified in the contract:

a) **BBSG** surface course; b) **BBSG** binder course; c) **GB**; d) **EME**; e) **BBM type C** surface course.

Answer:

- a) **BBSG surface**: **10%**;
- b) **BBSG binder**: **20%**;
- c) **GB**: **40%**;
- d) **EME**: **40%**;
- e) **BBM type C surface**: **10%**.

➢ **Exercise 4 — Layer eligibility when RAP is not characterized**

Q. If RAP is **not characterized** or parameters are **unspecified**, is recycling allowed in a **surface course**? If not, what is the fallback? State the rule for allowing RAP in a surface course.

Answer:

- **Not allowed** in surface courses when RAP is uncharacterized. It may be accepted up to **10%** in **binder or base** layers.
- To use RAP in a **surface course**, one of the following must hold: RAP **comes from a surface course**, **binder content ≥ 5.5%**, or RAP aggregates have **characteristics consistent with surface use**.

➢ **Exercise 5 — Plant technology & achievable RAP rate**

Q. Match plant configuration to the **maximum recommended RAP rate** and name the **limiting factor(s)**:

1. Batch plant, **hot elevator foot**;
2. Batch plant, **recycling dryer**;
3. Batch plant, **specific RAP dryer**;
4. **Parallel-flow drum (TSE équicourant)**, mid-drum;
5. **Counterflow drum (TSE contre-courant)**, outside gas stream.

Answer:

1. **15%**, limits: **steam evacuation & clogging**.
2. **25%**, limit: **clogging of hot elevator**.
3. **50%**, limit: **environmental impact**.
4. **30%**, limit: **filter bag clogging**.
5. **50%**, limits: **aggregate overheating**, **drum & gas temperature**.

➢ **Exercise 6 — Production planning (numerical)**

A batch plant with a **recycling dryer** (so max **25% RAP**) must produce **1,600 t** of HMA today. **Q1.** What is the **maximum RAP tonnage** you can feed while respecting the limit? **Q2.** If the client specification requires **BBSG surface** with default standard limits, does your 25% plan comply? If not, what is the highest **compliant** RAP mass?

Answer:

- **A1.** Max RAP mass = 25% × 1,600 t = **400 t RAP** (with 1,200 t virgin mix).
- **A2.** For **BBSG surface**, the standard limit is **10%** RAP by default → allowed RAP = 10% × 1,600 t = **160 t RAP**. The **25%** plan **does not comply** with default BBSG-surface limits.

- **<u>Exercise 7 — Preliminary studies (workflow)</u>**

Q. List the **three chronological steps** of preliminary studies and, for the **general case**, name two key checks in the first step.

Answer:

- **Steps:** (1) **Identification of components**; (2) **Mix design development**; (3) **Formulation trial** (performance verification).
- **General case checks (step 1):** e.g., **quantify RAP stock**, **characterize natural aggregates (NF EN 13-043)**, and **characterize RAP per XP P 98-135**—granulometry (before/after extraction) and **binder content**.

- **<u>Exercise 8 — Heterogeneous RAP (special case)</u>**

Your RAP yard is very mixed; representative characterization is **impossible** (RAP treated as **NS**). **Q.** State the **layer-wise recycling caps** and any **conditions** that still allow a **surface course**. Also, how should the designer proceed with the mix design?

Solution:

- **Caps: 10%** in **binder**, **15%** in **base** layers (special-case guidance).
- **Surface course** still possible if **any one** holds: RAP **originates from surface course**, or proof that RAP aggregates are ≥ **Category C**, or **average binder content > 5.5%** after conditioning/homogenization.
- **Designer procedure:** start from an **existing verified design** (with naturals or with RAP), then **adapt** using standardized tests for natural aggregates and **declared** values for RAP; verify by **formulation trial**.

➢ <u>**Exercise 9 — Storage & homogeneity (short answer)**</u>

Q. Why do storage/handling practices matter for RAP prior to production? Give two reasons.

Answer:

To **enhance homogeneity** so that:

1. **Tests are representative**;
2. **Production is regular**; and
3. **Quality in use is consistent** (performance levels are repeatable).

Tutorial 5

Waste Recovery

PART I – Definitions and Basic Knowledge

1. What is wastewater treatment sludge?

It is the mixture of organic and mineral matter removed from wastewater during treatment.

2. Cite and define the three main types of sludge produced in treatment plants.

- *Primary sludge*: obtained by settling.
- *Physico-chemical sludge*: rich in organic matter, produced after biological treatment.
- *Mixed sludge*: combination of primary and secondary sludge.

3. What is the purpose of thickening, stabilization, and dewatering in sludge treatment?

- *Thickening*: increases dry matter.
- *Stabilization*: reduces pathogens and odors.
- *Dewatering*: extracts excess water and reduces volume.

4. Give two examples of sludge valorization and two examples of sludge elimination.

- *Valorization*: agriculture (fertilizer/compost), energy recovery in furnaces.
- *Elimination*: incineration, landfill disposal.

5. Why are sludge from nuclear or chemical industries never valorized?

Because they may contain toxic, radioactive, or hazardous substances that make valorization unsafe.

PART II – Dredging Sediments

6. What is dredging and why is it necessary?

Dredging is the underwater excavation of sediments to maintain navigation channels or extract materials.

7. How can dredged materials be handled or transported after extraction?

By barge transport, pumping through pipelines, or storage on land.

8. Why are sampling and laboratory analysis essential for dredged sediments?

To detect contamination (heavy metals, pollutants) and determine safe disposal or valorization routes.

9. What is "Sea dumping" and under what condition is it authorized?

Sea dumping of dredged material; authorized only if no alternative exists and a special permit is obtained.

10. Give two examples of sediment treatment techniques.

Thermal treatment, biological treatment, physico-chemical treatment, immobilization.

PART III – Rubber Waste

11. What are the two main families of rubber?

Natural rubber (from Hevea latex) and synthetic rubber (from petroleum derivatives).

12. What are the four origins of rubber waste?

Industrial rubber waste (8%), tire manufacturing scraps (3.5%), used tires (86.6%), recycling residues (2%).

13. Give two non-industrial recycling examples for old tires.

Painted tires used as garden furniture; tires used as flower pots.

14. What is pyrolysis in the context of rubber recycling?

Pyrolysis is the thermal decomposition of rubber in the absence of oxygen to produce oil, carbon black, and gas.

15. In industrial recycling, what materials are extracted from used tires?

Rubber, steel, fibers, plastic, and pure rubber powder.

PART IV – Numerical Exercises

➢ **Exercise 1 – Sludge Volume Reduction**

A treatment plant produces **80 m³/day** of sludge with **4% dry matter**. After thickening, the dry matter increases to **15%**.

- Calculate the new volume of sludge (in m³/day).

Solution:

Dry matter = 4% of 80 = **3.2 m³ solids**

Final volume = solids / final dry matter

= 3.2 / 0.15

= **21.33 m³/day**

➢ **Exercise 2 – Sediment Storage Classification**

A sediment stockpile contains **32,000 m³** of dredged material. According to ICPE regulations:

- 15,000 m³ → declaration
- 75,000 m³ → authorization

- Classify the installation.

Solution:

32,000 m^3 > 15,000 m^3 → **Declaration required**

(Not high enough for authorization.)

- **Exercise 3 – Recycled Rubber Quantity**

A factory produces **10,000 kg/month** of rubber products. 10% of this quantity can be reintegrated as recycled micronized rubber.

Calculate the amount of recycled rubber used per month.

Solution:

10% of 10,000 kg = **1,000 kg recycled rubber per month**

- **Exercise 4 – Tire Pyrolysis Yield**

A batch of **5 tons** of tires undergoes pyrolysis with the following output ratios:

- Oil: 40%
- Carbon black: 35%
- Gas/energy: 25%

Calculate the mass (in tons) of each product.

Solution:

Oil: 40% of 5 tons = **2 tons**

Carbon black: 35% of 5 tons = **1.75 tons**

Gas/energy: 25% of 5 tons = **1.25 tons**

➢ Exercise 5 – Dewatering Efficiency

A sludge mass of **50 tons** contains **30 tons of water**. After dewatering, **half of the water** is removed.

a) How much water is eliminated?

b) What is the final mass of the sludge?

Solution:

Water eliminated = 30 / 2 = **15 tons**

Final mass = solids (20 tons) + remaining water (15 tons) = **35 tons**

Tutorial 6

Construction & Demolition Waste (C&DW)

PART I — Multiple Choice Questions

Q1. Construction and demolition waste (C&DW) generally represents:

A. 5–10%

B. 15–20%

C. 25–35%

D. More than 50%

✓ Answer: C. 25–35%

Q2. Which of the following is considered *inert* waste?

A. Solvents

B. Wood

C. Concrete

D. PVC

✓ Answer: C. Concrete

Q3. The primary goal of selective demolition is to:

A. Speed up demolition

B. Reduce labor costs

C. Improve sorting and recycling

D. Reduce building height

✓ Answer: C. Improve sorting and recycling

Q4. Which material can be infinitely recycled without quality loss?

A. Glass

B. Wood

C. Metals

D. Plastics

✓ Answer: C. Metals

Q5. Plaster (gypsum) belongs to:

A. Inert waste

B. Hazardous waste

C. Non-hazardous but non-inert waste

D. Liquid waste

✓ Answer: C. Non-hazardous but non-inert waste

Q6. Asbestos in buildings is classified as:

A. Inert

B. Non-hazardous

C. Hazardous

D. Biomass

✓ Answer: C. Hazardous

Q7. The main environmental impact of aggregate extraction is:

A. Higher cement price

B. Habitat destruction

C. Increased soil coloration

D. Noise reduction

✓ Answer: B. Habitat destruction

Q8. Recycled concrete aggregates (RCA) are mainly used for:

A. High-strength structural concrete

B. Road sub-base layers

C. Glass production

D. Metal manufacturing

✓ Answer: B. Road sub-base layers

Q9. Source separation (on-site sorting) allows:

A. More ultimate waste

B. Lower recycling quality

C. Reduced mixing of waste

D. More dangerous treatment

✓ Answer: C. Reduced mixing of waste

Q10. Which European directive addresses waste management?

A. Directive 2008/98/EC

B. Directive 2018/41/EU

C. Directive 1999/15/EC

D. ISO 9001

✓ Answer: A. Directive 2008/98/EC

PART II — Short Answer Questions

Q11. Define C&DW and explain why it is an environmental issue.

✓ Answer:

C&DW refers to materials generated from construction, renovation, and demolition activities. It is an environmental issue because it represents large volumes, consumes landfill space, contributes to pollution, and involves high resource consumption when not recycled.

Q12. List three demolition materials that can be directly reused.

✓ Answer:

- Bricks and pavers
- Steel beams
- Doors and windows

Q13. Difference between inert and hazardous waste?

✓ Answer:

- **Inert waste:** does not chemically or biologically react (e.g., concrete, bricks).
- **Hazardous waste:** contains toxic substances harmful to health or environment (e.g., asbestos, lead paint).

Q14. Give two applications of recycled aggregates.

✓ Answer:

- Road sub-base and foundation layers
- Backfilling and embankments

Q15. Why does prefabrication reduce C&D waste?

✓ Answer:

Because materials are manufactured in controlled factories, reducing cutting losses, handling errors, and on-site waste generation.

PART III — Numerical Exercises

➢ **Exercise 1 — Recycling Rate**

A demolition company produces **12,000 tons** of C&DW per year.
It successfully recycles **7,800 tons**.

- Calculate the recycling rate.

Solution:

→ Recycling rate = (Recycled / Total) × 100
= (7,800 / 12,000) × 100
= **65%**

✔ **Answer: 65%**

➢ **Exercise 2 — Material Savings**

Recycling 1 ton of aggregates avoids the extraction of **1.5 tons** of natural aggregates.
A construction project uses **4,000 tons** of recycled aggregates.

- How many tons of natural aggregates are saved?

Solution:

→ Natural aggregates saved = 4,000 × 1.5
= **6,000 tons**

✔ **Answer: 6,000 tons**

➢ **Exercise 3 — Emission Reduction**

Recycled concrete emits **25% less CO_2** than conventional concrete.
A project using conventional concrete emits **1,200 tons of CO_2**.

- How much CO_2 would be emitted using recycled concrete?

Solution:

→ Emission reduction = 1,200 × 0.25 = 300

→ New emission = 1,200 − 300 = **900 tons CO_2**

✔ **Answer: 900 tons CO_2**

- **Exercise 4 — Metal Recovery**

A building contains **150 tons** of steel.
During demolition, **92%** of the steel is recovered.

- Calculate the mass of recovered steel.

Solution:

→ Recovered mass = 150 × 0.92 = **138 tons**

✔ **Answer: 138 tons**

- **Exercise 5 — Landfill Pressure**

A city generates **30,000 tons** of C&DW.
With sorting and recycling, **68%** is recovered.

- How many tons still go to landfill?

Solution:

Total = 30,000 tons
68% recovered → 32% landfilled.

→ Landfilled = 30,000 × 0.32 = **9,600 tons**

✔ **Answer: 9,600 tons**