CHAPTER 1

INDUSTRIAL SOLID WASTES UTILIZATION AND DISPOSAL

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INTRODUCTION

There are a lot of definitions for the word *industry*. The most generic definition is, "An organized manmade activity that provides goods and services essential for maintaining and developing human life." As much as there is diversity in human needs and activities, there is also a great diversity in industry. North America Industrial Classification System (NAICS) has classified industries into the following industrial sectors according to their activities:

- Agriculture, forestry, fishing, and hunting
- Mining
- Utilities
- Construction
- Manufacturing
- Wholesale trade
- Retail trade
- Transportation and warehousing
- Information
- Finance and insurance
- Real estate and rental and leasing
- Professional, scientific, and technical services
- Management of companies and enterprises

- Administrative and support and waste management and remediation Services
- Educational services
- Health care and social assistance
- Arts, entertainment, and recreation
- Accommodation and food services
- Other services (except public administration)
- Public administration

Another approach to classifying industries in different Asian and African countries is by their potential environmental impact according to three different categories. The three main categories are white-list industries, "category A," gray-list industries, "category B," and black-list industries, "category C."

White-list industries/projects/establishments have minor environmental impacts. They include the following:

- Textile factories, excluding dying unit and located in approved industrial sites
- Leather and shoe factories situated in approved industrial sites without tanneries
- Rubber and plastic factories situated in approved industrial sites
- Smokehouses producing small quantities (500 Kg or less) of foodstuff per day
- Very small wastewater treatment plants with a capacity of 1,000 person equivalent or less
- The expansion or modification of an existing road that would be immediately carried out to lengthen the road or widen it by 15 percent or less
- Breweries, malt houses, and mineral-water factories situated in approved industrial sites

Gray-list projects or industries for establishments might result in substantial environmental impacts. They include the following:

- Iron foundries and nonferrous metal foundries
- Engine works and machine shops
- Manufacture and assembly of motor vehicles
- Cleaning establishments and commercial operated laundries
- Tanneries with a production of 1 million square feet/year or less
- Pharmaceutical and chemical factories
- Small wastewater treatment plants with a capacity ranging from 1,000 person equivalent to 1 million person equivalent, etc.

Black-list projects or industries for establishments have severe potential impacts. These include the following:

- Iron and steel works with production greater than 150 metric tons/day
- Cement works using dry process and lime works with high capacity (100 metric tons/hour and above)
- Mining minerals in new areas where the mining excesses a total area of 1,500 acre land
- Pesticide manufacturing plants
- Pulp and paper production
- Lead smelters
- Oil and gas fields development, production, and exploration

A third approach to classify industries into two major sectors: the primary sector and the secondary sector. The primary sector of industry is responsible for converting the natural resources into primary products. The major types of industries that are considered to be primary industry are agricultural industry, mining, fishing, and forestry. Those types of industry prepare the raw material for other industries. The secondary industries take the output of the primary industries and, through processing, manufacturing, and construction provide a finished product ready to be used by the consumer. The secondary sector can be further classified into heavy industries and light industries. Heavy industries include iron and steel industries, marble and granite industries, petroleum and petrochemical industries, industrial equipments, and cement industry. Light industries include textile, clothing, food (including sugar and dairy), oil and soap, chemical and pharmaceutical, pulp and paper, metal finishing, furniture, fertilizers, tanning, electronics, and telecommunication industries.

Whatever the methodology utilized to classify industries within the industrial sector, the most important concern here is that these classifications are usually done to assemble companies into common groups that reflect shared markets and products or to reflect their degree of impact on the environment so that more control or waste utilization could be achieved.

Industry has been an open system of materials flow. People transformed natural materials such as plants, animals, and minerals into tools, clothing, and other products. When these materials were worn out, they were dumped or discarded, and when the refuse buildup bothered the habitants, they simply relocated it, which was easy to do at the time due to the small number of habitants and the vast areas of land.

An open industrial system—one that takes in materials, energy and water, creates products and waste materials and then throws most of these—will probably not continue indefinitely and will have to be replaced by a different system. This system would involve, among other things, paying more attention to where materials end up, and choosing materials and manufacturing processes that generate a more circular flow through recycling concept. Until today, industrial societies have attempted to deal with pollution and other forms of waste largely through pollution control, treatment, or disposal regulations according to life cycle assessment (LCA), following the concept of cradle-to-grave shown

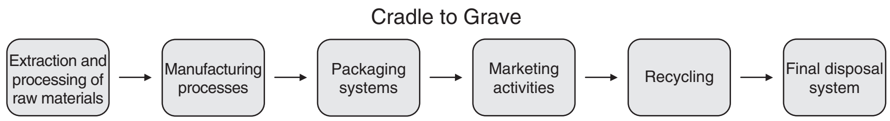

FIGURE 1.1 Traditional life cycle assessment.

in Figure 1.1. Although the "depletion of natural resources" strategy has been partially successful, the high capital and running costs, as well as the depletion of natural resources, cause it to be "unsustainable." Consequently, LCA should be based on the cradle-to-cradle concept, not cradle-to-grave concept, for industrial activities for conservation of natural resources.[1] The goals of any industry must include the preservation and improvement of the environment, as well as the conservation of natural resources. With industrial activities increasing all over the world today, new ways must be developed to make large improvements in our industrial interactions with the environment.

Industrial development/modernization is characterized by two main trends. The first is the establishment of new technologically competitive industries, and the second is the expansion and renovation of existing industries to increase their productivity. Industrial modernization is characterized by implementing cleaner production techniques to approach industrial ecology and reach cradle-to-cradle concept.[1] Industrial development and industrial modernization require establishing a good management system within an existing establishment such as an environmental management system or ISO 14001 to be able to approach cradle-to-cradle.

The new strategy for conservation of natural resources according to the cradle-to-cradle concept discussed in this chapter will help the developing countries to develop new job opportunities and reduce the cost of products as well as protecting the environment without any further burden to the investors. As for developed countries, this will help them conserve the natural resources so they can stop searching for more and more suitable sites for landfills. According to the Japan Environmental Agency, Japan currently consumes 1,950 million metric tons/year of natural resources and imports 700 million metric tons/year from overseas.[2] A total of 450 million metric tons of waste (industrial and municipal) are generated per year. Over 60 percent of this waste is either incinerated or landfilled. Current estimates predict that remaining landfill capacity will be exhausted by 2007. As a result, Japan's government has created a comprehensive program for achieving a *recycling economy* through a series of laws such as the Basic Law for Promoting the Creation of a Recycling Oriented Society and the law for the Promotion of Effective Utilization of Recycled Resources.

LIFE CYCLE ASSESSMENT AND CRADLE-TO-CRADLE CONCEPT

Life cycle assessment (LCA) is one of the very important tools to evaluate the environmental impacts associated with any given industrial activity, from the initial gathering of raw materials from the earth to the point at which all residuals are returned back to the earth, or cradle-to-grave. LCA results will not be promising for industrial activities that are based on a cradle-to-grave flow of materials. Unfortunately, most manufacturing processes since the Industrial Revolution began are based on a one way, cradle-to-grave flow of materials—starting with the extraction of raw materials, followed by processing, producing, and marketing of the goods, then utilization by consumers, and finally, disposal of waste generation, as shown in Figure 1.1.[3] The technological advancements in manufacturing processes and the constantly increasing variety of materials and products have led to a continuous rise in the amounts of waste generated. The cradle-to-grave flow of materials has proven to be just enough to protect the environment if proper and efficient disposal facilities are used. In developing countries, however, improper environmental design and operation of the disposal facility usually cause severe ecological impact as well as depletion of natural resources.

LCA helps identify the impact of the product on the environment throughout its life cycle. The main components of LCA should include the identification and quantification of not only the waste generated through the entire life cycle but also the raw materials and energy requirements throughout the entire life cycle and their environmental impacts.

A lot of work has been done to develop methodologies, guidelines, and benefits for LCA according to the cradle-to-grave concept to protect the environment throughout the life cycle of the product. The International Organization for Standardization (ISO) has develop a series of international standards to cover LCA in a more global sense, such as ISO14040 (LCA—Principles and Guidelines), ISO14041 (LCA—Life Inventory Analysis), ISO14042 (LCA—Impact Assessment), and ISO14043 (LCA—Interpretation). All ISO 1404Xs that are related to LCA are based on cradle-to-grave approach for environmental protection. It is time now to change the LCA-ISO standard from cradle-to-grave to cradle-to-cradle to protect not only the environment but also the natural resources.

LCA is a very important tool to guarantee that there are no harmful impacts on the environment, starting from extracting the raw material (cradle) all the way to the final disposal in a landfill (grave). In other words, the product's design should be selected, in part, according to safe disposal process. This process protects the environment but will deplete the natural resources. By contrast, under a cradle-to-cradle concept, the product's design would be such that materials could be reused or recycled, no wastes would get produced or would be recycled, and accordingly, no negative impacts on the environment would get generated within the closed loop of life cycle of the product, as shown in Figure 1.2. This can be achieved by having industries change their products from a cradle-to-grave design, where the product will eventually get disposed of in a landfill at the end of its life, to a cradle-to-cradle design, where the materials are circulated in a closed loop without losing any natural resources. The environmental and health impacts—as well as the consequences of depleting the natural resources as a result of using traditional treatment, incineration and/or final disposal through

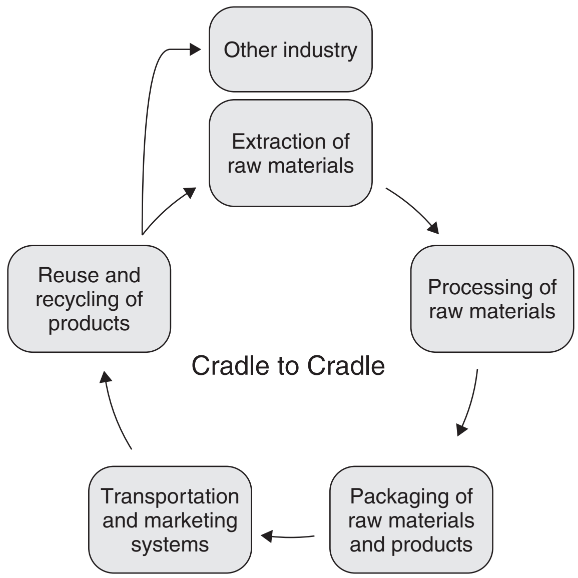

FIGURE 1.2 New life cycle analysis based on the cradle-to-cradle concept.

landfill—are becoming more dangerous, and making sustainable development a more urgent need. Establishing or approaching a new LCA based on the concept of cradle to cradle instead of cradle to grave by a full utilization of raw material, water, and energy is a must for sustainable development.[4]

Braungart and McDonough [2002] proposed a shift from a cradle-to-grave approach where waste products are disposed of in a landfill to a cradle-to-cradle approach, where waste can be used for the production of other products. They recommended the "eco-effective" recycling approach to enable material reuse with high quality. They added that combining different materials in one product prevents the products from being fully recycled. Accordingly, product designers need to plan for the reuse of their products in order to prevent waste generation. This shift in a product's design approach will require an added responsibility to the producer—extended producer responsibility, or EPR—to be able to recycle the products after its lifetime.

The cradle-to-cradle concept promotes sustainable development in a practical approach, as will be discussed throughout this chapter. It is a system of thinking based on the belief that human endeavors can emulate nature's elegant system of safe and regenerative productivity, by transforming industries to sustainable enterprises and eliminating the concept of waste.

Natural ecosystems are based on principles that can be adopted by humans in industry. For example, no waste generation—in natural ecosystems, an organism's waste is consumed by others. This can be applied in industry such that one industry's wastes are another's raw material. *Industrial ecology* will be discussed later in this chapter. This is the fundamental concept of eco-industrial parks, where industries are grouped together to have a continuous flow of material and no waste generation, as in the case of eco-industrial park in Kalundborg, Denmark, and other places worldwide.

Adopting cradle-to-cradle principles creates a cyclical flow of materials, as opposed to the one-way cradle-to-grave concept. The materials consumed in industry resemble the nutrients that flow cyclically in natural ecosystems and can circulate in one of two metabolisms, biological or technical.

According to the cradle-to-cradle concept, products would be made of materials that can be safely manufactured, used, recovered, and reused, while still maintaining their high value throughout their life cycle. This way, valuable used material can be continuously cycled in closed loops and transformed for reuse as other products. By applying the principle of cradle-to-cradle design and transforming industrial systems to a closed-loop system of material flow, not only will this design save the environment from waste generation and negative impacts, but industries can even benefit from the continuous availability of products made of high-value material even after the end of the product's lifetime.

INDUSTRIAL WASTE

The most common industrial wastes generated from industrial sectors are packaging materials using plastic and paper from almost all industrial sectors, organic wastes from food and other industries, dust from the cement industry and the marble and granite industries, glass culets from almost all industries, slag and foundry sand wastes from smelters or foundries, and waste from iron and steel industries.

Closing the loop for sustainable industrial waste management (SIWM) is very important for national development. SIWM means all components within the industrial wastes should be recycled in order to reach the cradle-to-cradle ideal for industrial waste management. This might require development of innovative recycling techniques through universities or research centers or added regulations on producers, such as extended producer responsibility (EPR) to design the products for recyclability. The cradle-to-cradle approach is new worldwide but has been implemented with success at The American University in Cairo (AUC) for most types of wastes, as will be discussed in this chapter.[1]

PLASTICS INDUSTRY

Plastics have played a very significant role in industrial development since their invention. If we take a look around us, we will discover that most tools, accessories, packaging, and equipment are made out of plastic, as shown in Figure 1.3. Some of these products have a very short life cycle and are highly consumable. Others might have longer life cycle. These products are used frequently and, in most cases, are then discarded and turned to wastes. Recycling of plastics has become a great industry throughout the world because of its effectiveness and high profits.

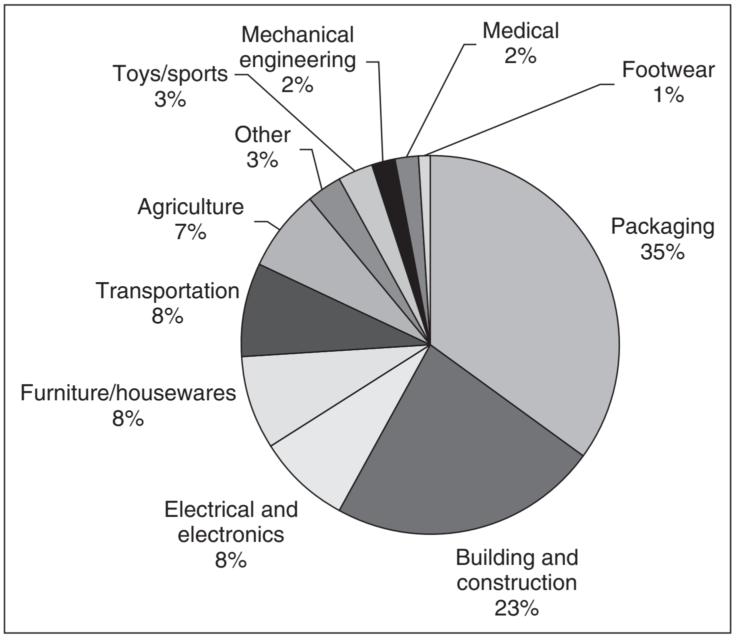

FIGURE 1.3 Uses of plastics by industry. (*Source:* R. J. Crawford, *Plastics Engineering*, 3rd ed. (Oxford: Butterworth–Heinemann, 1998).)

Even though plastics have a variety of benefits, they are detrimental to the environment. Many of the environmental impacts associated with the production and manufacturing of plastics include the fact that plastic production consumes a large amount of energy and materials, primarily fossil fuel, which, when combusted, emits toxins into the air. It is estimated that 4 percent of the world's annual oil production is used as a feedstock for plastics production and an additional 3-4 percent is used during manufacture.[5] Plastics production also involves the use of potentially harmful chemicals, which are added as stabilizers or colorants. Many of these have not undergone environmental risk assessment, and their impact on human health and the environment is currently uncertain.[5] An example of this is phthalates, which are used in the manufacture of polyvinylchloride (PVC). PVC has in the past been used in toys for young children, and there has been concern that phthalates may be released when these toys come into contact with saliva, if the toy is placed in the child's mouth or chewed by the child. Risk assessments of the effects of phthalates on the environment are currently being carried out.[5] Other environmental impacts of plastics include the extensive amount of water that is needed in manufacturing. Also, the numerous plastic bags that are dispersed as litter in urban areas have also become a plaguing concern. Due to the magnitude of the problem associated with plastic waste, this section focuses on methods and mechanisms to reduce this problem for the betterment of the environment and our lifestyles. A different study concluded that 1.8 metric tons of oil are saved for every metric ton of recycled polythene produced.[5] The benefits of recycling plastics are numerous, and thus should be investigated and utilized to the fullest extent.

There are numerous benefits to the recycling of plastics:

- Reduce water usage by 90 percent.
- Reduce CO_2 emissions by two and a half times.
- Reduce energy consumption by two-thirds.[5]

Plastic is divided mainly into two types: thermo plastics and thermo sets. Each type has its own manufacturing processes and its own characteristics. Most of the plastics are considered thermo plastics and can be recycled easily without any problems such as polypropylene (PP), Polyethylene terephthalate (PET), high-density polyethylene (HDPE), low-density polyethylene (LDPE), and polyvinyl chloride (PVC). The other type of plastics is called thermo sets. This type is difficult to recycle due to its chemical composition. As a result, products from this type of plastics are discarded. These include melamine, epoxy, phenolics, and alkyds. It is worth mentioning that most thermo sets have excellent mechanical properties rather than thermo plastics. Thus, it is considered a total loss and waste of energy if these wastes are not recycled.

Thermo Plastics

Most thermo plastics can be recycled; however, there are four types of thermo plastics that are commonly recycled due to their high percentage of usage. Figure 1.4 shows the distribution and the amount of the plastic materials to be

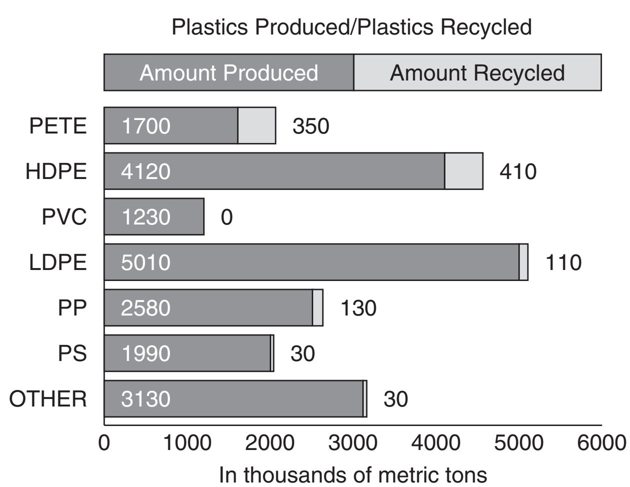

FIGURE 1.4 Amount of thermo plastics produced and recycled in the United States.

recycled every year in the United States. These recyclable materials are arranged from the most frequently used to the least frequently used as follows:

- Polyethylene (PE): it includes high and low density polyethylene
- Polypropylene (PP)
- Polystyrene (PS)
- Polyvinyl chloride (PVC)

Plastic recycling is still a relatively new and developing field of recycling. The postconsumer items made from PET and HDPE resins have found reliable markets within the United States, Asia, and Africa. Applications for recycled plastics are growing every day. Plastic waste can be blended with a certain percentage to virgin plastic to reduce cost without sacrificing properties. Recycled plastics are used to make polymeric timbers for use in picnic tables, fences, and outdoor toys, thus saving natural resources.

About 35 to 50 percent of the total volume of plastic wastes is in the form of packaging wastes, as shown in Figure 1.3. Once rejected, plastics packages gets contaminated and reuse creates a more serious problem, which is the so-called commingled plastics, affecting, in return, the properties of the new recycled products.[6]

The recycling of thermoplastics, or plastics, can be accomplished easily with high revenue. Each type of plastic must go through a different process before being recycled. Hundreds of different types of plastics exist, but 80 to 90 percent of the plastics used in consumer products are (1) PET (polyethylene terephthalate), (2) HDPE (high-density polyethylene), (3) PVC (polyvinyl chloride), (4) LDPE (low-density polyethylene), (5) PP (polypropylene), (6) PS (polystyrene), and (7) others (such as vinyl), as shown in Figure 1.5.

Plastics can be recycled mechanically or chemically. Chemical recycling can solve the problem of composites better than mechanical recycling.[7] Each one has its own pros and cons for recycling plastics. So, it is very important to decide which techniques will be selected according to the type of waste and the product(s) produced. Mechanical recycling is the most famous recycling technique because of its simplicity to use and ability to be handled by anyone. Mechanical recycling involve a number of processes such as cleaning, sorting, cutting, shredding, agglomeration, pelletizing, and finally reprocessing by injection molding, blowing, or extrusion according to the required products. A simplified schematic diagram for plastic recycling process is shown in Figure 1.6.

Recycled PET has many uses, and there are well-established markets for this useful resin. By far, the largest usage is in textiles. Carpet manufacturing companies can often use 100 percent recycled resin to manufacture polyester carpets in a variety of colors and textures. PET is also spun like cotton candy to make fiber filling for pillows, quilts, and jackets. PET can also be rolled into clear sheets or ribbon for audiocassettes. In addition, a substantial quantity goes back into the bottle market. China is currently using it in the manufacturing process of fiberoptics.

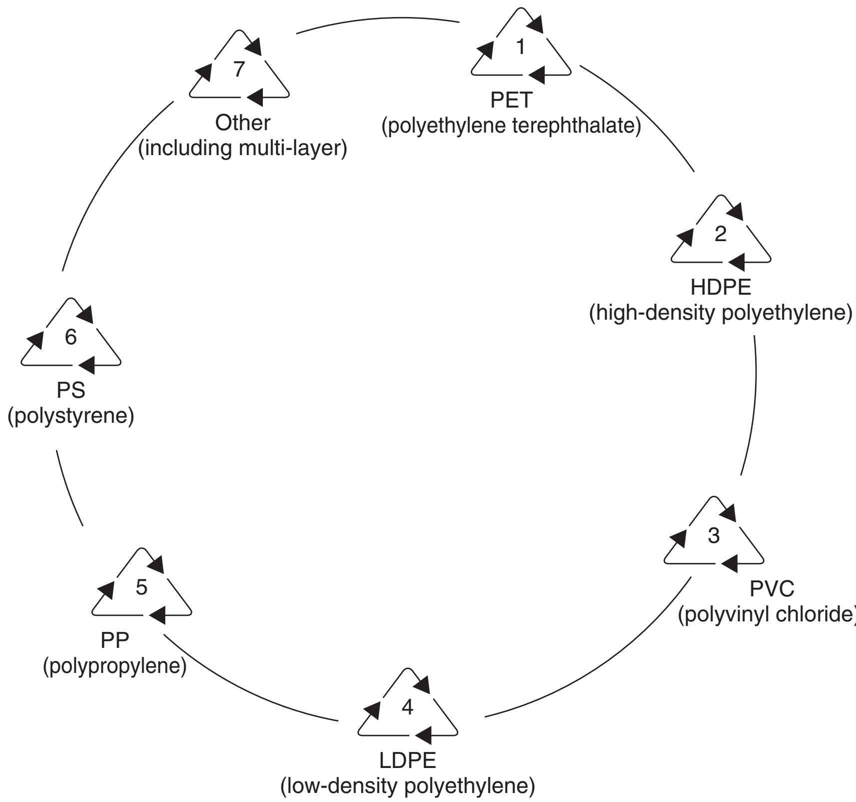

FIGURE 1.5 Coding of thermoplastics.

Some common end uses for recycled HDPE are plastic pipes, lumber, flowerpots, trashcans, or nonfood application bottles. Some end uses for recycled LDPE are plastic trash bags and grocery sacks, plastic tubing, agricultural film, and plastic lumber.

There are mainly three stages needed to recycle plastics. The initial stage, where the wastes are collected, sorted, separated, and cleaned, is labor intensive, requiring little capital investment and relatively no technical skills. Automating this stage requires high capital and might not be economically visible to be able to continue with recycling. Careful attention of this process is very important to guarantee the economics of recycling. It is always recommended to use plastic coding system shown in Figure 1.5 to sort plastic easily and to enhance the properties of recycled plastic. The second-stage, preprocessing, is where the collected wastes are being prepared for processing. In this stage, the wastes are reduced in size by undergoing cutting, shredding, and agglomeration. The final stage is the processing stage, where mixing, extrusion, blowing, injection, and product manufacturing takes place. All types of thermo plastics can be recycled if they are sorted and properly cleaned, as shown in Figure 1.6.[8]

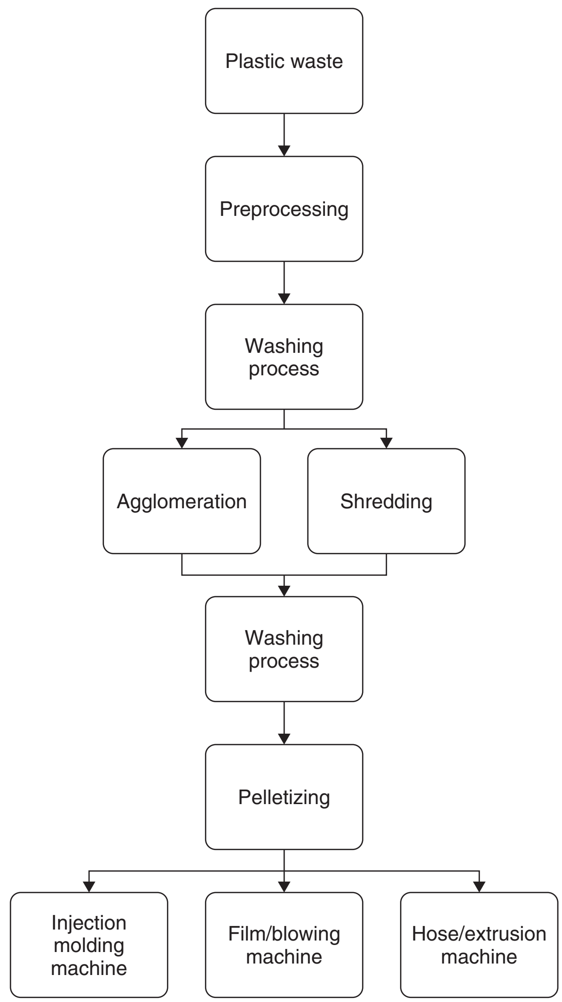

FIGURE 1.6 Process flow diagram for plastic recycling.

Thermosets

Thermosets are the second type of plastic products. Thermosets are formed by aid of the thermo plastics polymers when they covalently bonded to form chains that are interconnected and cross-linked to each other, and they differ from thermo plastics in that once they are formed with the aid of heat or pressure, they cannot be shaped or remelted again. The chain or the cross-link that forms the thermo sets occurs by the aid of some chemical reactions or due to heating or adding of a catalyst. The chemical reactions that are involved in producing the product are not reversible, and that's why it is so hard to reform it again. Once the product is converted from a liquid state to a solid state, it will be referred to as *cure*.

TABLE 1.1 Mechanical Properties for Thermosetting Plastics

Material	Tensile Strength 10^3 PSI	Tensile Modulus 10^5 PSI	Compressive Strength 10^3 PSI	Yield Strength 10^3 PSI
Epoxy	1–3	30–35	25–40	10–60
Unsaturated Polyester	4–50	7–9	15–50	10–80
Phenolics	4–9	16–20	10–40	5–12
Urea formaldehyde	5–13	10–15	25–40	10–18
Melamine	5–13	11–24	20–45	9–23
Alkyds	3–9	5–30	12–38	6–20

It is considered the last step in polymerization. The structure of all thermo sets looks like a network. All the molecules are permanently cross-linked together in a 3D network. This structure makes all thermo sets products maintain their high strength and hardness in relatively high temperatures. In addition, they have high chemical and creep resistance. Table 1.1 shows some of the mechanical properties of thermo sets materials.

Mixed Plastic Wastes

The unrecyclable mixed “different types” plastic waste “plastic rejects” can be collected and sorted into three groups (according to the technology used for size reduction): rigid thermoplastics, thin film thermoplastics, and thermo sets, as shown in Figure 1.7. The plastic rejects can be produced as a result of sorting and screening of mixed solid waste to separate organics from inorganic waste.

FIGURE 1.7 Mixed plastic waste.

The rejects might have some nonplastic waste, such as glass culets. The first step to recycle plastic rejects is to reduce the size so it can be mixed with other additives and produce a homogeneous mixture.

The size of rigid plastic can be reduced using horizontal axis shredders shown in Figure 1.8, while thin film plastics such as black plastic bags used for trash can be agglomerated using a vertical axis agglomerator machine shown in Figure 1.9 to reduce their sizes. Thermo sets can be crushed using a ball mill, shown in Figure 1.10.

Melamine, the most common type of thermo sets, will be used as an example of thermo set. It is usually found in a form of plates, cups, and other products. In order to recycle Melamine, it must be changed from the rigid forms into a powder form as to be mixed with the thermo plastics. Changing the Melamine into powder can be done through the ball mill machine shown in Figure 1.10.

The rigid thermo plastic waste is fed into a shredder shown in Figure 1.8 for size reduction and then cleaning with caustic soda in a warm-water bath after shredding. The shredder consists of a horizontal drum with four rotating blades opposite to stationary blades shown in Figure 1.8. The shredded plastics pass through a grid into a collecting tray. The sizes of shredded plastics range between 5 to 10 mm in size according to the grid used. The shredded plastics are collected in bags or containers to be further reprocessed or sold. The end products of shredding are irregularly shaped pieces of plastic, depending on the required final product and the type of industry that will use it.

FIGURE 1.8 Shredding “crushing” machine.

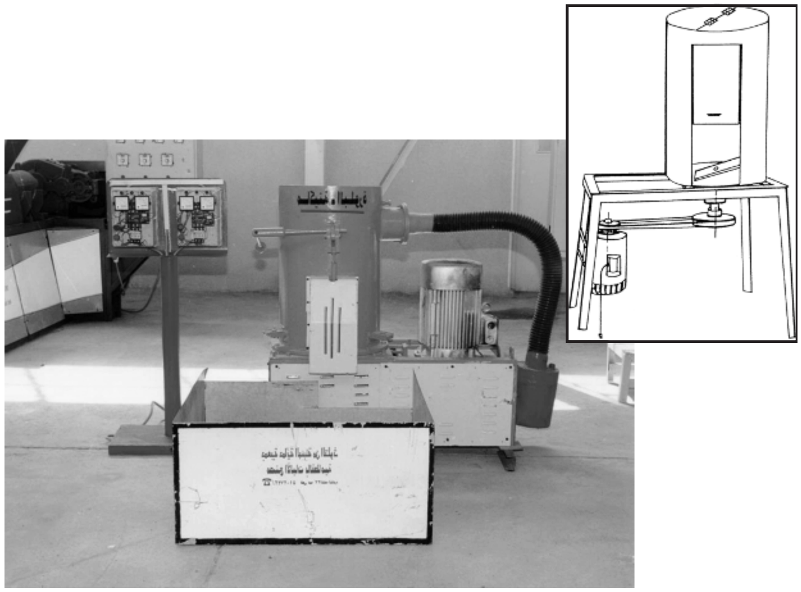

FIGURE 1.9 Agglomeration machine.

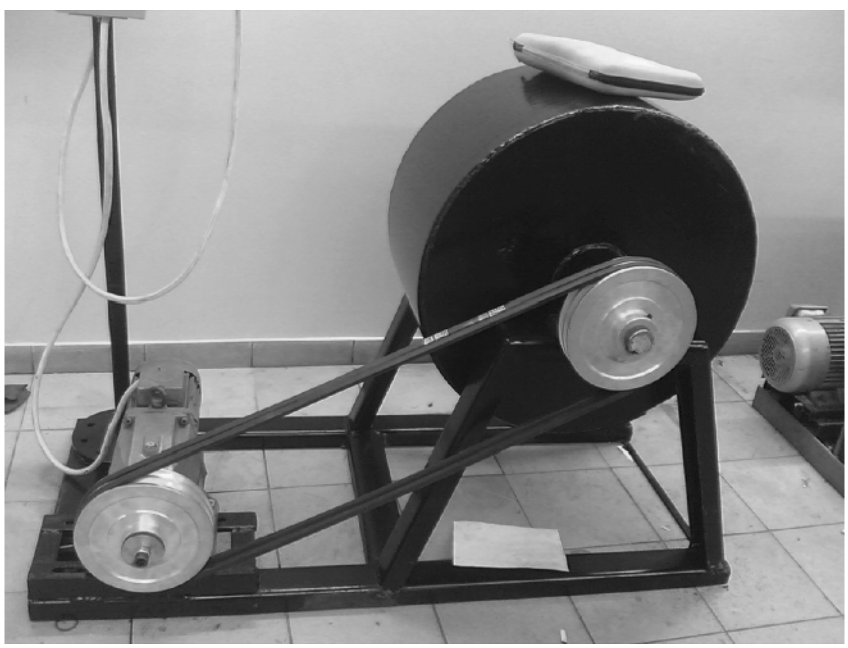

FIGURE 1.10 Ball mill machine.

Shredders can also be used for plastics films, bags, and sheets to be shredded into small pieces, but the energy consumption is more and the produced capacity is less. So, it is recommended to use an agglomerator that cuts, preheat, and dry the plastics into granules. The agglomerator will increase the material's density and quality, which will end up with a continuous flow in the extruder and hence better efficiency. In the process of agglomeration, heat is added indirectly through friction between plastic film and the rotating blade located at the bottom of the agglomerator, shown in Figure 1.9. It is therefore important to rapidly cool the plastic film to obtain the crumb shape desired. This is achieved through adding a small cup of water.

The ball mill machine used to crush thermo sets consists of an electric motor with a gearbox to make speed reduction down to 40 revolutions per minute. The motor is connected with a pulley to translate the motion through a belt to another pulley, which is connected to the shaft. The shaft carries a cylindrical drum in which the melamine or other form of thermo sets is inserted. The drum is welded to the shaft and the shaft is carried by two bearings at both ends of the shaft as shown in Figure 1.10. The balls within the ball mill machine will convert the thermo sets into powder by the gravitational force of the balls. Therefore, the particle size of the powder can be controlled through the number of balls, ball shape, and the time the machine will operate.

The recycling system for mixing plastic wastes as shown in Figure 1.11 consists of a volume-reduction step to reduce the size using agglomerator to cut the plastic bags into small pieces (granules), shredder to cut the rigid plastic into small pieces, and/or ball mill to crush the thermo sets. After the volume-reduction step, a mixture of the three with a certain percentage will be used with some additives to adjust the properties and appearance and heated indirectly to 140° to 240°C depends on the mixture and required applications. The indirect heating process occurs in an indirect heating furnace shown in Figures 1.12 and 1.13. Figure 1.12 demonstrates the vertical axis mixing and heating furnace. Figure 1.13 illustrates the horizontal axis mixing and heating furnace. Both designs guarantee a good mixing of the wastes and additives with indirect heating to produce a homogeneous hot paste for further processing.

The hot paste is then transferred to the mold according to the required shapes and applications. The mold will be placed in a hydraulic press to be pressed into the required shape shown in Figure 1.14. The mold will be cooled for 20 to 30 minutes according to the product.

Product development from mix plastic waste recycling, in general, is a must to maximize the benefits. This leads to a number of economic opportunities to remanufacture products with the recovered material. Just as market forces cannot be ignored when introducing a new product, they must also be taken into account when introducing remanufactured products. The product development from recycling mix plastic waste is more important and challenging than the product development of recycling of one type of plastic because the properties of products from mix plastic waste might change according to the product and required properties. Therefore, continual checking is a must for appropriate

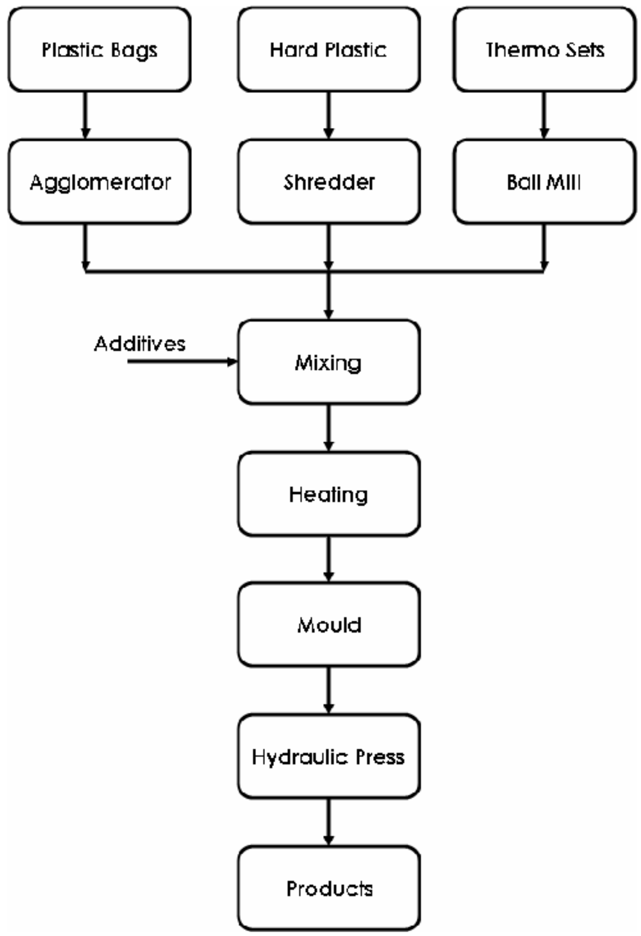

FIGURE 1.11 Process flow diagram for recycling plastic mix.

quality control and quality assurance. A number of products were produced with very good success according to the standard, such as bricks, interlocks, table toppings, wheels, manholes, road ramps, and sheets.

Figure 1.15 show the development of bricks from the solid brick (left) to bricks with holes to facilitate the assembly and disassembly of walls because bricks were made out of plastics with additives and cannot accept mortar to adhere bricks together. Any adhesive materials other than mortar are very expensive, which adds to the cost of the brick. Therefore, it is much more cheaper to bind them together using pins fitted in holes, as shown in Figure 1.15, for easy assembly and disassembly. Another problem of bricks made out of plastic rejects is the weight or density of the brick. The weight of the brick from plastic rejects is heavy compared with ordinary bricks. Thus, the bricks are not economically

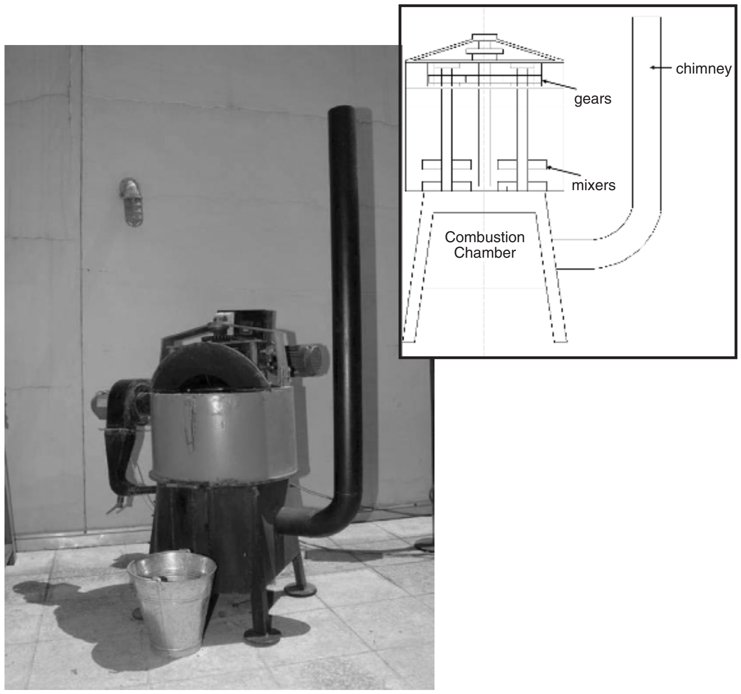

FIGURE 1.12 Vertical axis mixing and heating furnace.

FIGURE 1.13 Horizontal axis mixing and heating furnace.

FIGURE 1.14 Hydraulic press.

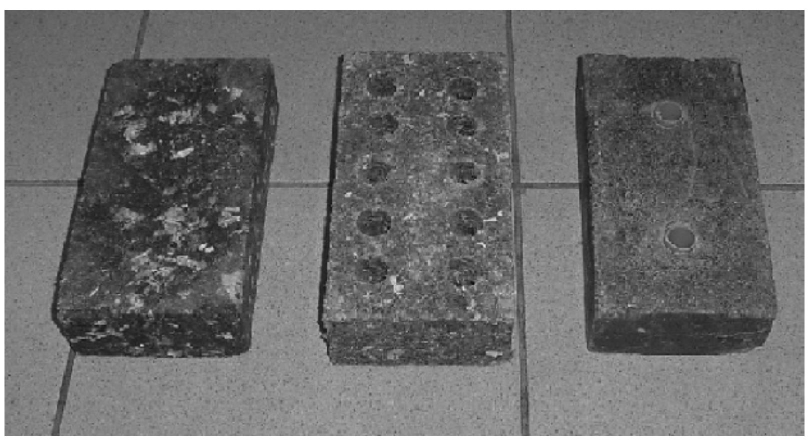

FIGURE 1.15 Development of bricks.

profitable when compared to the ordinary bricks, including the cost of adhesives. This type of bricks might have special application other than ordinary walls for construction applications.

Figures 1.16a and 1.16b show another application for plastic rejects that is much more profitable than bricks because it doesn't need adhesives. This new product is interlocks that can be used in pavements of roads, pedestrian gardens,

FIGURE 1.16a Development of interlock.

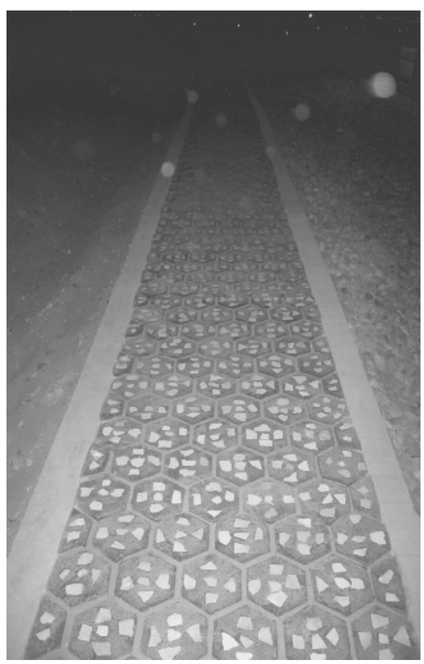

FIGURE 1.16b Application of interlocks.

FIGURE 1.17 Manhole cover and base.

factory floors, backyards, and so on. The interlocks made out of plastic rejects with additives proved to have higher strength according to ASTM standard than the normal interlock made out of cement, aggregate, and sand.[9] Figure 1.17 shows another very important application (manhole cover and base) that is much more profitable than interlock. A manhole or maintenance hole (sometimes called an inspection cover) is the top opening to an underground vault used to house an access point for making connections or performing maintenance on underground and buried public utility and other services including sewers, telephone, electricity, storm drains, and gas. The manhole cover is designed to prevent accidental or unauthorized access to the manhole. Manhole bases and covers are usually made out of case iron or reinforced fiber plastic (RFP), or can be produced out of plastic rejects. The main advantages of manholes made out of plastic rejects are less cost, less energy consumption, durability, and being acid proof. The weight can be adjusted by adding sand to the mix. Sand will increase the required specific weight up to a certain percentage (28 percent) to avoid any strength impact. The carrying load for 40 cm manhole is 1.8 metric tons, which is slightly higher than fiber-reinforced plastic (FRP) manholes and can be increased by adding steel bars.

Manhole covers are round because manholes are round; they could also designed with any geometry according to the required dimensions. Round tubes are the strongest and most material-efficient shape against the compression of the earth around them. A circle is the simplest shape whereby the lid cannot fall into the hole. Circular covers can be moved around by rolling. And they need not be aligned to be replaced.

Manholes are one of the very important applications to be produced from rejects. They can be used instead of ordinary cast-iron manholes and can be

FIGURE 1.18 Partitions made out of rejects.

made with different geometry and dimensions. Manhole bases and covers proved to be an excellent product out of rejects from social, economical and technical points of view.

Another application made out of rejects is sheets with any dimension and thickness, according to demand and needs. The partition shown in Figure 1.18 is 120 cm by 120 cm with 10 mm thickness to replace corrugated sheets or plywood. The sheets made out of rejects are much cheaper and more durable than corrugated sheets or plywood. These sheets can replace MDF (medium fiber boards) as well in many applications. Also, they can handle all weather conditions such as high/low temperatures, wind speed, and humidity.

PLASTIC AND CORK INDUSTRY

The objective of this case study is to recycle the PVC plastic offcuts from slippers production to produce new slippers from scrap PVC plastics and approach cradle-to-cradle design. This case study was implemented in a company located in Sohag, Egypt (upper Egypt), which produces around 1,500 metric tons/year of PVC sheets, cut to make footwear. The cutting and printing process used around 70 percent of the PVC sheet with the remaining 30 percent being discarded as scrap. In total, 450 metric tons of scrap PVC were sent to the local landfill each year.

This case study was prepared and implemented in cooperation between El–Ameer for plastic and Cork Company and Egyptian Environmental Affairs Agency (EEAA) SEAM project. The company produces 1,050 metric tons of products every year from 1,500 metric tons of raw material. This case study led to the recycling of 450 metric tons of scrap plastic to produce slippers. Capital investment was $100,000 and resulted in annual savings of $560,000, providing a payback in two months.

The process flow diagram to produce final product from raw material, as well as final product from recycled waste, is shown in Figure 1.19. A number of trials were undertaken to develop the optimum recipe, as shown in Table 1.2. Table 1.2 shows the recipes used for producing PVC sheets using new PVC and that for recycling scrap PVC.

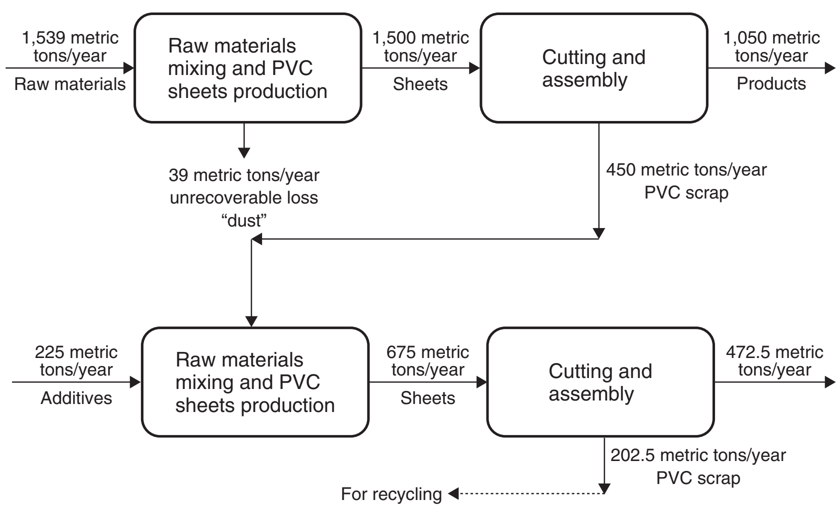

FIGURE 1.19 Process flow diagram for plastic and cork industry according to cradle-to-cradle concept.

TABLE 1.2 Raw Material Recipes Using Raw Material and Scrap PVC

No.	Raw Material	Using New PVC kg/batch	Using Scrap PVC kg/batch
1	PVC	45	–
2	Scrap PVC	–	50
3	Calcium carbonate	45	10
4	Rubber (NBR)	10	12
5	Zinc stearate	2.5	1.5
6	Fillers	1	–
7	Polyzar	1.5	–
8	Compor (azodicarbonamide)	1.5	1.5
9	DOP oil	2	–
10	Color	1	0.6
11	Sulfur, agriculture grade	0.35	0.05

The sheet-making process had to be modified to account for use of scrap plastic. In the case of new plastic, sheets formed are required to be cooled before imprinting and cutting. When scrap plastic is used in the recipe, the viscosity of sheets requires that hot sheets are directly subjected to imprinting and cutting. To cater for this, a new mechanical press was installed that could imprint and cut directly on the hot sheet.

A comparison of the costs of batch processing for raw PVC and recycled plastic scrap is given in Table 1.3. Average costs using new PVC is $0.95 per Kg against $0.46 per Kg using the scrap plastic. Figure 1.20 shows two slippers, one made from raw PVC and another one made from recycled PVC.

TABLE 1.3 Cost Comparison between Production with New and Scrap PVC

No.	Raw Material	Using New PVC		Using Scrap PVC	
		kg/batch	$/batch	kg/batch	$/batch
1	PVC	45	63	–	–
2	Scrap PVC	–	–	50	–
3	Calcium carbonate	45	2	10	0.4
4	Rubber (NBR)	10	17.5	12	21
5	Zinc stearate	2.5	3.5	1.5	2.1
6	Fillers	1	0.35	–	–
7	Polyzar	1.5	0.66	–	–
8	Compor (azodicarbonamide)	1.5	5	1.5	5
9	DOP oil	2.0	3.2	–	–
10	Color	1	6.32	0.6	3.8
11	Sulfur, agriculture grade	0.35	0.37	0.05	0.05
12	Electricity		0.1		0.1
13	Water		0.1		0.1
14	Labour		1.75		1.75
15	Fuel		1		1
Total Cost / Batch		**110 Kg**	**104.85**	**76 Kg**	**35.3**

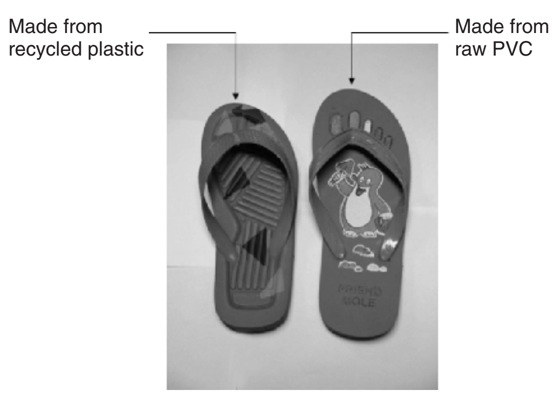

FIGURE 1.20 Slippers made from raw PVC and recycled plastic.

FOOD INDUSTRY

Food industry can be classified into a number of industries such as fruit and vegetable industry, vegetable oil industry, dairy industry, canning industry, beverage industry, meat industry, and so on. Most of these industries typically generate large volumes of effluents and solid waste. The main solid wastes generated from food industry are organic wastes, including discarded seeds, fruits, and vegetables. Odor problems can occur with poor management of solid wastes and effluents, when onions are processed, and when ready-to-serve meals are prepared, for example. So, it is very important to deal with such organic waste with full understanding of the processes, requirements, and hygiene.

Food waste recycling can take place through aerobic fermentation (composting) or anaerobic fermentation (biogas) processing. Composting is a process that involves biological decomposition of organic matter, under controlled conditions, into soil conditioner or organic fertilizer through aerobic fermentation.[10] While anaerobic fermentation process involves biological decomposition of organic waste under controlled conditions to produce fertilizer and biogas.[11]

Aerobic Fermentation Process

Aerobic fermentation is the decomposition of organic material in the presence of air. During the composting process, microorganisms consume oxygen, while CO_2, water, and heat are released as result of microbial activity, as shown in Figure 1.21. Four main factors control the composting process: moisture content, nutrition (carbon: nitrogen ratio), temperature, and oxygen (aeration).

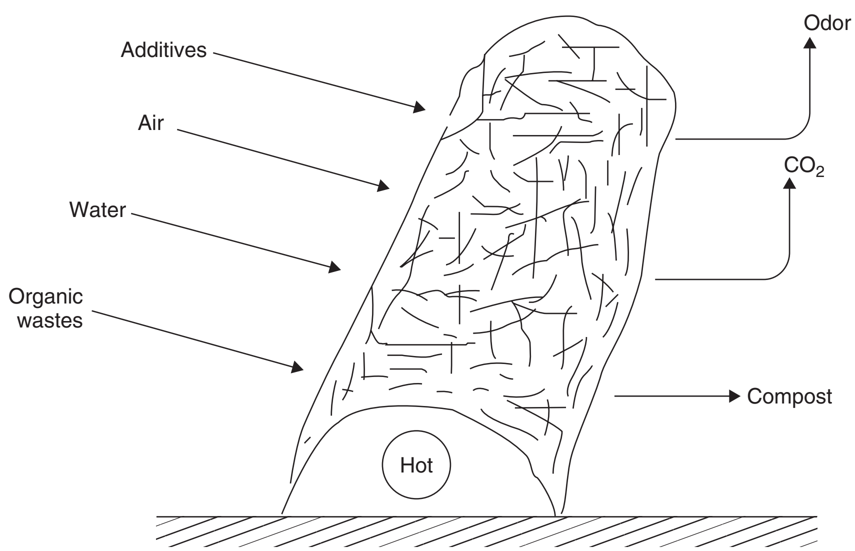

FIGURE 1.21 Composting process.

1. *Moisture content.* The ideal percentage of the moisture content is 60 percent.[10] The initial moisture content should range from 40 to 60 percent, depending on the components of the mixture. If the moisture content decreases less than 40 percent, microbial activity slows down and became dormant. If the moisture content increases above 60 percent, decomposition slows down and odor from anaerobic decomposition is emitted.
2. *Carbon to nitrogen ratio.* Microorganisms responsible for the decomposition of organic matter require carbon and nitrogen as a nutrient to grow and reproduce. Microbes work actively if carbon to nitrogen ratio is 30:1. If the carbon to nitrogen ratio exceeds 30, the rate of composting decreases. Decomposition of the organic waste material will slow down if C:N ratios are as low as 10:1 or as high as 50:1.

   However, in order to compensate the low nitrogen content of organic waste, nitrogen should be added to obtain more effective compost. To increase the C:N ratio in rice straw as an agricultural waste, for example, these techniques may be implemented:

   - *Chemical additives:* This method could be done by the addition of either uric acid, or urea or ammonia.
   - *Natural additives (manure):* In this technique, nitrogen is obtained from animal or poultry manure.
3. *Temperature.* The activity of bacteria and other microorganisms produce heat while decomposing (oxidize) organic material. The ideal temperature range within the compost to be efficient varies from 32°C to 60°C. If the temperature is outside this range, the activity of the microorganisms slows down, or might be destroyed. A temperature above 55°C while composting kills the weeds, ailing microbes, and diseases, including shengella and salmonella; this help to reduce the risk of diseases' transmission from infected and contaminated organic wastes.
4. *Oxygen (aeration).* A continuous supply of oxygen through aeration is a must to guarantee aerobic fermentation (decomposition). Proper aeration is needed to control the environment required for biological reactions and to achieve the optimum efficiency. Different techniques can be used to perform the required aeration according to the composting techniques. The most common types of composting techniques are natural composting, passive composting, forced composting, and vermi composting.

Natural Composting Piles of compost are formed along parallel rows, as shown in Figure 1.22 and are continuously moisturized and turned. The distance between rows can be determined according to the type and dimension of the turning machine.[12] Piles should be turned about three times a week at summer and once a week at winter to aerate the pile and achieve homogenous temperature and aeration throughout the pile. This method needs large surfaces of lands, many workers, and running cost.

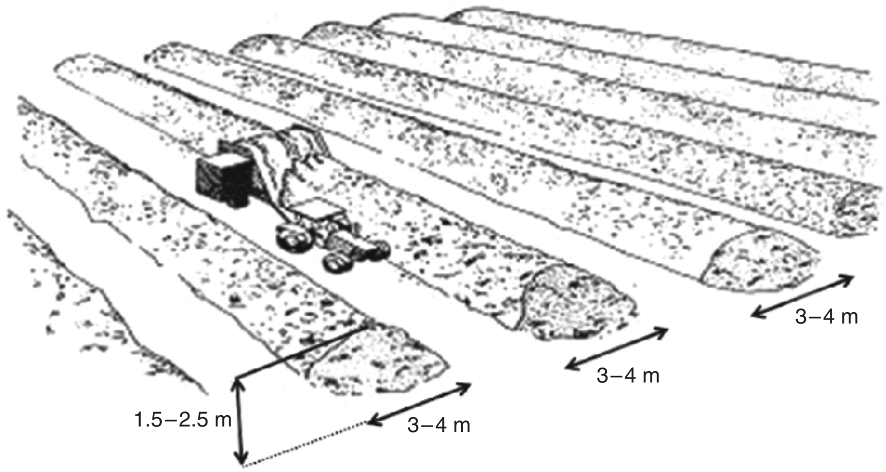

FIGURE 1.22 Natural composting process. (*Source:* F.R. Gouin et al., "On-Farm Composting," Northeast Regional Agricultural Engineering Services, NRAES-54, Cooperative Extension, 1993.)

Passive Composting Parallel rows of perforated high-pressure PVC piping are placed at the bottom, on which compost is added above it. The pipes are perforated with 10 cm holes to allow air to enter the composting piles, as shown in Figure 1.23. The pipe manifold helps in distributing the air uniformly. Air flows through the ends of the pipes to the compost. This system is better than the natural system because of the limited flow rates induced by the natural ventilation. This method needs limited surfaces of lands, less running cost, and does not need skilled workers. This method is recommended for cost effectiveness; it is the most economic aeration method. Therefore, it is the most suitable method for developing communities that want to achieve maximum benefit from the food recycling with the minimum capital investment and a good-quality soil conditioner. The soil conditioner can be converted into organic fertilizer by adjusting the NPK ratio (nitrogen: phosphorous: potassium) through additives.[13,14]

Forced Aeration Forced aeration works like the previous system except that the ends of plastic pipes are connected to blowers that force (or suck) the air through the compost with a specific rate and velocity. Otherwise, if the air rate exceeded a certain limit, the temperature inside the compost pile would decrease, affecting the microbial activity. Also, the air velocity during the day should always be higher than at night. This system needs higher technology with air velocity control and more energy consumption. That is why it is less economic compared to the other two systems and it is not recommended for rural or developing countries that want to make profit out of all recycling processes. This method needs capital investment, skilled workers, and running cost.

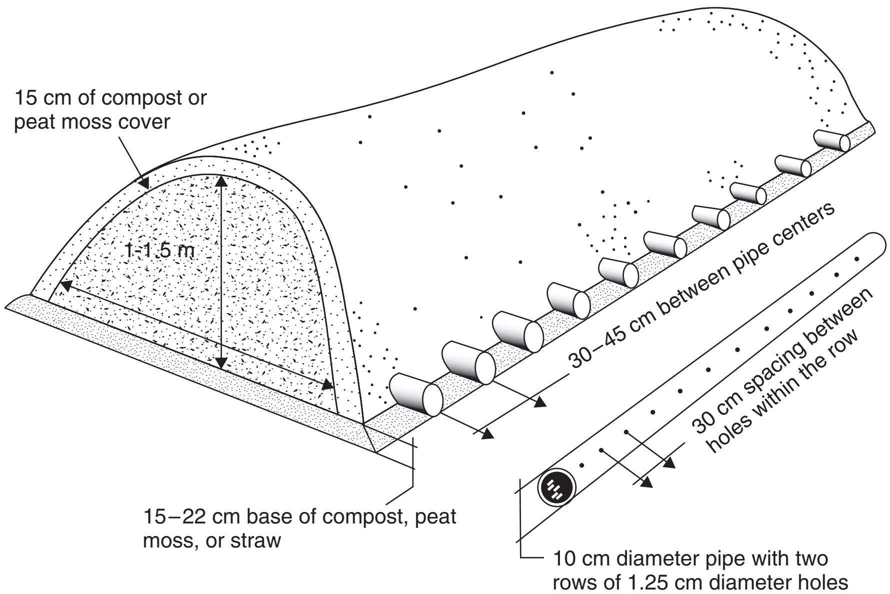

FIGURE 1.23 Passive aeration process. (*Source:* F.R. Gouin et al., "On-Farm Composting," Northeast Regional Agricultural Engineering Services, NRAES-54, Cooperative Extension, 1993.)

Vermi Composting It is an ecologically safe and economic method that depends on the worms' characteristic of transforming the organic wastes to fertilizers that are extremely beneficial to earth. There are two types of earthworms that are used due to their insensitivity to environmental changes:

1. The red wiggler (*Eisensia Foetida*)
2. The red worm (*Lumbricus Rebellus*)

Under suitable aeration, humidity, and temperature, worms feed on organic wastes and expel their manure (worm castings) that breaks up the soil, providing it with aeration and drainage. It also creates an organic soil conditioner as well as a natural fertilizer. Worm castings have more nutrients than soil conditioner in terms of nitrogen and phosphorous.

A mature worm will produce a cocoon every 8 to 10 days that contains an average of eight baby worms that mature in approximately 70 days, and in one year each 1,000 worms produce 1,000,000 worms.[15]

Vermi composting can be used in houses easily by using a special container (worm bin) that can be placed anywhere that is not subjected to light such as kitchen, garage, and basement. The organic waste is put in this container, and the worms with them. The worms are odorless and free from disease.

Anaerobic Fermentation Process

Biogas conversion is the anaerobic fermentation of organic matter (organic waste) by microbiological organisms under controlled conditions. The aim of fermentation is to produce methane (biogas) that can be used as an energy source. The fermentation process is done anaerobically—that is, without the presence of air—to allow the bacteria to perform the breakdown. The byproduct of fermentation consists of about 60 percent CH_4 and 40 percent CO_2, along with traces of H_2, N_2, and H_2S. Biogas is produced by means of a digester, which is a device used to process organic waste and produce methane. There are many types of digesters available; however, the two most famous designs are the Chinese fixed dome (constant volume) and the Indian floating cover (constant pressure). A combination of both could also be designed.

Chinese Fixed Dome The Chinese fixed-dome design is one of the oldest digester designs dating back to the 1930s. It consists of an underground fermentation chamber made of bricks and a dome-shaped tank on top of the chamber. The biomass mixture is entered through the inlet and fermentation occurs, with the gas rising to fill the tank and the slurry exiting through the outlet. This design combines the digester with the holding tank where the gas is stored. The gas then passes through an outlet pipe at the top, as shown in Figure 1.24.

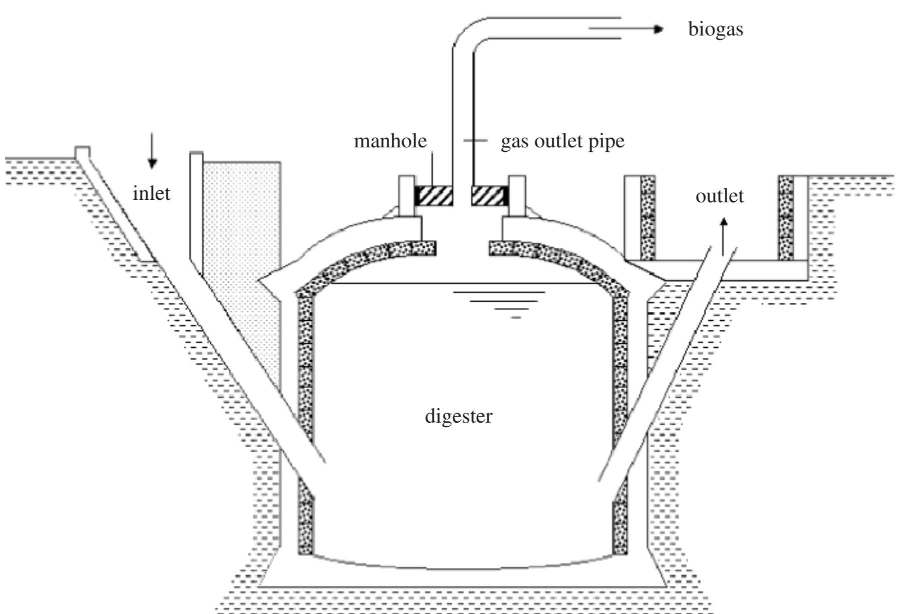

FIGURE 1.24 Chinese fixed-dome digester. (*Source:* Matthias Plöchl and Monika Heiermann, "Biogas Farming in Central and Northern Europe: A Strategy for Developing Countries?" 2006, cigr–ejournal.tamu.edu/submissions/volume8/Invited27Feb2006.pdf.)

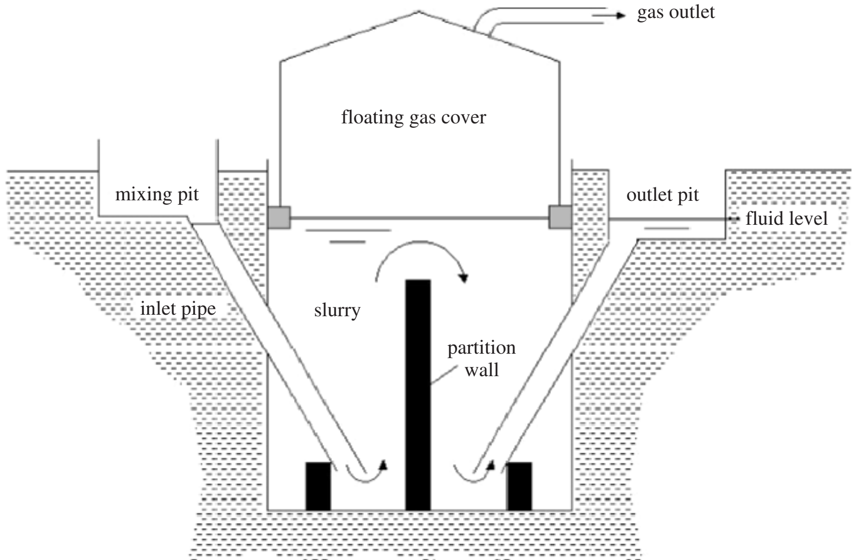

FIGURE 1.25 Indian floating cover. (*Source:* Matthias Plöchl and Monika Heiermann, "Biogas Farming in Central and Northern Europe: A Strategy for Developing Countries?" 2006, http://cigr−ejournal.tamu.edu/submissions/volume8/Invited27Feb2006.pdf.)

Indian Floating Cover The Indian floating-cover design is shown in Figure 1.25. This design was first presented as the Janata design but was further developed in 1984 to the Deenbandhu model, with both models based on the Chinese dome design. This model employs the same principles as the Chinese fixed-dome digester, with the biomass mix entering through the inlet and decomposed in the underground brick chamber. However, in this design the cylindrical gas tank is a floating cover that is separate from the mixing tank. The slurry left from the fermentation process is used as a fertilizer. The mixing process should occur at a high temperature range (30° to 40° or 50° to 60°C), and could take up to two months, depending on the quantity of biomass processed.[16]

TABLE 1.4 Uses of Biogas as Energy Sources

Applications	1 m^3 Biogas Equivalent
Lighting	Equal to 60 to 100 W bulb for 6 hours
Cooking	Can cook 3 meals for a family of 5 to 6
Fuel replacement	0.7 kg of petrol
Shaft power	Can run a 1 horsepower motor for 2 hours
Electricity generation	Can generate 1.25 kilowatt hours of electricity

Source: Practical Action, "Biogas And Liquid Biofuels," 2006, www.itdg.org/docs/technical_information_service/biogas_liquid_fuels.pdf.

Biogas can be used in several applications as an energy source, ranging from light bulbs to internal combustion engines. It has an energy content of about 5,000 Kcal/m^3. Some of the uses of biogas as an energy source are shown in Table 1.4.

CEMENT INDUSTRY

The cement industry is an important resource for development, and it is an intensive energy-consuming industry. It produces significant releases to the environment, primarily as airborne emissions such as dust emissions (cement bypass dust) and gaseous emissions of NO_x, SO_x, CO_x. It plays an essential role in the international market because cement, which is the most important ingredient of concrete, is one of the most dynamic products that directly contribute to the construction industry. Therefore, the cement industry is necessary for sustainable development in any country and can be considered the backbone for development.

Cement is a controlled chemical combination of calcium, silicon, aluminum, iron, and small amounts of other ingredients.[17] Lime, which can be extracted from limestone, shells, or chalk, constitutes 60 to 67 percent, and silica constitutes 17 to 25 percent, while alumina and iron oxide constitute the remaining small percentage.[17] According to Van Oss and Padovani, the chemical composition of a typical Portland cement clinker is mainly four oxides: calcium oxide or lime (CaO), about 65 percent; silica (SiO_2), about 22 percent; alumina (Al_2O_3), about 6 percent; and iron oxide (Fe_2O_3), about 3 percent.[18]

These elements are found in a wide variety of raw materials, and they are also found in byproducts of different industries such as blast-furnace slag from the iron and steel industry and fly ash from the electric power industry. From 115 operating plants reporting in the Portland Cement Association, 45 plants used blast furnace or iron slag as a raw material and over 40 plants used fly ash or bottom ash from electric power plants as an alternative raw material.[17]

Input materials for the cement industry are natural resources that are extracted from earth and have no negative effects on the environment. These materials are limestone, clay, and sand. Meanwhile, the final product is also an environmentally friendly product that is composed primarily of calcium silicate.[17] This means that the environmental impacts of the cement industry is associated with the process rather than with the materials themselves.

A closer look into the production process of cement will provide us with an insight of how the production system works; further, this will enable us to determine and identify potential sources of emissions and wastes. There are four main process routes in the manufacturing of cement: the dry, semi-dry, semi-wet, and wet process.[19] According to World Business Council for Sustainable development, common to all four processes are the following subprocesses:[20]

- Substances containing lime are quarried or shipped in.
- The raw materials are crushed into a fine powder to facilitate mixing and blending.

- The fine mixture is heated up to a temperature of 1430^o to 1650^oC in large rotating cylinders known as *cement kilns* to produce clinker.
- Then the clinker is cooled down and gypsum is added to it. The mixture is then ground into fine powder to form Portland cement.
- A large percentage of the final powder cement is stored in silos to be further transported or shipped, while a small percentage is packaged in 50 kg sacks.

Within the production process of cement, there are two different types of process methods, referred to as *wet* and *dry*. The major difference between the two types is the medium used to mix the powdered raw materials prior to heating, and the amount of moisture content in the materials entering the kiln. Karstensen added that between these two ends of the spectrum, there are semi-wet and semi-dry processes.[19] In the wet method, water is added to the raw materials after milling to facilitate thorough mixing, and the mixture is added to the kiln as slurry containing 30 to 40 percent water.[17] In the dry method, the powders are generally blended in a silo using compressed air. If the material entering the kiln is wet or has a high moisture content, this will require more energy and more time for driving off water. The wet process was the dominant older technology, because, in the age of abundant cheap energy, it was cheaper to burn more fuel and add length to the kiln than to add extra devices.[17]

Nowadays, kilns use the dry method. The dry method provides substantial energy savings, as well as a higher throughput. However, the energy advantages of the dry process were more fully realized with the addition of pretreatment equipment to condition the powdered raw materials before their introduction into the kiln.[17,20] A further development, called a *precalciner*, pumps more heat into the pretreatment phase, often combining some additional fuel with air from the clinker cooling stage, which has thus been preheated. The precalciner system is the most energy-efficient arrangement, and also has the highest throughput, with the shortest kiln (PCA).

Emissions may come from different stages during cement production processes, depending on the raw materials, preparation procedures, kiln type, and emissions control systems used.[20] The largest volume substances emitted during the production of cement are carbon dioxide, particulate matter (dust), oxides of nitrogen, and sulfur dioxide.

Dust and *particulate matter* include emissions of coarse dust, fine dust, soot, particles, and aerosols.[17] The emission of dust, particularly from kiln stacks, has been the main environmental concern in cement manufacture.[19] During the manufacturing steps of cement, exhaust gas passes through the fine material, resulting in a dispersed mixture of gas and particulates. According to PCA, the product is a fine powder, and various process steps involving grinding, both of the input materials and the final product, have the tendency to emit fugitive dust. Therefore, particulate control systems on exhaust air from the clinker cooling and grinding processes produce a waste material known as *cement kiln dust* (CKD).

Reduction and control of dust emissions in a modern cement plant requires investments and adequate management practices. Dust emissions from cement kilns have been reduced dramatically over the last two to three decades due to regular improvements in design and operation, including increased use of modern dedusting equipment such as electrostatic precipitators or bag filters.

Kiln dust collected from the gas cleaning devices is highly alkaline and may contain trace elements such as heavy metals corresponding to the contents in the source materials.[19,20] Usually, kiln dust is completely returned to the process either to the kiln system or to the cement mill, only in rare cases, it is not possible to recycle kiln dust or bypass dust completely in the process.[19] This residual dust is disposed of on a controlled landfills or is treated and sold to other industries as additive for waste stabilization or as fertilizer.[20]

The most popular way of disposal of the cement bypass dust is landfilling, which—to be done properly with all the required lining and covering—costs a lot of money and still pollutes the environment and depletes the natural resources. That is why proper and effective disposal or reuse of cement bypass dust is always one of the main concerns for both the cement industry and environmental protection. The chemical analysis for the bypass dust is shown in Table 1.5.

Utilization through Cleaner Production Techniques

Treatment or proper disposal of wastes to be able to comply with environmental protection regulations has always been considered as an additional cost that has no return to industry or community, which will also have a bad effect on the environment one way or another—its cost sometimes represents a significant portion of the total cost of the produced product, which is passed on to consumers or deduced from the profits of the industry resulting—either way—in an indirect waste of money.

The core element of cleaner production techniques is prevention versus clean-up or end-of-pipe solutions to environmental problems. In other words, its core element is the establishment of a safe sustainable environment yet doing

TABLE 1.5 Chemical Analysis of Cement Bypass Dust

Chemical Formula	Percentage
SiO_2	9.0–13.0
Al_2O_3	3.0–4.0
Fe_2O_3	2.0–2.5
CaO	45.0–48.0
MgO	1.7–1.9
SO_3	4.0–11.0
Na_2O	3.0–8.0
K_2O	2.0–6.0
Cl	4.0–13.0

it the most efficient way to avoid any unnecessary cost. It is considered a new and creative approach toward products and production processes.

Cleaner production focuses on reducing the use of natural resources, thus minimizing the waste generated from the process. It also stresses preventing these wastes at the source by the use of cleaner production techniques, which does not mean changing processes, as a process may be made "cleaner" without necessarily replacing process equipment with cleaner components. It can simply be done by changing the way a process is operated. Some people might suggest changing the technology or process from dry technology to wet technology to reduce the amount of cement bypass dust as one of the cleaner production techniques. This is true from the bypass dust point of view only, but wet process will increase the energy consumption and the amount of fuel consumed. This will lead to more consumption of natural resources, more air pollutant emitted to the atmosphere, more air pollution control devices installed, and more money spent in terms of capital cost and running cost. Others might think of recycling the bypass dust as one of the cleaner production technique options. This option might be cost effective if the product from the recycling process is competitive with similar product in the market from the quality and price point of views.

Therefore, cleaner production has many benefits if managed properly; it can reduce waste disposal cost, raw material cost, and the environmental impact of the business, and improve profitability and worker safety. It can also improve the public relations and image, thus also improving the local and international market competitiveness. It is simply a win–win concept, and the challenge that rises here is how to achieve cleaner production in an appropriate manner. The proper approach to tackle this challenge is: (1) source inventory (Where are wastes and emissions generated?), (2) cause evaluation (Why are wastes and emissions generated?), (3) option generation (How can these causes be eliminated?). Knowing the answer of these questions and achieving a proper cleaner production can be made using the six-step organized approach:

1. Simply getting started and taking action toward the issue
2. Analyzing process steps, inputs, outputs (flows and emissions)
3. Generating cleaner production opportunities
4. Selecting cleaner production solutions that fit your environment and that you're capable of doing
5. Implementing cleaner production solutions
6. Sustaining cleaner productions

Following this simple, logical approach, one can simply help alleviate the problems of environmental pollution with significant economical benefits.

Industrial Ecology Approach

Under what we may call the same umbrella of cleaner production, a philosophy/strategy/framework of industrial ecology came to life.[21] However, most definitions of industrial ecology include similar attributes with different emphases, and these attributes include the following:

- A systems view of the interactions between industrial and ecological systems
- The study of material and energy flows and transformations
- A multidisciplinary approach
- An orientation toward the future
- An effort to reduce the industrial systems' environmental impacts on ecological systems
- An emphasis on harmoniously integrating industrial activity into ecological systems
- The idea of making industrial systems emulate more efficient and sustainable natural systems

The concept of industrial ecology beyond already existing practices is to reduce negative impacts of industrial using a systems-oriented approach and linking with natural ecosystems in a twofold manner:

1. *Analogy:* Natural systems are seen as a "... model of highly efficient use of resources, energy, and waste," which industrial systems should try to adopt.[22] This is the same idea that had been introduced and discussed in the cleaner production approach.
2. *Integration:* Industrial systems are viewed as only one part of the surrounding systems, with which they must be in concert,[23] which is—to a limit—a new point that can be further studied.

Using the industrial ecology concept, many benefits would be provided, other than the same gains that are provided by the cleaner production, which are reduction in the use of virgin materials, reduction in pollution, increased energy efficiency, and reduction in the volume of waste products requiring disposal, many other benefits of great importance are to be gained such as increase in the amount and types of process outputs that have market value,[24] and the birth of new industries which means more work chances and high economic benefits, also like hidden resource productivity gains, synergies between production and distribution beyond production chain: closed loop, and the creation of eco-industrial parks and interfirm relations.

This takes us to the recognition of what eco-industrial parks are all about. Eco-industrial parks actually represent the form that every industrial community should be according to industrial ecology. In these parks, every single waste is either reused or retreated in a certain way that sustainability of resources and environment is assured. Most industrial ecologists believe that Kalundborg, a small city on the island of Seeland, 75 miles west of Copenhagen, is the first recycling network in history.[25] The four main Industries and a few smaller businesses feed on each other's wastes in transforming them into useful inputs.

As Gertler explains, the basis for the Kalundborg system is “creative business sense and deep-seated environmental awareness,” and “while the participating companies herald the environmental benefits of the symbiosis, it is economics that drives or thwarts its development.”[24]

The same idea and approach to reaching a sustainable environment is what the—cradle-to-cradle concept calls for compared with the—cradle-to-grave approach. The cradle-to-grave concept means that the raw materials of a certain industry are being used only once and then are dumped in a landfill, which is a one-way stream of materials. As explained earlier, this has been happening all over the world one way or another since the Industrial Revolution. But now to realize environmental reform in the cement industry, the cradle-to-cradle concept has to get into place, where every material is considered as a nutrient either to the environment or to the product itself. In order to form a community to cope with such concept and action, according to Braungart and McDonough, there are four steps to be made:[26]

“Phase 1—Creating Community: identification of willing industrial partners with a common interest in replacing hazardous chemicals with natural one or less hazardous, targeting of toxic chemicals for replacement;

Phase 2—Utilizing Market Strength: sharing list of materials targeted for elimination, development of a positive purchasing and procurement list of preferred intelligent chemicals;

Phase 3—Defining Material Flows: development of specifications and designs for preferred materials, creation of a common materials bank, design of a technical metabolism for preferred materials;

Phase 4—Ongoing Support: preferred business partner agreements amongst community members, sharing of information gained from research and material use, co-branding strategies.”

Recycling Opportunities

According to cleaner production techniques and industrial ecology concept, a number of alternatives can be demonstrated to utilize the cement bypass dust as a raw material in another industry or another process or within the same process, such as the following:

- Recycling within the cement production process (most efficient in wet process) and requiring more research to optimize the percentage of bypass dust to be recycled without affecting the cement properties
- Production of tiles/bricks/interlocks blended cements
- Production of glass and ceramic glass
- Production of safe organic compost (soil conditioner) by stabilizing municipal wastewater sludge
- Enhancing the production of road pavement layers

Recycling through Tiles/Bricks/Interlocks By pressing the cement bypass dust in molds under a certain pressure force, bricks/interlock/tiles can be formed with a breaking strength directly proportional to the pressure used to form it, and sometimes the breaking strength is even higher than the pressure used to form it. In Cement Turah factory in Egypt, experiments were conducted on the following:

- Using 100 percent cement bypass dust with pressure force of 200 kg to form a cylindrical cross-section bricks of 50 cm^2 area where the breaking pressure of these bricks reached 120 kg/cm^2. In addition, chemical treatment of these bricks during the hydraulic molding can achieve a breaking pressure of 360 to 460 kg/cm^2 for the 100 percent cement dust bricks.
- Using 15 to 20 percent cement dust with clay and sand along with pressure thermal treatment to reach breaking pressure of 530 to 940 kg/cm^2.
- Using 50 percent cement dust with sand along with thermal treatment only to reach breaking pressure of 1,300 kg/cm^2

Using cement bypass dust with clay to produce bricks has proven to reduce the weight of the bricks along with reducing the total linear drying shrinkage. In addition, this opportunity can utilize very high percentages of the bypass dust. However, this will still depend on the market needs and the availability of easily transported bypass dust.

Recycling through Glass and Ceramic Glass Using bypass dust as a main raw material (45 to 50 percent) along with silica and sand stone and melting the mix at temperatures ranging 1,250° to 1,450°C, glass materials were obtained. The glass product has a dark green color with high durability due to the high calcium oxide (CaO) content in cement bypass dust. It can be used for bottle production for chemicals containers. This step was then followed by treatment for 15 to 30 minutes at temperatures ranging from 750° to 900°C to form what is known as ceramic glass. This new product, unlike glass, has a very high strength, is unbrittle, is untransparent, and looks like marble. The produced ceramic glass is highly durable and can resist chemical and atmospheric effects. Consequently, this new product opens the way for utilizing huge quantities of bypass dust in producing architectural fronts buildings, prefabricated walls, interlocks for sidewalks and many other engineering applications.

Recycling through Composting of Sewage Sludge Because of the high alkalinity and pH value of cement kiln dust (11–12), it can be used in stabilizing municipal sewage sludge. Municipal sludge contains bacteria and parasites. Therefore, if used directly as a soil conditioner, it will cause severe contamination to the soil and the environment and may be very hazardous to health.

Two types of sludge from sewage treatment plants can be used. The first one is from a rural area where no heavy metals were included and the second is from an urban area where heavy metals might exist, depending on the level of awareness and industrial compliance.

Due to the high alkalinity of cement bypass dust, when it is mixed with municipal sludge, it enhances the quality of sludge by killing the bacteria and viruses.[27] Also, it will fix the heavy metals (if they exist) in the compost and convert them into insoluble metal hydroxides, thus reducing flowing of metals in the leachate. Agricultural waste such as rice straw, corn stalk, and so on, which is considered a major environmental problem in most countries, can be added to the sludge for composting process to adjust the carbon to nitrogen ratio and enhance the fermentation process. Agricultural waste will also act as a bulking agent to improve the chemical and physical characteristics of the compost and help reduce the heavy metals from the sludge.

The uniqueness of this process is related to the treatment of municipal solid waste sludge, which is heavily polluted with ascaris eggs (most persistent species of parasites) using passive composting technique. This technique is very powerful and very efficient, with much less cost (capital cost and running cost) than other techniques, as explained before. First, primary sludge will be mixed with 5 percent cement dust for 24 hours. Second, agricultural waste as a bulking agent will be mixed for passive composting treatment. Passive composting piles will be formed from sludge mixed with agricultural waste (bulking agent) and cement dust with continuous monitoring of the temperatures and CO_2 generated within the pile. Both parameters are good indicators of the performance and digestion process undertaken within the pile.

Passive composting technique explained before have shown very promising results, especially by adding cement dust and agricultural wastes. Results show that ascaris has not been detected after 24 hours of composting, mainly due to the high temperature elevations reaching 70° to 75°C for prolonged periods, as well as the high pH from cement dust. Also, the heavy metal contents were way beyond the allowable limits for both urban sludge, as well as rural sludge.[27]

As a result of previous discussion, three major wastes (cement bypass dust, municipal wastewater sludge MWWS from sewage treatment plants, and agricultural waste) can be used as byproducts to produce a valuable material instead of dumping them in the landfill or burning them in the field. This technique will protect the environment and establish a new business where cement bypass dust exists. If cement bypass dust does not exist, quick lime can be used to treat the MWW sludge. Sludge has a very high nutritional value but is heavily polluted with ascaris and other pollutants, depending on location. Direct application of sludge for land reclamation has negative environmental impacts and is health hazardous. Cement bypass dust is always considered a hazardous waste because of high alkalinity. The safe disposal of cement dust costs a lot of money and still pollutes the environment because it is very fine dust with high pH (above 11) and has no cementing action. Agricultural waste has no heavy metals and contains some nutrients, which will be used as a bulking agent. The bulking agent can influence the physical and chemical characteristics of the final product.

It will also reduce the heavy metal content of the sludge and control C/N ratio for composting.

Recycling through Road Pavement Layers Cement bypass dust can be used in three ways in road pavement layers. The first application deals with subgrade layer. The second application deals with base layer, while the third application deals with asphalt mixtures.

Subgrade Layer Adding 5 to 10 percent of cement bypass dust to the soil improves its characteristics and makes it more homogenous and stiff to maintain loads.

Base Layer Limestone is used in the base layer for road paving in general. Also, good binding and absence of voids in this layer are crucial to maintain strength and to prevent settlement and cracking of this layer, which is located right below the asphalt layer. Therefore, adding cement bypass dust as filler material to the base layer eliminates the voids formed between rocks and each other due to its softness. Consequently, it increases the density (weight/volume) of this layer due to increase of weight and fixation of volume, which improves the overall characteristics of binding, especially if base layers of thickness more than 25 cm is required in the design using the same paving equipment. Also, the absence of voids in the base layer provides protection against the negative impact of acidic sewage water and underground water, which work on cracking and settling the base layer.

Asphalt Mixtures The asphalt mixture is a mix of sand, gravel, broken stones, and soft materials, along with the asphalt. In Marshal's standard test for designing asphalt mixtures, it has been found that the percentage of asphalt required can be reduced as the density of the mixture increases. Therefore, adding cement bypass dust, which has very fine and soft particles, improves the mixture efficiency by filling the voids. Also, the bypass dust contains high percentages of dry limestone powder and some basic salts that, in nature, decrease the creeping percent of the asphalt concrete, enhance the binding process, and reduce the asphalt material required, which is very desired in hot climates.

This process was implemented in the road joining the stone mill of Helwan Portland Cement Company and the company's factory in Egypt. The results from binding the base and subgrade layers assured that adding the cement bypass dust to the layers improved the overall characteristics of the road. The road is still operating in perfect condition, after 12 years of trucks using the road with a load capacity not less than 100 metric tons.

Final Remarks

The environmental and socioeconomic benefits as a result of utilizing cement bypass dust can be summarized as follows:

- Reducing air pollution problems
- Utilizing high percent of bypass dust, if not all
- Improving the pavement layer characteristics with very low cost
- Reducing the asphalt percent required in the design for the same performance asphalt mixture
- Providing more job opportunities
- Using low-price product with high quality and strength
- Developing new business opportunities
- Preventing biomass field burning to get rid of the agricultural waste in sludge treatment process
- Reducing greenhouse gas emissions
- Killing microbes and parasites in sludge, forming a high-quality soil conditioner, as well as improving land reclamation and public health

MARBLE AND GRANITE INDUSTRY

Marble and granite industry is considered one of the oldest and largest industries in the world. Marble and granite have been used in Egypt since the time of the ancient Egyptians. Historically, the industry moved from labor-intensive to capital-intensive with the advent of technological advancement, including development of automated production tools such as cranes and diamond-cutting wires. Marble consists mainly of calcite or dolomite, or a combination of these carbonate minerals. Marble is a type of metamorphic rock formed from limestone. It is formed from limestone by heat and pressure in the earth's crust that causes the limestone to change in texture and makeup (recrystallization process). Impurities present in the limestone during recrystallization affect the mineral composition of the marble that forms. The minerals that result from impurities give marble wide variety of colors. The purest calcite marble is white. Marble containing hematite has a reddish color. Marble that has limonite is yellow, and marble with serpentine is green.[28] The specific gravity of marble usually ranges from 2.5 to 3, while granite has a very high specific gravity and can go up to 9.

Marble consists of soluble residue (0.89 percent), Fe_2O_3 (0.28 percent), $CaCO_3$ (97.74 percent), $MgCO_3$ (1.22 percent), phosphoric acid –(0.04 percent), along with the impurities: SiO_2, Fe_2O_3, limonite, manganese, Al_2O_3, and FeS_2 (pyrite).[29] Granite, the hard natural igneous rock having visible crystalline texture, is formed essentially of quartz and orthoclase or microcline. It is formed from volcanic lava. The principal constituents of granite are feldspar, quartz, and biotite. However, the percentage composition of each varies and accordingly imparts different color and texture to the final product. The percentage composition of feldspar varies between 65 and 90 percent, of quartz can extend from 10 to 60 percent and that of biotite lies between 10 and 15 percent.[30] Granite consists of silica (SiO_2), 70 to 77 percent; alumina (Al_2O_3), 11 to 14 percent; potassium oxide (P_2O_5), 3 to 5 percent; soda (Na_2O), 3 to 5 percent; lime, 1 percent; iron (Fe_2O_3), 1 to 2 percent; iron (FeO), 1 to 3 percent; magnesia (MgO), 0.5 to 1 percent; titina, less than 1 percent (.38 percent); and water (H_2O), 0.03 percent.[30]

Nature has gifted Egypt with large deposits of high-quality marble and granite. Since 2700 B.C., the Ancient Egyptians used granite to build their important temples and buildings. Ancient Romans, as early as the third century B.C., acquired the Egyptian knowledge in quarrying and cutting the ornamental stones, especially granite. This technology was transferred back to Italy and, due to the natural endowment of Italy coupled with the acquired technical knowledge, the marble industry flourished and the Italians became world leaders in the production of marble. The production of marble passes through several stages.[31] The main stages are demonstrated in Figure 1.26:

1. *Exploration and identification of a quarry location.* The locations are identified, followed by testing and verification of characteristics of the marble quarry.
2. *Extraction of marble from the quarries.* Extraction of the marble stone happens in several ways, depending on the technology owned by the quarrymen. Marble does not split easily into sheets of equal size and must be mined carefully.

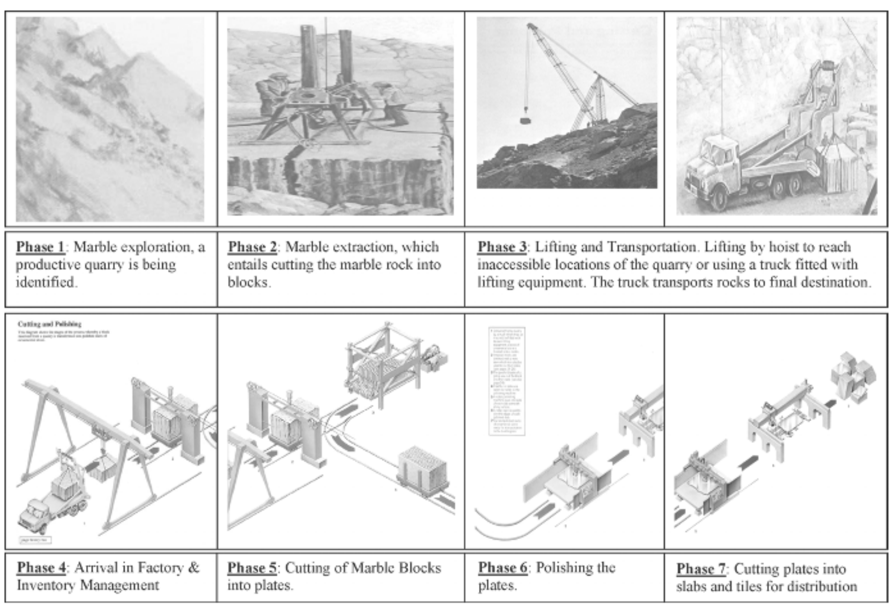

FIGURE 1.26 Marble production process (*Source:* Azza Kandil and Tarek Selim, "Characteristics of the Marble Industry in Egypt," www.aucegypt.edu/academic/economics/papers/wk6.pdf, Accessed July 5, 2007.)

3. *Lifting and transportation.* After cutting the rocks of marble, marble blocks need to be lifted to a truck for transportation to the factories.
4. *Inventory management.* The inventory of raw stone blocks is very bulky and requires a very spacious area.
5. *Cutting the stone into slabs and tiles.* When a certain order is placed, the raw stone block is transported to the factory to be cut as demanded, either into tiles or slabs of various thicknesses (usually 2 cm or 4 cm). Stone cutting is a lengthy process that can take more than a continuous 12 to 16 hours of operation, depending on the model of the cutting machine, as well as the status of its diamond wire or diamond blades.
6. *Polishing.* After the stone has been cut to the specific dimensions, there are different techniques towards reaching a "finished" product. The most known of these techniques is polishing. The polishing operation is fully automated, with the use of powdered abrasives that keeps on scrubbing the surface of the marble until it becomes smooth and shiny. The smoother the abrasive used, the shinier and smoother is the surface of the marble. Here, water showers are essential to prevent overheating.
7. *Distribution to end users.* The distribution channels depend very much on the end product produced by the factory. If the factory produces finished tiles and slabs, then this is a finished order, processed according to the customer requirements, and a customer delivery takes place. Distribution often goes to workshops that are usually the middleman between the supplier and the end user. These workshops receive the cut plates of marble and store them in their shops for the end user to choose from.

Marble and Granite Waste

Nearly 70 percent of this precious mineral resource gets wasted due to mining, processing, and polishing, as shown in Table 1.6. The processing waste being dumped on the riverbeds is threatening the porosity of aquifer zones.[32] However, for each marble or granite slab of 20 mm produced, a minimum of 5 mm is crushed into powder during the cutting process. This powder flows along with the water, forming marble slurry. In other words, a minimum of 20 percent marble/granite produced results in powder in the form of slurry. This slurry has approximately 35 to 40 percent water content. In India, about 30 percent weight

TABLE 1.6 Waste Distribution among Different Phases

Process	Marble Production	Mine Waste	Processing Waste	Polishing Waste	Total Waste	Mine Out Reserve
Quantity	30 percent	50 percent	15 percent	5 percent	70 percent	100 percent

Source: Siddharth Pareek, "Gainful Utilization of Marble Waste: An Effort towards Protection of Ecology and Environment," 2007, www.cdos-india.com/papers/18%20-%20Gainful%20Utilization%20of%20Marble%20Wast%20-%20Siddharth%20Pareek.doc.

of marble blocks are converted into powder, and it is about 1.5 million metric tons per annum. Requirement of water in the processing plants is about 2,750,000 liters per hour.[32]

Therefore, there are mainly two types of wastes solid wastes and semisolid or slurry that can be produced from marble and granite processing. Solid waste consists of stone rubble with inadequate dimension for use in any application. This rubble is of low commercial value and is usually disposed of in landfills. Natural stone slurry occurs during physical processes such as extraction, sawing, and polishing. The equipments used in these activities necessitate the use of large amounts of water, for cooling, lubrication and cleaning. This mixture of water and very small particles produces a semiliquid substance that is generally known as '*natural stone slurry'*, due to its appearance.[33] Thus, a ”filter press” is a key component in the eco-friendly technology for marble processing. The amount of water saved can be recirculated as a coolant from the settling tank to the saw nozzle after collecting the slurry for possible utilization as tiles or bricks, or to be used in cement industry or paving roads.

Another type of waste can be generated during quarrying. The quarrying waste disposal practices are as follows:[32]

- The waste generated during the quarrying operations is mainly in the form of rock fragments.
- The generated waste by the quarries are usually dumped in empty pits in the nearby area, thereby creating huge mounds of waste.
- The waste and overburden is dumped on roads, riverbeds, and agriculture fields, leading to widespread environmental degradation.
- The quarry operators express their inability in proper segregated and disposal of waste due to the small sizes of the quarry.

Physical and Chemical Properties of Slurry

The dimension of slurry particles was therefore compatible with the filling and densing of the transition zone (measuring between 10 and 50 μm) and of the capillary pores (which range from 50 nm to 10 μm of diameter), thus acting as a microfiller. According to parallel specific testing, it was concluded that the used slurry had no hydraulic or pozzolanic activity.

The average dimension of the slurry particles was inferior to 74 μm (which would exclude its use as an aggregate for concrete production, according to the conventional concrete technology approach). Their chemical nature was exclusively dependent on the original material (without clay or other deleterious materials), and the test results showed that the slurry was fit to be used in concrete mixtures.

The chemical analysis of marble slurry is shown in Table 1.7. The high content of CaO confirmed that the original stones were marble and limestone. It was also verified that the slurry did not contain any organic matter, thus confirming that it could be used in concrete mixtures.

TABLE 1.7 Chemical Analysis of Marble Slurry

Test Carried Out	Test Value (in percent)
Loss on ignition	43.46
Silica	1.69
Alumina	1.04
Iron oxide	0.21
Lime	49.07
Magnesia	4.46
Soda	Less than 0.01
Potash	Less than 0.01

Source: Sanjay Singh and V. Vijayalakshmi, "Marble Slurry—A New Building Material," *Technology Information*, Forecasting, and Assessment Council, 2006, http://www.tifac.org.in/news/marble.htm

The tested slurry had a specific density of 2.72 g/cm^3. Furthermore, by using an easy particle sizer M6.10 equipment, it was possible to compare both grading curves of cement and slurry particles. The specific surface area of the slurry particles was 7128 cm^2/g and its average size was 5.0 μm (smaller than cement particles).

Scrapes

Another waste is marble/granite scrapes (small pieces), which represent nearly 10 to 15 percent. These are usually dumped into landfills without any precaution. There are two types of scrapes: bulk stone and polished scrapes. Bulk stone scrapes are the huge masses produced at the mine when large blocks are cut out of their natural environment. These masses are usually crushed to small aggregates with a crusher, and ultimately used in tiles. Polished scrapes are normally 2 to 4 cm thick. Both types of scrapes have the following in common:

- They consume space.
- When piled up, they form hills of scrape that can house harmful animals like snakes and rats.
- They are not self-degrading materials.

Environmental Impacts and Mitigation

The environmental impacts and mitigation of both marble slurry and scrapes will be discussed in this section. As a result of disposal of the marble slurry generated during the processing of marble and granite, the following environmental damage might occur:

- The porosity and permeability for the topsoil is reduced tremendously, and in due course of time it results in waterlogging problems at the surface, which does not allow the water to percolate down.

- The fine marble particles with high pH reduce the fertility of the soil by increasing its alkalinity. The high pH of the dry slurry makes it corrosive material that is harmful to the lungs, and may cause eyesores.
- Dry slurry diffuses in the atmosphere, causing air pollution to human and possible pollution to nearby water. It settles down on crops and vegetation, thus severely threatening the ecology of the marble clusters.
- It may corrode nearby machinery.
- It depletes natural resources in terms of wastewater, marble, and granite powder, small pieces of marble, and granite.

The solid larger pieces can be easily incorporated in concrete or in sculptures, as in bonded marble. As for the slurry, it has much potential—from pavement filler material to agricultural fertilizers. Almedia et al. produced a paper that briefly describes many of the applications of marble and stone waste:[33]

- Cement industry
- Tiles
- Red ceramic bricks and tiles
- Mortars and concrete
- Polymer concrete
- Other cement-based products
- Pavement
- Embankment
- Agglomerate marble

Cement Industry Recent research studies concluded that there is technical viability to incorporate massive quantities of natural stone slurry as "raw material" in the production of clinker, without any previous complex treatments.

As an example, the Portuguese cement industry is responsible for the consumption of 12 million metric tons of raw materials each year, about 10 million metric tons of which is limestone. The Portuguese natural stone slurry produced annually represents 3.5 percent of the total limestone raw material needed by the national cement industry.

Tiles India also presents successful cases related to the production of tiles containing 90 percent of stone slurry bonded by 10 percent of resin.

Red Ceramic Bricks and Tiles A European research project concluded that it is possible to incorporate large amounts of natural stone slurry by substituting conventional calcium carbonate used in the production of red ceramic bricks, without compromising the behavior of the obtained final product.

The presence of this slurry in a 2 to 3 percent ratio solved the expansion problems usually associated with structural ceramic materials. Furthermore, depending on the kind of basic raw material used, it is possible to use up to 25 percent of slurry.

Confirmation on the behavior of this kind of recycled material was also obtained from similar research done in Brazil and India, where red ceramic tiles are produced with 20 percent of stone slurry input.[33]

Generally speaking, the bricks and floor tiles are heterogeneous because they consist of natural clays with a very wide-ranging overall composition. Consequently, they can tolerate the presence of different types of wastes, even in considerable percentages.

The raw materials that will be used in brick type compositions are plastic red clay (PRC) and low-grade clay (LGC). While in floor tile formulations, in addition to the PRC, shale clay (SC) is added and the granite sludge is added to both. Regarding the chemical composition of these three types of clay, (the PRC is based on illite, kaolinite, montmorilonite and some quartz and feldspar, while the LGC clay is mainly based on quartz and illite. The SC consists essentially of a mixture of quartz, mica (muscovite), kaolinite, illite, and montmorilonite.[34]

The sludge in general has relatively fine particle size distribution, and this means that it doesn't require any further grinding step and can replace the low-grade clay components used in the fabrication of brick type products or the feldspar in floor tiles compositions.

There were tests conducted regarding adding the sludge to the bricks and floor tiles as in the case of incorporating the cutting sludge in industrial porcelain tiles. The tests were conducted on granite sludge as a trial. The clay materials, together with the sludge, were mixed at different weight percentages regarding both the brick type and the floor tiles type, as shown in Table 1.8.

Regarding both compositions, the brick type were fired at 950°C in an industrial furnace and then followed by a long cycle of about 9 hours. The floor tile type were fired at 1100°C in an electrical laboratory furnace with a holding time of 1 hour at the maximum temperature.[34] The results were satisfactory concerning the tests, but focused more on the linear shrinkage, the water absorption, and the flexural strength. The results are shown in Table 1.9.

TABLE 1.8 Tested Brick and Floor Tiles Compositions

	Brick-type composition (wt percent)				
	1	2	3	4	5
PRC	30	35	35	40	45
LGC	70	30	15	0	5
Granite sludge	0	35	50	60	50
	Floor tile–type compositions (wt percent)				
	6	4	7	8	9
PRC	30	40	50	0	0
SC	0	0	0	40	50
Granite sludge	70	60	50	60	50

Source: J. M. F. Ferreira et al. "Recycling of Granite Sludges in Brick-Type and Floor Tile-Type Ceramic Formulations," University of Aveiro, 2007.

TABLE 1.9 The Properties of the Fired Products

Temperature	Composition	Fired Properties		
		Linear Shrinkage (percent)	Water absorption (percent)	Flexural Strength (Mpa)
	1	0.15	13.02	13.4
950°C	2	0.18	12.97	12.3
(BT)	3	0.16	12.92	10.3
	4	0.21	13.00	11.8
	5	0.29	13.01	11.7
	6	0.17	6.04	39.8
1100°C	4	0.19	1.60	53.8
(FTT)	7	0.28	0.43	57.4
	8	0.26	0.10	68.2
	9	0.30	0.00	74.6

* BT = Brick type
* FTT = Floor tiles type

Source: J. M. F. Ferreira et al. "Recycling of Granite Sludges in Brick-Type and Floor Tile-Type Ceramic Formulations," University of Aveiro, 2007.

Focusing on the results that were achieved after conducting the tests, it was found that the granite sludge that is derived from the cutting processes of this natural stone can be considered and reused to be an interesting raw material for the brick type and floor tile formulations. The results shown above clarify that there is a wide range of results regarding all the tests. For instance, focusing on the results of samples 4 and 5, the granite sludge represents approximately 50 percent of the total weight and the results of these samples regarding the linear shrinkage, water absorption, and the flexural strength are acceptable. Also from the results, it is obvious that PRC is beneficial because it enhances the overall performance and its absence will negatively affect the properties of the end product.

In the final analysis, "the granite sludge in brick type compositions can be as high as 60 percent. For floor tile type products, the incorporation of the sludge can be used in the range of 50 to 60 percent when combined with the SC, or it can be limited to a maximum of 50 percent in the case of PRC."[34] Therefore, since the brick type and floor tile type industry requires several tons of raw materials, it will be economical and environmental to consume the marble and granite sludge.

Mortars and Concrete Technical possibilities of producing concretes and mortars containing stone slurry have been studied with positive results in several countries. Research works in Portugal led to similar conclusions, demonstrating improvements in several properties. Tests were performed by Almeida et al. in order to investigate the maximum percentage of marble slurry that can be incorporated in concrete.[33] The mixes used for the tests are shown in Table 1.10.

TABLE 1.10 Concrete Mix Properties

Mixture	Sand Substitution	Compressive Strength 7 days (MPa)	Compressive Strength 28 days (MPa)	Spitting Tensile Strength (MPa)	Modulus of Elasticity (GPa)
CMSSO	0	60.3	85.1	4.2	40.5
CMSS5	5	66.5	91.1	4.8	43
CMSS10	10	55.3	79.4	4.2	41.4
CMSS15	15	58.1	79.5	4.3	38.8
CMSS20	20	53.9	77.5	4	36.9
CMSS34	34	41.1	60.8	3.3	33.5
CMSS67	67	36.4	58.2	3.2	30.7
CMSS100	100	30.1	50.3	3	26.7

Source: Nuno Almeida, Fernando Branco, and José Roberto Santos "Recycling of Stone Slurry in Industrial Activities: Application to Concrete Mixtures," (2005), http://www.sciencedirect.com/science.

Different concrete mix proportions were tested for compressive strength, tensile strength and modulus of elasticity as shown in Table 1.10.

Compressive Strength When 5 percent of the initial sand content was replaced by stone slurry (CMSS5), 10.3 percent higher compressive strength after 7 days, and 7.1 percent higher compressive strength after 28 days were detected, when compared with CMSS0. This increase can be related to the higher concentration of hydrated cement compounds within the available space for them to occupy. Furthermore, by acting as micro filler, the stone slurry promoted an accelerated formation of hydrated compounds, thus resulting in a significant improvement of compressive strength at earlier ages (7 days).[33]

In fact, the amount of slurry present in CMSS5 enabled the very fine particles of it to act as nucleation points. This is related to an effect of physical nature that ensures effective packing and larger dispersion of cement particles, thus fomenting better hydration conditions. Moreover, the slurry particles completed the matrix interstices (transition zone and capillary pores) and reduced space-free water. The combination of these phenomena resulted in a better bonding among the concrete components.[33]

CMSS10, CMSS15, and CMSS20 presented a reduction of compressive strength ranging from 3.6 percent to 10.6 percent at 7 days of age, and from 6.7 percent to 8.9 percent at 28 days of age (when compared to CMSS0). Lower performance of CMSS10 could seem improbable, taking into account its water/cement ratio. However, for this extremely low water/cement ratio, the available space for accommodating hydrated products was insufficient, thus inhibiting chemical reactions.[33]

Regarding higher contents of stone slurry (substitution of more than 20 percent of sand), the decrease of compressive strength values was significant. The incorporation of such amounts of very fine material did not permit the microfiller effect to prevail, which, in addition to a rather inappropriate grading, caused lower results.[33]

When substituting all the sand for stone slurry (CMSS100), test results showed 50.3 MPa at 28 days and 30.1 MPa at 7 days. Although these results were acceptable by comparison with conventional concrete, the relative reduction amounted to 40.9 percent for 28 days and 50.1 percent for 7 days. Therefore, it is possible to conclude that full substitution of fine aggregate for stone slurry is not reliable when compressive strength is a critical aspect to take in consideration.[33]

Tensile Strength The benefits obtained in compressive strength property due to the microfiller effect induced by stone-slurry particles was even further important regarding the splitting tensile strength tests (relative increase of 14.3 percent detected for CMSS5). These are coherent results, in light of the explanation advanced regarding the compressive strength variation of CMSS5.[33]

As for the compressive strength, when the substitution level of sand surpassed 20 percent, the tensile splitting strength was significantly reduced. Nevertheless, test results show that tensile splitting strength is less sensitive to high content of very fine particles than compressive strength. CMSS100 presented a result of 3 MPa, correspondent to a quite acceptable reduction of 28.6 percent relatively to CMSS0.[33]

Modulus of Elasticity In accordance with the analysis made concerning the other mechanical properties, CMSS5 test results determined that this was the concrete mixture with better behavior in terms of modulus of elasticity (6.2 percent higher than CMSS0) and that all mixtures containing less than 20 percent of stone slurry obtained acceptable results. CMSS10 also presented a slight improvement of 2.2 percent in behavior. In the extreme case of slurry incorporation (CMSS100), the average of test results for the modulus of elasticity was 26.7 GPa (34.1 percent less than the reference concrete mixture CMSS0).[33]

It is known that cement paste modulus of elasticity is generally half the modulus of elasticity of aggregates. Therefore, when introducing stone slurry (very fine particles, with slightly inferior size than cement particles), the paste could be considered as increased, thus promoting a negative effect on the modulus of elasticity of the hardened concretes. This fact, in addition to the higher water/cement ratio, could explain the lower modulus of elasticity attained for more than 15 percent substitution (inclusively).[33]

Another reason that might explain the negative behavior detected for more than 15 percent of aggregate replacement for slurry, apart from the higher water/cement ratio, might be associated with a possible volumetric expansion occurring among the different materials, withdrawing aggregates (which better contributes to a higher modulus of elasticity) from one another, thus losing some ability to restrain deformations (further dependent on the paste).[33] In light of this, better behavior of CMSS5 and CMSS10 can be explained by better grading and packing of hardened concrete mixture, attained by reduced space among the different particles.[33]

The results showed that the substitution of 5 percent of the sand content by stone slurry induced higher compressive strength, higher splitting tensile strength, and higher modulus of elasticity. The feasibility of incorporating up to 20 percent stone slurry in detriment of the respective amount of fine aggregate without prejudicing mechanical properties in a serious manner was also determined.

Polymer Concrete (PC) Marble and granite waste, in addition to organic binders, can be utilized in many different applications. Less-expensive recycled polymer binders have been used with marble, basalt, and quartz, as well as rice straw, bagasse, and cotton stalk fibers in polymer concrete (PC) production. Reasonable cost, durability under anticipated exposure conditions, adhesion to aggregate, handling properties, and ease of curing are the most important considerations in the choice of the resin used. The high cost of the traditional resins used in the preparation of PC makes it relatively expensive compared to the cement-based materials and is limiting the growth of PC-based products. Therefore, recycling of plastic polymers has received a great deal of attention to reduce the cost of resin production; in addition, it is an acceptable, convenient solution to some ecological problems resulting from the accumulation of these wastes.

Other Cement-based Products Applications include cement-based products such as structural blocks, lightweight blocks, soil–cement bricks, pavement coatings, and even acoustic panels developed at an experimental level that contained granite slurry, limestone aggregates, cement, and cork industry waste.[33]

Pavement Stone slurry was not considered as suitable for pavement use, but some laboratory tests demonstrated that it is possible to incorporate this byproduct in asphalt mixtures as a commercial filler substitute. The use of slurry in road works is not common. In fact, some researchers attest that it is possible to use marble slurry in roadwork layers that account for 25 to 35 percent of the total pavement thickness.

In Turkey, limestone dust was generally used in asphalt mixtures as filler material. However, in recent years, many quarries were closed off because of the environmental protection rules put into use. Therefore, highway authorities and municipalities have difficulties for finding suitable filler material. As a result, using the waste material as filler should be investigated for road construction. For this reason, Almeida et al. has investigated using marble dust in asphalt mixtures as filler material.[33]

Embankment As with pavements, opinions about the use of stone slurry in embankments are not unanimous. Despite the existence of bibliography referring to the possibility of using stone slurry in embankments (taking advantage of the insulation capability of the slurry) or mixed in a 25 percent ratio with soil, there are also several studies referring to environmental impacts related with the presence of this industrial waste in soil.[33]

Agglomerate Marble Agglomerate marble is the designation for products that bind pieces of natural marble together with specially formulated polyester resin. This process allows the reconstruction of large recycled "marble" blocks, similar to the ones extracted from quarries, both in quality and visual aspects, which can be submitted to the same processing activities as natural stone. Research concerning the reutilization of marble slurry as a substitute of calcium carbonate was developed for agglomerate marble fabrication. For a total amount of slurry that reached up to 6 percent of the total compounds, it was technically possible to adopt this procedure.[33]

This is sometimes called *cast marble*. It is a manmade product consisting of marble dust (calcium carbonate) and polyester resin. The type of resin used in bonded marble products is crystal clear and sometimes referred to as *casting resin*. This type of resin is costly to produce, thus adding more to the cost of the finished product. The calcium carbonate in the bonded marble creates a semiporous surface that has a very unique look and feel. The calcium carbonate also makes the piece pure white and allows for a very high degree of detail. Most bonded marble products are made in Italy, which has the whitest marble in the world. Other names for bonded marble are cast marble, cultured marble, and bonded Carrara marble.[35]

Natural Carrara marble powder is mixed with a resin. The mixture is then poured into a mold of the statue design. The resin gives the marble powder an added strength superior to the natural stone. The finished product bears a near identical resemblance to the original hand-carved statue. The texture and features are duplicated and the color is a consistent ivory white. Because of the characteristics of the resin material, these bonded marble statues shown in Figures 1.27 are waterproof, and can be washed and cleaned with most agents. Water and weather will not harm the material, and it is very strong. It will not yellow over time, can handle high detail, doesn't have bubbles, and will not crack.[36]

METAL FOUNDRY INDUSTRY

The metal foundry industry can be divided into two sectors: ferrous and nonferrous. Ferrous foundries cast iron and steel products, while nonferrous foundries cast a variety of other metals such as aluminum, copper, zinc, lead, tin, and nickel. More than 75 percent of products by volume are ferrous. Although nonferrous industries use the same basic molding and casting techniques, byproducts can be different from those produced from ferrous industries.

The casting of metal in foundries is one of the oldest and largest recycling industries in the world. Metal foundries exist everywhere worldwide to produce different products such as valves, pipe fittings, pipe accessories used in water, and wastewater networks made out of cast iron, copper, or aluminum through metal foundry using sand-molding technology. Many other components in engines, pumps, blowers, compressors, and so on can also be produced in metal foundries. The sand molding technology consists of the following processes:

FIGURE 1.27 Bonded marble with antique stone finish 10 inches H (25 cm) (*Source:* www.goddessgift.net/page20.html.)

1. *Sand and mold preparation.* The sand is first mixed with a hardening material, like bentonite slurry for example, inside the sand preparation mixers. After that the sand molds are formed and are placed on the production line
2. *Melting.* The main types of metals are used in metal foundry: iron, aluminum, and copper. Other metal can also be used according to requests, such as zinc, aluminum alloy, copper alloy, and so on. A large quantity of slag, which is about 20 to 25 percent of the melted material, comes out from the melting process. The utilization of slag will be discussed with details in the next section.

3. *Pouring.* The end metal product is then poured into the moulds and left to cool and gain its strength. Then the moulds are untied to get the product from.
4. *Cleaning and Inspection.* All the products are gathered for inspection and quality assurance. Some of those are rejected and sent back to the furnace for remelting, and others are approved and cleaned. However, there is a huge quantity of wasted sand that creates a disaster to the company and surrounding environment, if it is left without use.
5. *Product final preparation phase.* The products are sent to workshops for cutting, making holes, and trimming. This process results in many metal wastes that are then delivered again to the furnaces for remelting.
6. *Assembly and examination phase.* After all the products are prepared, they are assembled according to the specifications, and then their mechanical properties are tested.
7. *Finishing and storage phase.* The final product is then painted by spraying it either with bitumen or epoxy in a controlled outdoor area. After the product is painted, it is stored in its final shape.

Foundry Sand

Foundry sand is a byproduct waste sand from a foundry or factory that produces castings of metal. Iron is the most common element used in foundries, but other heavy metals have been known to be used, including aluminum, copper, lead, and zinc.[37] Foundry sand is essentially uniformly sized sand with high-quality silica content. It is used as a mold to cast the metals into the desired product. The sand mold is bonded together using organic binders. The sand-casting system is the most commonly found system in the metal-molding industry. The foundry sand is generally clean before it is used in the casting process, but once it has been used, it may be hazardous.[38] The used or spent material often contains residues of the heavy metals and binder that may act as leachable contaminants. The residual sand is routinely screened and returned to the system for reuse. As the sands are repeatedly used, the particles eventually become too fine for the molding process and, combined with heat degradation from repeated pourings, requires periodic replacement of “spent” foundry sand with fresh foundry sand. This *spent sand* is black in color and contains a large amount of fines (particles of 100 sieve size or less).[39] Most of the sand-cast molds used for iron castings are of a type of foundry sand called *green sand*, which consists of high-quality silica, bentonite clay, sea coal, and water. The green sand is not actually green in color, but refers to the fact that it is used in the wet state. In the past, once the casting has been done, the spent foundry sand was often no longer used due to fears of environmental concerns and contamination. However, an article in *Civil Engineering* magazine stated, “Fears of environmental contamination have recently been laid to rest with new studies indicating that certain types of waste foundry sand are not only ecologically safe but literally cheaper than dirt in some cases.”[40] According to a study done by the U.S. National Transportation Board, "the annual generation of foundry waste, including dust and spend foundry sand, in the United States is believed to range from 9 to 13.6 million tons. Typically, about 1 ton of foundry sand is required for each ton of iron or steel casting produced."[41] Most of this waste is landfilled, sometimes even being a cover material at landfill sites. It has been shown that spent foundry sand may be used in a multitude of applications without environmental considerations. A study done by Oakland–Berkeley Recycling Market Development Zone shows that spent foundry sand may be used as an addition to asphalt mixes and in the design of decorative tiles with the sand.[42] The physical and chemical properties of spent foundry sand are shown in Tables 1.11 and 1.12, respectively.

Uses of Foundry Sand

According to a technology brief done by the Clean Washington Center in Seattle, the uses for spent foundry sand in different applications include the following.[43]

Agricultural Products

- Amendments
- Commercial soil blends
- Compost
- Top dressing

Geotechnical Applications

- Barriers
- Embankments
- Highway construction
- Landfills
- Road bases
- Structural fills

TABLE 1.11 Physical Properties of Spent Green Foundry Sand

Property	Results	Test Method
Specific Gravity	2.39–2.55	ASTM D854
Bulk Relative Density, kg/m^3 (lb/ft^3)	2590 (160)	ASTM C48/AASHTO T84
Absorption, percent	0.45	ASTM C128
Moisture Content, percent	0.1–10.1	ASTM D2216
Clay Lumps and Friable Particles	1–44	ASTM C142/AASHTO T112
Coefficient of Permeability (cm/sec)	10^{-3}–10^{-6}	AASHTO T215/ASTM D2434
Plastic limit/plastic index	Nonplastic	AASHTO T90/ASTM D4318

Source: Highway Research Center, U.S Department of Transportation: Federal Highway Administration, "Foundry Sand," American Foundrymen's Society, Inc., http://www.tfhrc.gov/hnr20/recycle/waste/fs1.htm, Oct. 2, 2006.

TABLE 1.12 Chemical Composition of Foundry Sand

Constituent	Value (in percent)
SiO_2	87.91
Al_2O_3	4.70
Fe_2O_3	0.94
CaO	0.14
MgO	0.30
SO_3	0.09
Na_2O	0.19
K_2O	0.25
TiO_2	0.15
P_2O_5	0.00
Mn_2O_3	0.02
SrO	0.03
LOI	5.15
TOTAL	99.87

Source: Highway Research Center, U.S Department of Transportation: Federal Highway Administration, "Foundry Sand," American Foundrymen's Society, Inc., http://www.tfhrc.gov/hnr20/recycle/waste/fs1.htm, Oct. 2, 2006.

Manufactured Products

- Asphalt
- Concrete products
- Flowable fill
- Portland cement

A detailed case study to utilize spent foundry sand as a reinforcement material to mixed polymeric waste will be discussed later in this chapter.

IRON AND STEEL INDUSTRY

The iron and steel industry is considered one of the most important industries for the sustainable development. It is considered the base for numerous industries that could not have been established without the steel industry, such as construction, automotive, and steel structure industries. There are three basic routes to obtain finished steel products:

1. Integrated steel production
2. Secondary processing
3. Direct reduction

Integrated steel production involves transforming coal to coke in coke ovens, while iron ore is sintered or belletized prior to being fed into the blast furnace (BF). The ore is reduced in the blast furnace to obtain hot metal containing some 4 percent carbon and smaller quantities of other alloying elements. Next the hot metal is converted to steel in the basic oxygen furnace (BOF). Then, it is continuously cast to obtain semifinished products, such as blooms, bars or slabs. These semifinished products are rolled to the finished shapes of bars, sheet, rail, and H or I beams.

The secondary processing, often called minimills, starts with steel scrap that is melted in an electrical arc furnace (EAF). The molten steel produced is possibly treated in a ladle furnace and then continuously cast and finished in a rolling operation. Originally, minimills provided only lower grade products, especially reinforcing bars. But, they recently have been able to capture a growing segment of the steel market.

In the direct reduction method, production starts with high-grade iron ore pellets that are reduced with natural gas to sponge pellets. Then, the sponge iron pellets are fed into an electrical arc furnace. The resulting steel is continuously cast and rolled into a final shape.

There is a huge amount of solid waste "slag" generated from the iron and steel industry as a result of the impurities. Usually, slag is collected from the process and left in a nearby area occupying millions of square meters of land. Slag is not only hindering the use of millions of square meters of land for more useful purposes but also contaminating it with heavy metals such as barium, titanium, and lead. Also, it is well known that toxic substances tend to concentrate in slag that floats at the top of the furnace. Health hazards of heavy metals and toxic substances are well known. Based on the concentration levels of heavy metals, slags may be classified as hazardous waste materials. Furthermore, groundwater, as well as surface water, is susceptible to serious pollution problems due to the likely leaching of these waste materials.

Another type of solid waste generated from the secondary processing is the iron dust produced at the beginning of the process during feeding the scrap to the electrical arc furnace (EAF) for melting. Small quantity of sludge might also be produced during the process of iron in blast furnace.

This section describes the different types of solid waste materials generated from the iron and steel industry and the associated environmental problems. Different techniques of managing these waste materials are presented with a focus on utilizing slag, dust, and sludge in construction engineering applications. Test results of many research efforts in this area are summarized. In addition, numerous ideas to mitigate the environmental impacts of this problem are suggested.

Environmental Impacts

Iron making in the BF produces a slag that amounts to 20 to 40 percent of hot metal production. BF slag is considered environmentally unfriendly when fresh because it gives off sulfur dioxide and, in the presence of water, hydrogen sulfide and sulphoric acid are generated. These are at least a nuisance and, at worst, are potentially dangerous. Fortunately, the material stabilizes rapidly when cooled and the potential for obnoxious leachate diminishes rapidly. However, the generation of sulphoric acid causes considerable corrosion damage in the vicinity of blast furnaces. In Western Europe and Japan, virtually all slag produced is utilized either in cement production or as road filling. In Egypt, almost two-thirds of the BF slag generated is utilized in cement production. Some 50 to 220 kg of BOF slag is produced for every metric ton of steel made in the basic oxygen furnace, with an average value of 120 kg/metric ton. At present, about 50 percent of BOF slag is being utilized worldwide, particularly for road construction and as an addition to cement kilns.[44]

Recycling of slags has become common only since the early 1900s. The first documented use of BF slag was in England in 1903;[45] slag aggregates were used in making asphalt concrete. Today, almost all BF slag is used either as aggregate or in cement production. Steel for making slag is generally considered unstable for use in concrete but has been commercially used as road aggregates for over 90 years and as asphalt aggregates since 1937. Steel-making slag can contain valuable metal and typical processing plants are designed to recover this metal electromagnetically. These plants often include crushing units that can increase the metal recovery yield and also produce materials suitable as construction aggregates. Although BF slag is known to be widely used in different civil engineering purposes, the use of steel slag has been given much less encouragement.

BF dust and sludge are generated from the processing and cleaning, either by wet or dry means. The dust and sludge typically are 1 to 4 percent of hot metal production.[46] These materials are less effectively utilized than BF slag. In some cases, they are recycled through the sinter plant, but, in most cases, they are dumped and landfilled. Finding better solutions for the effective utilization of BF dust and sludge is an important problem. BOF dust and sludge are generated during the cleaning of gases emitted from the basic oxygen furnace. The actual production rate depends on the operation circumstances. It may range from about 4 to 31 kg/metric ton of steel produced, and has a mean value of about 18 kg/metric ton.[44] The disposal or utilization of BOF dust and sludge is one of the critical environmental problems in some countries.

Electrical arc furnace produces about 116 kg of slag for every metric ton of molten steel. Worldwide, about 77 percent of the slag produced in EAFs is reused or recycled.[44] The remainder is landfilled or dumped. Due to the relatively high iron content in EAF slag, screens, and electromagnetic conveyors are used to separate the iron to be reused as raw material. The EAF slag remaining is normally aged for at least six months before being reused or recycled in different applications such as road building. All efforts in Egypt have focused on separating the iron from EAF slag without paying enough attention to the slag itself. However, pilot research work conducted at Alexandria University in Egypt has investigated the possibility of utilizing such slag.[47] The test results proved that slag asphalt concrete could, in general, fulfill the requirements of the road-paving design criteria.

EAF dust contains appreciable quantities of zinc, typically 10 to 36 percent. In addition, EAF dust holds much smaller quantities of lead, cadmium, and chromium. EAF dust has been classified as a hazardous waste (K061) by the U.S. Environmental Protection Agency, and therefore its safe disposal represents a major problem. Although there are several technologies available for processing this dust, they are all quite expensive, on the order of US$150 to US$250 per ton of dust.

The Problem in Egypt

Apart from the granulated BF slag used in producing slag cement, all types of waste from any steel plant in Egypt were simply dumped in the neighboring desert. Based on the production figures of the major steel plants in Egypt and the generation rates of different waste materials per each metric ton of steel produced, the annual waste materials generated in Egypt was estimated and summarized in Table 1.13 over and above the accumulated stock pile in the near by area. There are stockpiles of 10 million metric tons of air-cooled BF slag and another 10 million metric tons of BOF slag laying in the near by area.

Obviously, waste generators will be required to pay a certain fee per metric ton disposed. In 1993, the cost of disposing one ton of steel plant wastes in the United States was $15.[48] Today, it goes up to $100. Large tonnage of iron and steel slags are increasingly produced in Egypt, and the huge space needed to dump them has become a real challenge. To have an idea about the considerable area needed for disposal, it is quite enough to know that the 20 million metric tons of BF and BOF slags currently available are estimated to occupy 2.5 million square meters.

Potential Utilization of Slag

Many of the environmental problems of solid waste materials generated from the iron and steel industry have been known for some time, and attempts have been made to tackle them with varying degrees of success. During the past few years, the iron and steel industry has been able to produce some creative

TABLE 1.13 Waste Materials Generated from Iron and Steel Industry in Egypt

Type of Waste	Annual Amount Generated (metric tons)
Blast furnace slag	600,000
Basic oxygen furnace slag	200,000
Electrical arc furnace slag	300,000
Blast furnace dust	20,000
Electrical arc furnace dust	15,000
Rolling mill scales and sludge	25,000

solutions to some of these environmental problems. It is highly probable that many other creative solutions also could emerge as a result of well-thought-out and well-supported research programs.

Processing of slag is a very important step in managing such waste material. Proper processing can provide slag with high market value and open new fields of application. Cooper et al. discussed the recent technologies of slag granulation.[49] The main steps of the granulation process were addressed with schematic drawings, including verification, filtering, and denaturing systems. The most recent continuous granulation technology at that time was introduced in detail with the help of many illustrative figures, as shown in Figure 1.28.

Foster addressed the high cost of disposing wastes generated from the steel industry and discusses an innovative idea from South Africa to manage BOF slag, which has a limited usage.[48] He came up with a new idea for processing BOF slag. This process starts with preparing the slag by grinding it, mixing it with a reductant such as sawdust or charcoal, and feeding it into a modified cyclone-type preheater. This reduction process removes iron oxide from iron. The slag is then passed over a magnet, which removes the iron particles. The low-iron slag is then mixed with other materials, such as clay, to produce an acceptable type of cement kiln feed.

Featherstone and Holliday introduced the idea of dry slag granulation shown in Figure 1.29.[45] The existing slag treatment methods, the new dry granulation method, and the value of granulated slag products were reviewed. The development, application, and advantages of the dry method of granulating molten slags were described. The dry granulated slag was proved to have many environmental

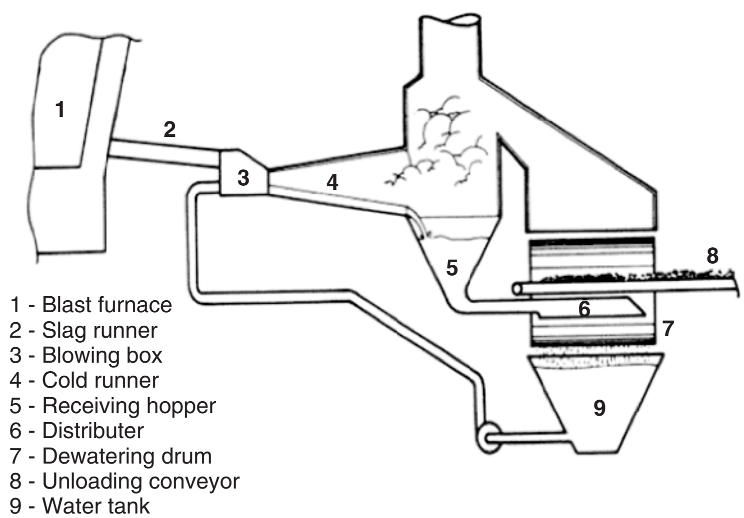

FIGURE 1.28 Continuous slag granulation system. (*Source:* A.W. Cooper, M. Solvi, and M. Calmes, "Blast Furnace Slag Granulation," *Iron and Steel Engineer*, 63, (July 1986): 46–52.)

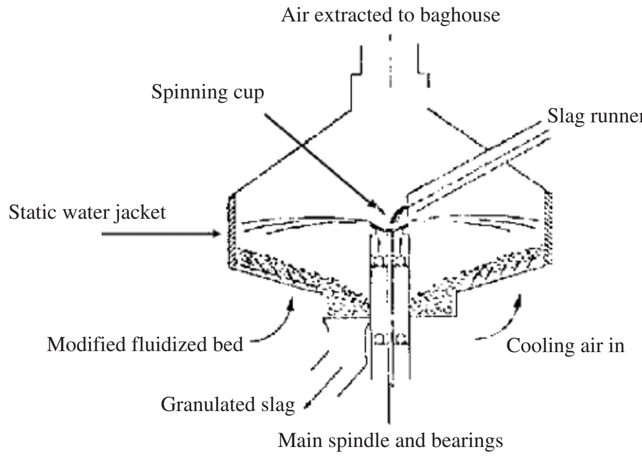

FIGURE 1.29 Dry slag granulation. (*Source:* W. B. Featherstone and K.A. Holliday, "Slag Treatment Improvement by Dry Granulation," *Iron and Steel Engineer* (July 1998): 42–46.)

advantages over conventional processes, while generating a product of equal quality in addition to its low cost and simplicity.

Swamy presented an extensive and critical examination of the use of ground granulated BF slag in concrete.[50] It was shown that the use of BF slag as aggregate in concrete can lead to high strength concrete with excellent durability. Apart from its ability to reduce the temperature rise due to hydration, test results showed that BF slag has a hidden potential to contribute high early age strength, excellent durability and very good chemical resistance. A mix proportioning method was advanced that assured the development of early strength for slags of normal surface area of 350 to 450 m^2/kg. Table 1.14 summarizes the compressive strength development up to 180 days age for mixes with 50 percent (A) and 65 percent (B) slag replacement of coarse aggregates. Curing was shown to be a critical factor that affects early age strength, continued strength development, and fine pore structure responsible for durability. It was also shown that with a well-defined curing period, the mineralogy and chemistry of slag could be mobilized to develop a very fine pore structure that is far superior to that of Portland cement concrete. Such a fine pore structure can impart a very high resistance to concrete to the transport of sulfate and chloride ions and water.

Nagao et al. proposed a new composite pavement base material made of steel-making slag and BF slag. When the new composite base material was prepared by mixing steel-making slag, air-cooled slag, and granulated blast furnace slag in proportions of 65 percent, 20 percent and 15 percent, respectively, it was found to have material properties and placeability similar to those of conventional hydraulic and mechanically stabilized slags.[51] Also, it was found feasible to quickly and economically suppress the swelling of steel-making slag by the hot water immersion that involves hydration reaction at 70° to 90°C, under which

TABLE 1.14 Compressive Strength Development of Slag Concrete

Mix	Age, Days	Compressive Strength, (MPa)
A	1	7.20
B	1	4.10
A	3	28.90
B	3	19.00
A	7	39.00
B	7	27.40
A	28	46.80
B	28	34.20
A	90	54.90
B	90	38.20
A	180	57.10
B	180	36.47

Source: R. N. Swamy, "Concrete with Slag: High Performance and Durability without Tears," 4th International Conference on Structural Failure Durability and Retrofitting, Singapore (1993), pp. 206–236.

slag can be stabilized in 24 hours at an expansion coefficient of 1.5 percent or less, as proposed by Japan Iron and Steel Federation.

One of the interesting research efforts in Egypt to find fields of application for iron and steel slags among other waste materials is the project carried out by Morsy and Saleh from 1994 to 1996.[52] This project was funded by the Scientific Research and Technology Academy to investigate the technically sound and feasible utilization of two solid-waste materials, iron and steel slags, and cement dust, in addition to some other different liquid wastes. The study dealt with BF slag, both air-cooled and water-cooled, and BOF slag. The use of such slags in road paving as a base, subbase, and surface layers was examined through laboratory and pilot field tests. The results proved that these slags are suitable for use in all paving layers. Better performance and higher California bearing ratio were obtained for slags compared to conventional stones. The Egyptian standards for ballast require that the weight of cubic meter of ballast not be less than 1.1 metric tons, and that Los Angeles abrasion ratio does not exceed 30 percent. Test results showed that the properties of iron and steel slags surpassed the requirements of these standards and can be used as ballast provided that suitable grading is maintained.

Another study performed in Egypt in 1997,[47] by the Institute of Graduate Studies and Research at Alexandria University in conjunction with Alexandria National Iron and Steel Company, was aimed at investigating the use of EAF slag as road-paving base material and as coarse aggregate for producing concrete suitable for applications such as wave breakers, sidewalk blocks and profiles, and manhole covers. The physical and chemical properties of EAF slags

TABLE 1.15 Marshall Test for Asphalt Concrete Containing Slag

Asphalt Content, percent	Unit Weight (Ib/ft^3)	Stability (Ib)	Flow/ inch	Voids in Agg., percent	Voids in Total Mix
3.5	2.62	2279	10.2	14.8	9.2
4.5	2.72	2726	11.7	14.3	5.9
5.5	2.77	2550	12.4	14.5	3.5
6.5	2.73	2100	15.9	15.6	1.5
Design criteria	–	>1800	8–18	>13	3–8

Source: M. El-Raey, "Utilization of Slag Produced by Electric Arc Furnace at Alexandria National Iron and Steel Company," Institute of Graduate Studies and Research, Alexandria University—Egypt, 1997.

of different ages were determined. EAF slag was crushed to the desired size and the applicability of slag in producing asphalt concrete was tested laboratory by the Marshall test. Table 1.15 shows some of the results obtained for asphalt concrete containing slag. The test results proved that slag asphalt concrete could, in general, fulfill the requirements of the road-paving design criteria. EAF slag was successfully used as a coarse material for the base layer in a field-scale test.

The study also covered the use of EAF slag as coarse aggregate for concrete, and the obtained results revealed that slump values for slag concrete were lower than those of gravel concrete by 33 percent for the same water/cement ratio. The unit weight of slag concrete was found to be 2.6 to 2.7 t/m^3. It ranged from 2.35 to 2.38 t/m^3 for gravel concrete. The higher unit weight is attributed to the higher specific gravity of slag compared to gravel, 3.5 and 2.65, respectively. For the same cement content and water/cement ratio, and at both early and later ages, slag concrete exhibited higher compressive strength than gravel concrete, with an average increase of 20 percent at 7 days age and 10 percent at 28 days age. The same classical effects of water/cement ratio, aggregate/cement ratio, and curing on gravel concrete were observed for slag concrete. From a durability point of view, no sign of self-deterioration was noticed for slag concrete. Slag concrete has been successfully applied in manufacturing sidewalk blocks and profiles, manhole covers, and balance weights.

Korany and El-Haggar investigated the utilization of different slag types as coarse aggregate replacements in producing building materials, such as cement masonry units and paving stone interlock.[53] Cement masonry specimens were tested for density, water absorption, and compression and flexural strengths. The paving stone interlocks were tested for bulk density, water absorption, compressive strength, and abrasion resistance. They also studied the likely health hazards of the proposed applications. The test results proved in general the technical soundness and suitability of the introduced ideas. Most of the slag solid brick units showed lower bulk density values than the commercial bricks used for comparison. All slag units exhibited absorption percentages well below the ASTM limit of 13 percent. A substantially higher compressive strength results

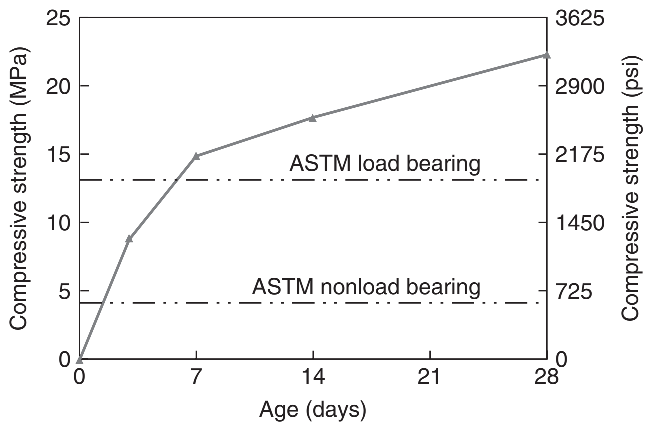

FIGURE 1.30 Development of compressive strength with age for solid brick groups at 100 percent slag replacement levels. (*Source:* Y. Kourany and S. M. El-Haggar, "Utilizing Slag Generated from Iron and Steel Industry in Producing Masonry Units and Paving Interlocks," 28th CSCE annual conference, June 7–10, 2000, London, Ontario, Canada.)

were reached for all masonry groups at 28-day age compared to the control and commercial bricks as seen in Figure 1.30. All test groups showed higher compressive strength than the ASTM limit of 4.14 MPa for nonload-bearing units. At slag replacement levels higher than 67 percent, all groups resulted in compressive strength higher than the ASTM requirement of 13.1 MPa for load-bearing units. All slag types resulted in paving stone interlocks having water-absorption values far below the ASTM limit, as shown in Figure 1.31. All slag paving stone interlocks showed higher compressive strength and abrasion resistance than the control specimens made of dolomite. Moreover, the proposed fields of application were found to be safe to the environment and have no drawbacks based on the heavy metals content and water-leaching test results.

Szekely proposed a comprehensive research program to reduce fume formation in the BOF and EAF, find an effective approach to reduce and utilize steel-making slag, and to effectively use the oily sludge produced in rolling mills.[44] Related environmental problem areas were discussed and preliminary solutions were identified. From Szekely's viewpoint, although several technologies are available for treating EAF dust, they are quite expensive, and satisfactory solutions for the EAF dust problem have not yet been produced. He suggested some possible solutions worthy of exploration, such as modifying the charging, blowing, and waste gas exhaustion system to minimize dust formation. Another proposed solution is to examine the composition of the dust produced during different phases of furnace operation and, if appropriate, segregates the recovered dust.

Some of the methods used to turn steel plant dust into a valuable raw material were described by one of the solid waste processing companies in its article published 1997.[54] One of the commonly used methods is micropelletizing, where dust is mixed with lime as a binder and is pelletized to produce a fine granular

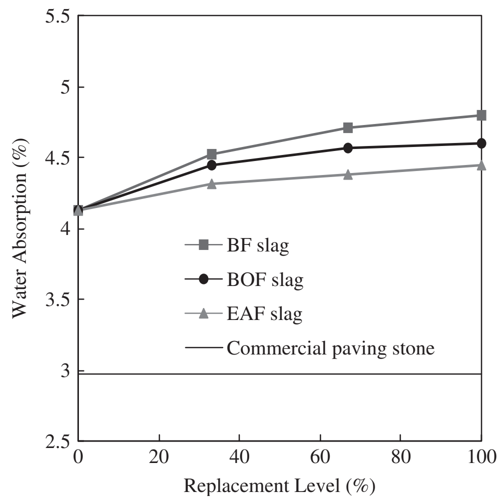

FIGURE 1.31 Comparison between absorption ratios of the different slag types with replacement level. (*Source:* Y. Kourany and S. M. El-Haggar, "Utilizing Slag Generated from Iron and Steel Industry in Producing Masonry Units and Paving Interlocks," 28th CSCE annual conference, June 7–10, 2000, London, Ontario, Canada.)

form, the major proportion being in the size range of 2 to 3 mm with a total size range of 1 to 10 mm. The water content is adjusted to 12 percent during mixing and the pellets are air-cured for a minimum of three days before charging to the sinter plant, where they account for 3 percent of the total charge. The article also addressed the direct injection process currently on trial in Germany and the United Kingdom, where injection is used to pass fine dust into the liquid metal in the furnace. Fine dust is blended with hydrating dusts such as burnt lime and carbon. The metal oxide content of the material is about 70 percent and has a particle size range of 0 to 8 mm, making it ideal for direct injection into a range of furnaces.

Final Remarks

Besides the economic and technical importance of utilizing waste materials generated from the iron and steel industry, this activity is of great importance from the environmental protection point of view, as well as conservation of natural resources. The first environmental impact is the useful consumption of the huge stockpiles of these waste materials. When these waste materials are used as replacements for other products such as cement, the natural resources that serve as raw materials are preserved. Also, air pollution levels will be reduced due to the reduction in fuel consumption. All slag types should be treated as byproducts rather than waste materials. All existing and new steel plants should have a slag-processing unit within the factory property to extract steel from slag and to crush the slag and sieve it to the desired grading for ease of promotion.

WASTE INDUSTRY

This is a new industrial sector, and the most challenging industrial sector to be addressed all over the world. The challenging part came from the nature of the waste industry because it is a multi-industrial activity containing all types of wastes, including hazardous wastes. This sector will utilize the wastes as a byproduct in order to conserve the natural resources through the cradle-to-cradle concept and reach sustainability. Sustainability or sustainable development will never be achieved without conservation of natural resources. Therefore, the main indicator for sustainability is life cycle assessment (LCA), based on the cradle-to-cradle concept, not cradle-to-grave concept, as discussed before. In other words, *cradle to cradle* is the indicator for sustainability. The degree to which cradle to cradle is achieved will give an indication of how close the industry or any manmade activity is to sustainability.[1]

Waste industrial sector can be classified into four categories: (1) direct waste recycling industry, (2) multiple waste recycling industry, (3) waste exchange network industry, and (4) environmentally balanced industrial complexes (EBICs). Direct waste industry that can relay on specific type of waste to be recycled on-site or off-site. This category is the most common type of waste industry to convert waste into products. Some additives might enhance the quality of products.

Multiple waste-recycling industries integrate more than one type of waste as a raw material in order to enhance the properties of the products. For example, use of spent foundry sand, which is hazardous waste from metal foundry industries, to enhance the properties of recycled mixed plastics from the plastics industry will be discussed next section (Multiple Waste Recycling Industry). Each waste stream represents an environmental problem for their related industry. Combining each waste together with a certain percentage will enhance the properties of new products. Some additives might be added according to product's specifications. Another example, discussed in Cement Industry section, is adding cement kiln dust (CKD) with agricultural waste to municipal sludge to produce soil conditioner. CKD will treat the sludge by killing all parasites including Ascaris eggs through high PH of CKD. Agricultural waste will act as a bulking agent to convert this mixture into a soil conditioner suitable for land reclamation.

The third category is the waste exchange network industry by integrating a new waste-related industry (based on waste generated from the current industry) into the current industry to recycle their waste, such as different new industries initiated in Kalunbourg industrial estate in Denmark located 75 miles west of Copenhagen based on waste generated from the current industries, as will be discussed later. This category can also be called *industrial symbiosis* or *byproduct exchange* (bpx) network.

The fourth category is environmentally balanced industrial complexes (EBICs), developed by Professor Nelson Nemerow to approach zero pollution.[55] EBICs can be defined as a selective collection of compatible industrial plants located together in one area "complex" to minimize both environmental impact and industrial production costs.

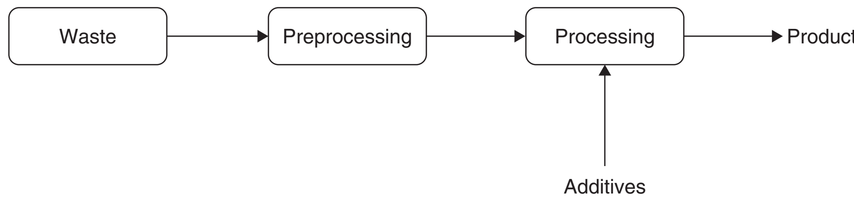

FIGURE 1.32 Direct waste recycling industry.

Direct Waste Recycling Industry

This category is commonly used within the industrial process (on-site recycling) to recycle the waste from within the process, or it could be off-site recycling within small microenterprises (SMEs) to recycle a certain type of waste, as shown schematically in Figure 1.32.

On-site recycling involves returning the waste material either to the original process as an input material or to another process as input material (inside the same factory). In other words, on-site recycling means re-entering the waste into the process as a substitute for an input material or sent as useful by products or raw material for other processes within the same factory. For example, in the plastic industry, any plastic waste from the industrial process can be added with a certain percentage to the virgin raw material to control the mechanical properties and costs. Another example in the pulp and paper industry, the fiber recovery from white paper, the surplus pulp fiber, paper mill off cuts and damaged paper rolls are recycled back into the pulping process. A third example, in oil and soap industry, the gravity oil separator (GOS) will separate the oil from the industrial wastewater stream by gravity and return it back to the industrial process.

Off-site recycling implies that the recycling process takes place by another party that recycles the industrial wastes or at the postconsumer stage such as municipal solid waste. There are companies that specialize in recycling the specific wastes. They buy certain types of wastes, recycle them, and then sell them back to other industries or direct to consumers.

Advanced direct waste recycling industry could also be included within this category such as converting recycled polypropylene (PP) into the properties of polycarbonate (PC) blends by adding some additives such as fire-retardant, impact modifier, ultraviolet stabilizer and antioxidant.[56] This additives will modify the properties of recycled PP into the properties of PC. This new material can replace the PC blends in some applications such as garden spotlights (outdoor lighting) and three-phase circuit breaker boxes. This new material based on recycled PP will maintain a good quality for the product with less cost.

Multiple Waste Recycling Industry

This category can include different wastes together to enhance the properties of a product and reach a certain specification. The famous waste exchange mechanism applied in different countries can help developing this category, such as:

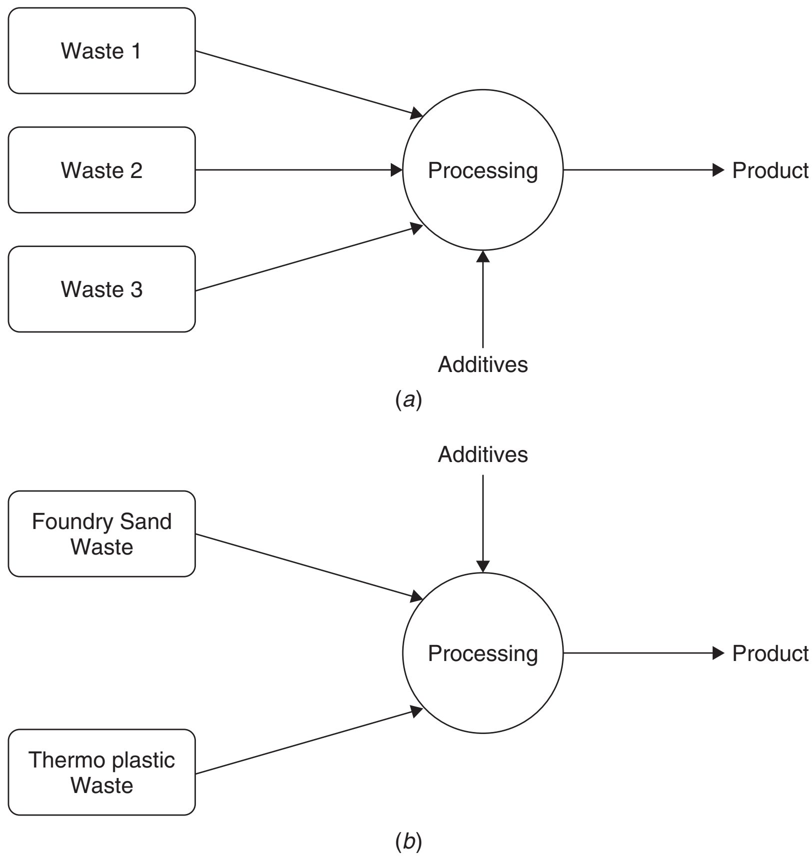

FIGURE 1.33 Multiple waste recycling industry (a) general (b) specific

- Use of foundry sand as a reinforcement to enhance the properties of plastics in different applications as will be discussed in the next section and represented schematically in Figure 1.33.
- Thermosets such as Milamean cannot be recycled directly by direct waste recycling method. Adding thermoset waste into thermoplastic waste will enhance the properties of the products as discussed before.
- Polystyrene foam can be recycled by crushing through shredding machine, and then melted. The melted product can be crushes again and mixed with PP to give the product some ductility and recycle the produced mixture.

Waste Exchange Network Recycling Industry

This is the most important category within the waste sector to develop a new industry within the existing industries and should be developed in *cooperation* with the mother industries to guarantee sustainability. Promoting this category will enhance not only the conservation of natural resources to approach cradle-to-cradle concept and the protection of the environment, but also will disseminate the culture of waste industry within the industrial communities and decision makers. This promotion will lead to the end of construction of any new disposal facilities such as landfills or incinerators. The italicized word *cooperation* mentioned before is very important to guarantee a continuous supply of raw materials (wastes) and reach sustainable development. This industrial category should be located any where between the waste generators to minimize the transportation cost. The most famous examples of waste integration category are the new industries established within Kalundborg industrial estate in Denmark. New industries joined Kalunbork Industrial Estate (eco-industrial park) based on the waste of the core industries as a byproduct as shown in Figure 1.34. They ended up with the following added new industries:

- *Gyproc—plasterboard production:* Asnaes power station "mother company" installed a desulfurization unit to remove sulfur from its flue gases, which allows it to produce calcium sulfate (gypsum). This is the main raw material in manufacturing of plasterboard at Gyproc. By purchasing synthetic "waste" gypsum from Asnaes power station, Gyproc has been able to replace the natural gypsum that is imported from Spain.

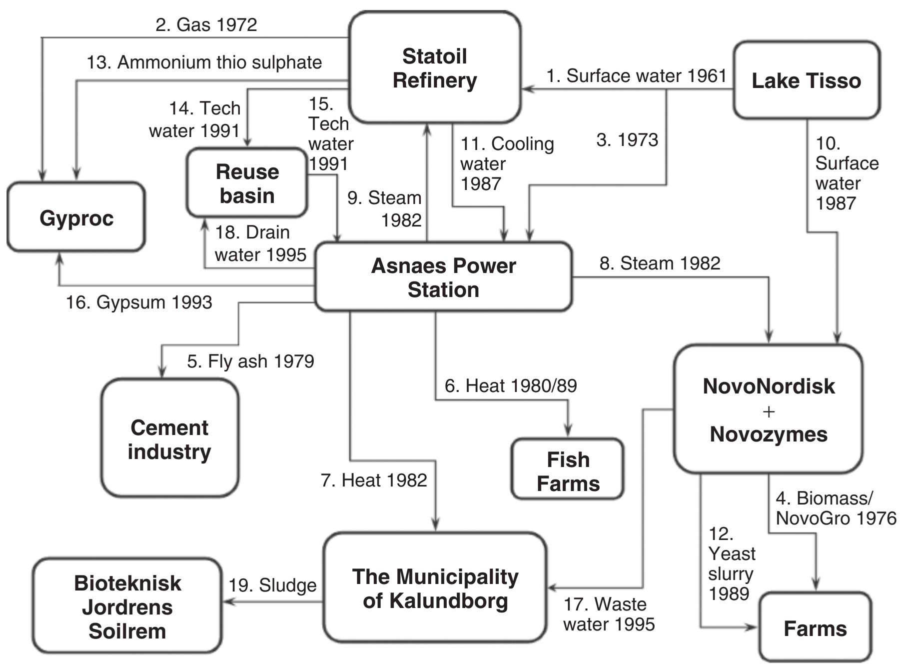

FIGURE 1.34 Waste exchange network recycling industry, Kalundborg Industrial symbiosis in 2000. (*Source:* Laura Saikkuu, "Eco–Industrial Parks: A Background Report for the Eco-Industrial Park Project at Rantasalmi," Finland: Publications of Regional Council of Etela–Savo, 2006.)

- *Fish farm — consists of 57 fish ponds*: Asnaes Power Station started fish farming to solve the problem of thermal pollution generated from the cooling water. The seawater used to cool the condenser of the thermal power plant was utilized to develop an artificial fish farm; the fish grew faster in such a warm temperature.
- *Fertilizer*: Regulation in Denmark placed significant restriction on the discharge of organics into the sea. Since Novo Nordisk (main company) used to mix the industrial sludge (organic) with wastewater and discharge it to the sea, it found out the most cost-effective way for sludge disposal is to convert it into fertilizer and give it to the nearby farmers.
- *Cement company — Aalborg Portland and road paving*: Asnaes Power Station (main company) using coal as a fuel source and produced a huge quantity of ash to be landfilled. Asnaes Power Station started to sell fly ash to cement factories to reduce the cost of waste disposal in landfill and gain money for further development. They built Ash silo with an unloading facility to accomplish this duty.
- *Kemira — a sulfuric acid producer*: Statoil refinery process the oil and separate the sulfur from the oil to produce high quality fuel. Statoil refinery begins selling sulfur to Kemira in Jutland. Excess gas from the operations at the Statoil refinery is treated to remove sulfur, which is sold as raw material for the manufacturing of sulfuric acid at Kemira.

Another subcategory can also be fitted within this category to use the waste of one plant as one of the raw material to be replaced for another plant. The waste generated from iron and steel industry, such as water-cooled slag and air-cooled slag, can be used to replace natural resources as:

- Grinding water-cooled slag produced from iron and steel industry discussed before to be mixed with raw cement to produce a special type of cement
- Cutting air-cooled slag produced from iron and steel industry discussed before to be used as an aggregate in flexible pavement or interlocks to enhance the properties and reduce the use of natural resources

Environmentally Balanced Industrial Complexes

Environmentally balanced industrial complexes are a selective collection of compatible industrial plants located together in one area “complex” to utilize the waste of one plant as the raw materials for another plant with minimum transportation and storage facilities. This category will reduce the overall production cost significantly because it eliminates waste treatment cost, reduces raw material cost “substituted by waste,” minimizes storage facility and transportation cost as well as reducing pollution and protects the environment. A number of EBICs were investigated and proposed to produce zero waste out of such complexes, such as sugarcane complexes, tannery complexes, textile complexes, pulp and paper mill complexes, fertilizer–cement complexes, fossil fuel power plant complexes, steel mill fertilizer–cement complexes, cementlime, and power plant complexes.[55]

MULTIPLE WASTE RECYCLING INDUSTRY

Thermoplastics bags generally may be recycled under the condition that they are not contaminated as discussed before in plastic industry section. If they are contaminated, then usually they are burned or landfilled. They are often referred to as *plastic rejects*, such as black garbage bags. This is basically due to the fact that it is too expensive to recycle these plastics. They require immense amounts of water, chemicals, and energy in order to clean them, which defeats the purpose of conservation in the first place. At this point, it is noteworthy to mention that the objective of this case study is to use rejected plastic waste that is no longer usable. Hence, the product that will be produced will naturally have lower physical and mechanical properties than that of virgin plastic material. It may be used as a basis of comparison, but the properties of the products can be improved by using foundry sand waste (hazardous waste) as a reinforcing material for thermoplastics.

The objective of this case study is to investigate the reinforcement of contaminated thermoplastic rejects discussed under "Unrecyclable Plastics" with foundry sand waste as a reinforcing material. Rejected plastics are either burned, producing harmful emissions into the air causing pollution; landfilled, causing the inefficient use of land that could otherwise be used for more beneficial purposes; or left on the streets, causing visual pollution and potential health hazards, as well as depleting the natural resources. The mechanism of utilizing rejected plastics would be by heating the rejects indirectly at high temperatures (150° to 250°C) and then reinforcing it with foundry sand waste and regular sand to enhance its strength. The case study investigates the mechanical and environmental properties of this new material. Each of these reinforcing materials will be used in combination with the rejected plastics in varying quantities. Through this, not only will this material be able to eliminate the pollution of air, water, and land, but will also be able to utilize a certain waste as a new material, and thus not deplete the earth's natural resources. It will also be able to save energy through the means of conserving a certain waste, thus conserving material and energy, and it will be able to save costs of waste material by using it as a raw material for another product. This will not only save the cost of the waste material, but also make a profit from the new product made of this new recycled of unrecyclable material. It will be a tool in approaching the concept of cradle to cradle and will ultimately protect the environment by producing zero waste through this mechanism of efficient use.

Seven different samples were used in this case study to mix plastic rejects with different percentages of foundry sand waste and regular sand. The two reinforcing agents that were added to the plastic rejects were added in varying percentages to determine the most efficient combination. The percentages of each material are relative to the total weight of the mix. For simplicity and ease, each mix had a total weight of 1 kg. The seven mixes and their designated percentages are shown in Table 1.16.

As shown in Table 1.16, there were a total of seven mixes, including the control mix with 100 percent plastic rejects and no reinforcing agent. All the other

TABLE 1.16 Combination of Mixes with Designated Percentages

Sample No.	Plastic Rejects (percent)	Foundry Sand Waste (percent)	Regular Sand (percent)
1	100	0	0
2	90	10	0
3	80	20	0
4	70	30	0
5	90	0	10
6	80	0	20
7	70	0	30

Source: S. M. El-Haggar and L. El-Hatow, "Reinforcing Thermoplastics Rejects with Foundry Sand Waste," Submitted for publication to ASCE (2007).

variable mixes are compared to this control mix. The percentage reinforcements are a percentage of the total weight of the sample.

Mechanical Tests

Tensile strength and flexural strength were investigated for different sand contents to determine their impacts as a reinforcement material on the mechanical properties of plastic rejects.

Tensile Strength Test To determine the properties of tensile strength of the specimens, tests were done in accordance with ASTM D3039−00.[57] Tensile strength test was performed in order to determine the ultimate tensile strength. Specimens were machined to dimensions of 25 by 250 by 2.5 mm in accordance with ASTM D3039−00. Gauge length was 100 mm, with the grips firmly holding the tabs. The tensile test occurs on a universal testing machine (UTS). Standard ribbed grips were used to hold the specimen in place. A constant head speed of 5 mm/min was used to allow for failure anywhere between 1 and 10 minutes.

The tensile properties for the different reinforcing elements showed great significance in the way the material behaves, as shown in Figure 1.35. In terms of foundry sand reinforcement of the plastic rejects, the results show that 10 percent reinforcement was the most suitable percentage that gave the highest tensile strength of 19.13 MPa. As for regular sand, 10 percent reinforcement was also the most suitable percentage that gave the highest tensile strength of 19.11 MPa. However the trend of foundry sand reinforcement curve in comparison to the regular sand reinforcement curve shown in Figure 1.34, shows that both sands reached a highest tensile strength of 19 MPa at 10 percent reinforcement and then declined with 20 percent and 30 percent, however the degree of decline of the regular sand in comparison to the foundry sand was much steeper. The regular sand declined much worse than the foundry sand, indicating the possibility that the heavy metals within the foundry sand, in fact, have a promising effect on the tensile strength. Foundry sand was shown to be a better reinforcing

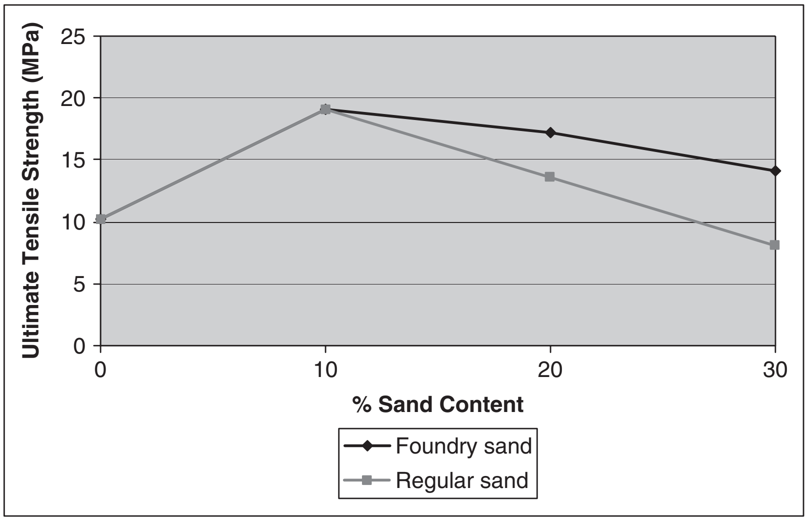

FIGURE 1.35 Tensile strengths of Composite material with foundry sand and regular sand. (*Source:* S. M. El-Haggar and L. El-Hatow, "Reinforcing Thermoplastics Rejects with Foundry Sand Waste," Submitted for publication to ASCE (2007).)

element in plastic rejects than regular sand, which is an optimistic observation considering the fact that foundry sand is also a hazardous waste.

When the best percentages of both reinforcing elements were selected and compared, many observations can be seen. First, it can be noted that both reinforcing elements showed improvement from the 0 percent no-reinforcement specimens. Second, the highest tensile strength resulted from reinforcement with foundry sand waste with 10 percent reinforcement, followed by regular sand with 10 percent reinforcement.

Flexural Test To determine the properties of flexural strength of the specimens, tests were done in accordance with ASTM D 790-03 [2003]. The flexural test was performed on the specimens in order to determine the ductility of the specimens as well as their flexural strength. Specimens were machined to dimensions of 127 by 12.7 by 4.5 mm in accordance with ASTM D790-03. Gauge length was 70 mm, with a span to depth ratio of 16. The flexural test occurs on a universal testing machine (UTS). A flexural apparatus was constructed to hold the specimen in place and allows for a three-point bending test. The apparatus was placed and aligned on the UTS machine with two concentric compression plates below and above the apparatus to allow it to function properly. A constant head speed of 2 mm/min was used to allow for failure anywhere between 1 to 10 minutes. The flexural strength for the different reinforcing elements showed varying results. The maximum flexural load of the composite material, reinforced with foundry sand waste and regular sand, are shown in Figure 1.36.

The foundry sand reinforcement of the plastic rejects, the 10 percent reinforcement shown to have the highest flexural strength with a maximum flexural

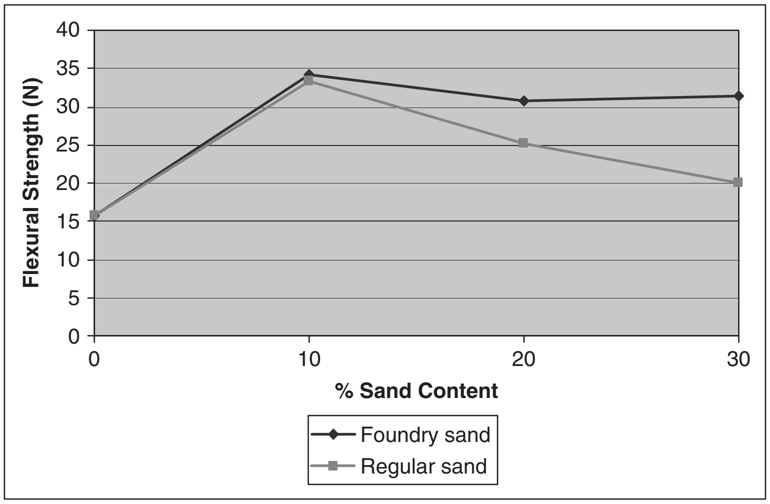

FIGURE 1.36 Maximum flexural load of composite material with foundry sand and regular sand. (*Source:* S. M. El-Haggar and L. El-Hatow, "Reinforcing Thermoplastics Rejects with Foundry Sand Waste," Submitted for publication to ASCE (2007).)

load of 34.3 N, which is higher than the 0 percent no-reinforcement value. The regular sand reinforcement of the plastic rejects proved that the 10 percent reinforcement was the best percentage of regular sand reinforcement, with a 33.3 N maximum flexural load. This value was significantly greater than the 0 percent no-reinforcement value. All the regular sand and foundry sand percentage reinforcements were significantly higher than the 0 percent no-reinforcement specimens and thus showed that their addition was enhancing the flexural strength of the specimen by reinforcing it with either regular sand or foundry sand. From Figure 1.36, it is evident that 10 percent foundry sand reinforcement was the best reinforcement in terms of flexural strength and gave the highest value that superseded all other values. The 10 percent regular sand value came in second best.

Environmental Tests

Chemical Resistance Test To determine the properties of chemical resistance of the specimens, tests were done in accordance with ASTM D543-95.[58] Thus, the specimens were tested toward their resistance to an acidic solution. Sulfuric acid with a pH of 3 was chosen, due to the fact that it plays a dual role of examining the effect of its high acidity and its sulfates content. Sulfates may also be corrosive and thus must be investigated. The specimens were measured for dimensions and weight prior to immersion into the acid. They then remain immersed for seven days in the acid and are then removed and are measured for dimensions and weight. The difference is recorded, and the differences in the specimens are examined and analyzed. It is expected that the acid should not affect the plastic specimens and that they should be able to withstand chemical resistance quite well. From this it can be assumed that the specimens will be quite resilient to chemicals.

The specimens were immersed in sulfuric acid for a week to determine their resistance to high acidic solutions of pH 3. The specimens' weight and dimensions were measured before and after the immersion. The results indicated that the specimens' dimensions did not change. Thus, it can be said that the composite material has high chemical resistance to acids and to sulfates, and will thus be useful in many applications such as manhole covers and bases.

Leachate of Heavy Metals The leachate test is necessary due to the heavy metals existing in the reinforcing element of foundry sand. According to both Abou Khatwa et al.[9] and Ibrahim,[59] the recycled plastic rejects did not leach any heavy metals that were worth noting, and thus were deemed safe. The existence of heavy metals in these specimens with the foundry sand reinforcement is minimal. The leachate test is done in accordance with ASTM D3987-85.[60] The foundry sand waste was tested separately for heavy metals, as well as the mixed composite specimen in two separate containers. The specimen and the foundry sand waste were immersed in distilled water for 18 hours, and then tested for pH, total hardness, and heavy metals of magnesium and silicon. A MACH DR/2000 direct reading spectrophotometer was used to analyze the heavy metals in the composition.

The solid specimen and the foundry sand were separately immersed in distilled water for 18 hours with continuous shaking to allow for any leachate material to be extracted from the designated samples. The liquid was then filtered. When this was complete, the pH and total hardness were analyzed, upon which the Mg hardness and thus the Mg concentration were calculated. In order to determine the silicon concentration, however, the two samples were heated at 90°C until the liquid evaporated to 10 ml. This is done in order to separate any organic material from the liquid. The samples are then tested on the spectrophotometer for silicon concentration. Table 1.17 shows the results of the leachate test; it can be seen that the foundry sand as a separate entity contained a significant composition of heavy metals of Mg and Si, while the solid specimen of recycled plastic with reinforced foundry sand contained no leachate material with these

TABLE 1.17 Results of Leachate Test

Sample	pH	Total Hardness (mg/L)	Mg Hardness (mg/L)	Mg Concentration (mg/L)	Si Concentration (mg/L)
Specimen	6.45	0.0	0.0	0.000	0.001
Foundry Sand	9.58	1.6	1.6	0.384	41.11

Source: S. M. El-Haggar and L. El-Hatow, "Reinforcing Thermoplastics Rejects with Foundry Sand Waste," Submitted for publication to ASCE (2007).

heavy metals composition. The pH of the solid specimen is quite close to that of distilled water, although that of the foundry sand waste was quite alkaline with a pH of 9.58. From these results it can be inferred that foundry sand waste as an entity contains the heavy metals of Mg and Si; however, when it is used as a reinforcing element in plastic rejects, the melting and thus solidification process enables these heavy metals to dissolve and thus does not pose a threat to the final recycled plastic specimen in terms of leachate material.

Final Remarks

It was shown from the data within the case study that contaminated plastic rejects combined with hazardous waste as a reinforcing elements proved to have durable and environmentally friendly properties that allow this new material to be used as an application in different products such as manhole cover and base. Through analysis of the material with difference percentage reinforcements, it was shown that foundry sand waste at 10 percent reinforcement showed the most promising results.

The environmental-related tests proved to show that material is highly resistant to acidity and thus will not corrode away in many applications of highly acidic applications such as sewer systems. The environmental-related tests also showed that the material does not produce any harmful leachate that may be toxic to the waters or surrounding areas, even though the leachate of the foundry sand contained heavy metals and thus might contaminate the soil and surface water as a result of land disposal. The heavy metals in the foundry sand dissolved upon the solidification process with the plastic rejects to become the new paste, and thus no longer became a problem.

In terms of economics, this new material made out of two hazardous waste will have a lot of benefits, such as saving the disposal cost and saving the natural resources, as well as protecting the environment. In order to recycle contaminated plastic rejects, the plastic first must be washed and cleaned with water in order to be deemed recyclable. This has often been very costly, and consumes a lot of water, energy, and labor. However, by recycling this contaminated material as is, we are not only saving water, energy, and labor, but also using a waste that previously had been incinerated, causing harmful emissions. This case study has shown that the mechanical properties of this new recycled material in no way match the properties of virgin plastic; however, when reinforced with different reinforcing elements such as foundry sand waste (a potential health hazard and waste), the properties of this material increase to an extent that enables it to be used in many applications. Foundry sand waste is in fact a waste material, and thus generally has no cost. Regular sand has also shown promising results in terms of durability; however, regular sand may be considered a natural resource of considerable use and thus might not be the more suitable material. Through this analysis, it can be seen that the benefits outweigh the costs incurred to produce a product out of this new composite material to alleviate the environmental hazards associated with this product.

DISPOSAL OF INDUSTRIAL WASTES

Disposal of industrial waste can be done according to a cradle-to-grave system through incineration and/or landfill. Incineration will convert the industrial solid wastes (hazardous or nonhazardous) into ash that requires landfill for final disposal. According to international regulations, industrial hazardous wastes should be treated first before landfill.

Incineration is the process of thermally combusting solid waste and converting it into ash or briefly incinerating it in a thermal treatment process. There are various types of incinerators. The type used depends on the type of waste to be burnt. Conceptually, incinerators for solid wastes can be classified into (1) rotary kiln incinerator, (2) grate type incinerator, and (3) fluidized bed incinerator. Rotary kiln incinerator can handle both liquid wastes as well as solid wastes. Grate type incinerators are used for large, irregular-shaped solid waste to allow air to pass through the grate from below into the wastes. The fluidized-bed type incinerator is used for liquid, sludge, or uniformly sized solid waste.

The main advantage of the incineration process is to reduce the amount of solid waste into 10 percent (ash). Energy may be recovered from the incineration process. But, the cost of energy produced from waste is higher than the traditional system of energy conversion system. The main disadvantages of incineration are (1) high capital cost, (2) high running cost for operation and management, and (3) disposal of ash resulting from incineration is another added cost. The mismanagement of incineration process may cause severe damage to the environment.

Industrial solid waste and/or ash produced from the incineration process should be landfilled. A landfill is a very complicated structure, very carefully designed either into or on top of the ground in which industrial solid waste is isolated from the surrounding environment. There are many steps before starting to construct a landfill. The first step is to choose a suitable site. Site location is one of the very important steps to avoid any impacts on the surrounding environment. After choosing the appropriate location for a landfill, the designing process starts. Beside the design of the lining and coverage of the landfill, a leachate collection system, biogas collection system and a stormwater drainage system should also be designed and planned for implementation during operation. The bottom liner isolates the industrial solid waste from the soil preventing the groundwater contamination. The liner is usually some type of durable, puncture-resistant synthetic plastic (polyethylene, high-density polyethylene, polyvinyl chloride). In landfills constructed below surface level, a side-liner system is used in mechanical resistance to water pressure, drainage of leachate, and prevention of lateral migration of biogas.

The main disadvantage of landfill is high capital cost for construction as well as high operation cost for compaction, daily cover, leachate treatment, and so on. The mismanagement of landfill may cause a severe impact on the environment. The major disadvantage of both incineration and landfill, over and above the previously mentioned disadvantages, is depletion of natural resources that lead to unsustainable solid waste management system.

Thus, one can see the tragedy of depleting the natural resources under the title "waste disposal," through incineration or landfill. For example, 60 percent of our precious stone resource is wasted in the marble and granite industry, our environment is polluted, and our health is put at risk. We need to put an end to this disaster by conserving the natural resources through cradle-to-cradle concepts as discussed before. We need to close our material and energy cycles, and apply cradle-to-cradle concepts. Industrial sectors should be approached as discussed throughout this chapter. All parties should cooperate to reduce wastes and emissions. The governments should issue strict rules controlling or prohibiting the use of landfills and/or incinerators and providing alternatives. *Alternatives* is the key word for sustainable industrial waste management to be able to develop a full utilization of natural resources and cradle-to-cradle approaches. Utilization of the waste needs to be researched through academic institutions and research centers to add value not only to individuals but also to the globe.

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