CHAPTER 19

Materials and Manufacturing

19.1 The Manufacturing Process

Businesses are seeking ways to prosper while reducing their use of materials. This process can be called **dematerialization** or simply "doing more with less material." Dematerialization is based on a closed-loop system in which materials, once used, are returned to the system for reuse. In such a system, materials and energy sources are continually "cycled" within the economy, rather than consumed and disposed of. Waste is redefined as by-products that have no useful application anywhere in the system. New products will evolve from or consume available waste streams, and processes are developed to produce usable waste. For instance, recycling packaging materials or burning waste products to recover their energy is preferable to putting materials into landfills.

The manufacturing process of industrial companies can be represented by the model shown in Figure 19.1. Energy and materials are inputs to the process and the desired output is the product to be sold. Any process has undesired outputs, called **wastes**. From this waste stream, we can separate products that can be remanufactured ①. Also, we can separate parts of the waste that can be recycled back into the original manufacturing process ② or other manufacturing processes ③. Finally, if waste materials cannot be used, they are subject to storage or disposal ④.

Six factors that can be considered for reduction in the manufacturing process are shown in Table 19.1. In the next section we consider the reduction of material intensity and energy intensity.

During the past two decades, recycled aluminum has become a major element of overall and domestic aluminum supply. The cost benefits of recycling include savings of 95 percent in energy usage and 90 percent in capital and labor. Aluminum can be recycled again and again without loss of its original properties. FROM IMCO RECYCLING. PHOTOGRAPH COURTESY OF CORBIS.

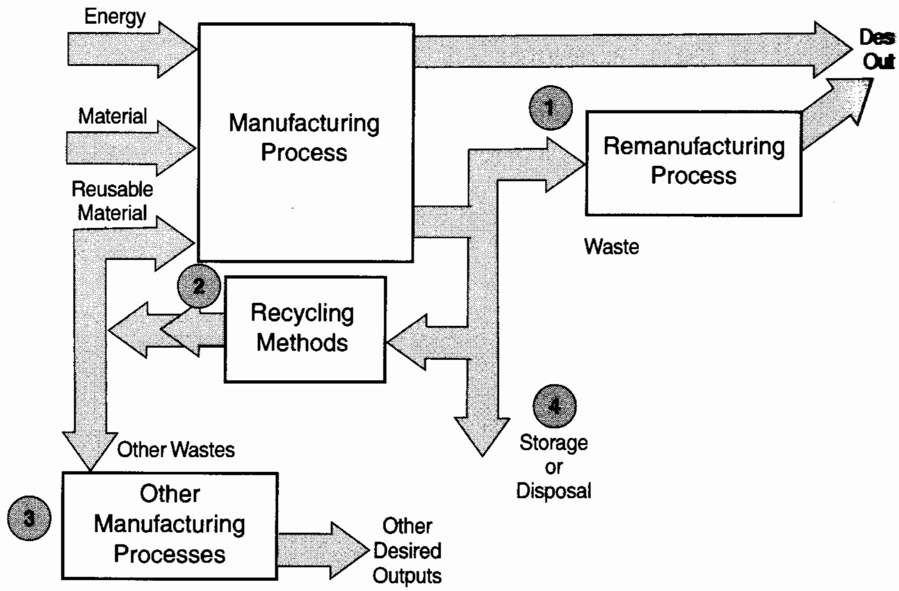

Figure 19.1 **The manufacturing process.**

Table 19.1 **Six Factors for Reduction in the Manufacturing Process**

Reduction of:

1. Material intensity
2. Energy intensity
3. Amount of waste not recycled or reused
4. Amount of depleting resources used
5. Service intensity
6. Health and environmental risk

19.2 Material Intensity and Energy Intensity

Materials and energy are the resource inputs to manufacturing processes as well as throughout the supply chain of a company. The materials and energy supply chain is shown in Figure 19.2. The goal is to reduce the total materials intensity and energy intensity of a product. The materials intensity of a product may be measured in the total materials used to produce one product unit. Similarly, the energy intensity is the energy used to produce one product unit. As an example, consider the production of a plastic. The output of the production is measured in pounds (or kg) of plastic. The materials input, primarily petroleum, is measured in pounds (or kg) of petroleum. Then, the materials intensity for this plastic would be measured as a ratio with the units kg/kg. Similarly, we could measure the energy intensity as the ratio of energy, in joules, per kilogram of plastic produced.

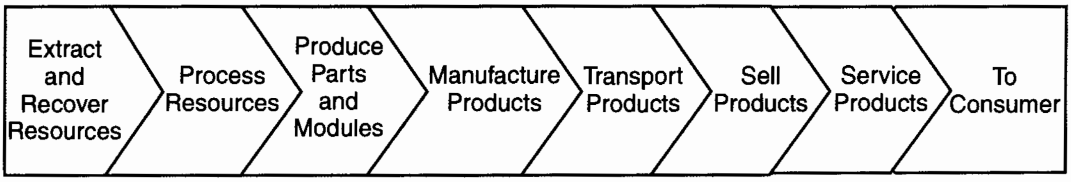

Figure 19.2 **The materials and energy supply chain.**

An example of a lower intensity product is Procter & Gamble's Ultra detergent. This product uses only one-half a cup of powder for washing compared to the traditional one-cup detergents. Procter & Gamble claims reduced soap and packaging as well as halving of the energy used (Fussler, 1996).

The design of an automobile is a good example for reduced materials and energy intensity. By the use of plastics and aluminum, an automobile may be lighter and gain better fuel consumption. Reduced materials intensity and energy intensity may be obtained by means of improved design. (For a review of design for the environment methods see Section 5.3.)

The chemical industry is an excellent example of an industry that has developed improved methods that reduce energy and materials intensity. By means of chemical engineering advances chemical companies in the United States have increased yields with reduced intensities during the past several decades. Dupont, for example, a decade ago had a materials yield of 75%. That is, every pound of raw material yielded only three-quarter pound for products such as Lycra. That yield exceeded 90% in 2000. The goal is to reduce the materials intensity while increasing the value of the product.

An example of an industry that may dematerialize and reduce energy intensity is the paper industry. In 1997, the world produced 299 million tons of paper, over six times the amount produced in 1950. Paper is used for many different purposes. Today packaging claims about 48% of all paper use. Printing and writing papers accounts for 30%, newsprint another 12%, and sanitary and household papers, about 6%. Perhaps paper consumption will decline as better means are developed for reading electronic documents and books. The supply chain for producing paper products (see Figure 19.2) affords many possibilities for reducing energy and material intensities. From forest to harvest to processing, the chain is ripe with opportunity.

The design of a product can depend on "design for the environment" (DFE), which requires that environmental objectives and constraints be inserted into process and product design, and materials and technology choices.

The focus is on the design stage because, for many products, that is where most, if not all, of their life cycle environmental impacts are explicitly or implicitly established. Traditionally, electronics design has been based on a correct-by-verification approach, in which the environmental ramifications of a product (from manufacturing through disposition) are not considered until the product design is completed. DFE, in contrast, takes place early in a product's design phase as part of the engineering process to ensure that the environmental consequences of a product's life cycle are understood before manufacturing decisions are committed.

It is estimated that a majority of the environmental impacts generated by product manufacture, use, and disposal are locked in by the initial design. The design of a product and its component selection control many environmental impacts associated with manufacturing. Product design also establishes the ease with which a product can be refurbished or disassembled for parts or materials reclamation after consumer use. DFE tools and methodologies offer a means to address such concerns at the design stage.

While every organization in the supply chain bears some responsibility for effecting environmental change, producers have the greatest responsibility because they have the most ability to reduce the adverse effects of their products on the environment. In the past, however, environmental factors entered into product design with low priority. At the same time, retailers and consumers seldom took the environment into account in their choice, use, and ultimate disposal of products. The goal is to extend responsibility up and down the product chain so that everyone involved has an incentive to minimize the environmental impacts of energy and resource use. This approach could lead to meaningful source reduction, extensive recycling of materials, and significant product innovation.

Consider the 40 million personal computers (PC) manufactured for the U.S. market in 2000. Each PC contains at least one printed-circuit board, the components of which include lead-based surface finishes that are attached with lead solder. The electronics industry uses some 8,000 metric tons for solder applications. In 1998 only 10% of the PCs taken out of service were recycled or refurbished. Most of the rest went into waste dumps.

Lead is a heavy metal. Like other heavy metals, including cadmium and mercury, it is toxic; in humans, it affects the nervous system, blood circulation, and kidneys. Placed in landfills or incinerated, it can leach into the groundwater, where it can get into the food chain. In recent years, lead use has been restricted. The electronics industry is attempting to reduce or eliminate lead solder from a majority of its products by 2001.

Similarly, another goal is to reduce the energy requirements in the manufacturing process and along the supply chain. The goal is to design energy efficient products that can be manufactured with energy efficient methods. The designs for new electronics, appliances, machines, and autos provide examples of ways to reduce the energy intensity of products. For example, about 65% of the electric energy in an industrial country is consumed by constant-speed motor drives, about 80% driving fans and pumps. One estimate is that new and improved designs could improve the efficiency of lightly loaded pumps and fans by 30%. These new designs could save up to 20% of the nation's electric energy consumption (Kaplan, 2000).

19.3 Recycling and Reusing Waste Products

Natural systems recycle or reuse waste products and industrial systems can be designed to do so. The aim is to make our wastes into useful products or raw materials for other systems as shown in Figure 19.1. We can remanufacture, recycle, convert to inputs, or store and dispose of waste. The highest goal is to use waste for its best and most valuable use. Thus, remanufacturing or recycling are usually the best use since the part or module being reused is already fitted for use in our manufacturing process.

Remanufacturing is the process of reconditioning a part or module so that it is suitable for use in a new product. A subassembly or module is taken apart, cleaned, and reconditioned so that it can be used again.

Voluntary take-back of products is one form of product stewardship that supports remanufacturing and reuse. The five largest manufacturers of rechargeable nickel-cadmium batteries formed an organization to handle the collection and recycling of such batteries throughout the United States. This corporation plans to collect more than 85% of the batteries for recycling by 2001.

An aggressive initiative is Xerox Corporation's asset recycle management program, which is aimed at attaining "waste-free" factories and developing waste-free products. Under this program, for instance, the company achieved a 60% return rate for copier cartridges in 1998. These cartridges were then sent to dismantling centers where the component parts were sorted, cleaned, and repaired to meet the standards for new parts.

Some of the best opportunities for reducing the overall environmental impact of manufactured goods lie upstream with suppliers. Consequently, involving the entire supply chain in the design of reusable products is becoming more and more prevalent in industry. Federal Express has announced a goal to all its suppliers of using fully recycled paperboard for its envelopes.

The European Commission (EC) is moving toward a directive that stipulates that the EC's member states must "take the necessary measures to ensure that producers set up systems so that last holders and distributors can return end-of-life electrical and electronic equipment." Manufacturers are also held responsible for financing the collection system, which is to apply to all products, new and old.

The disposition process for a product at the end of its initial useful life is to collect it, disassemble it, and process its recyclable materials and parts and remake or upgrade older parts. Many engineers assert that it is cheaper to collect and update older machines than it is to build new ones. The design process can specify products that will be naturally upgradable after its normal life.

It is possible to sell the waste material from a company's product stream to other industries for use in their products. The Internet is providing new e-commerce marketplaces where a company can sell its wastes. Almost every industry seems to have at least one Web site dedicated to buying, selling, bartering, or exchanging surplus goods and waste materials.

Table 19.2 **Recycling and Reuse Methods**

- Establish recovery and recycling programs for all major materials, including oils, paper, metals, glass, and plastics.
- Develop an integrated waste management program that makes judicious use of reuse, recycling, incineration, composting, and landfilling.
- Develop a remanufacturing and upgrade program for most products.
- Find new markets for wastes in other industries.

Table 19.3 **Issues for Reuse and Recycling of Products**

- What portion of a product is economically feasible to recycle or reuse?
- What is the most profitable/least costly way to retire a product?
- How long would it take to fully or partially disassemble the product for recycling?
- What are the economical trade-offs between reuse, remanufacturing, recycling, and disposal?
- How much of it will end up in the landfill?
- How can the recovery process itself generate the highest possible return on investment?
- What would happen if material prices or disposal fees radically changed?

The four methods of reducing wastes are summarized in Table 19.2. Issues that should be considered in the development of a recycling and reuse program are provided in Table 19.3.

19.4 Resource Conservation

It is important to reduce the amount of depleting resources used. Fossil fuels, such as petroleum, may run out eventually. Products that rely on renewable and biodegradable materials are more sustainable. Examples of industries that practice resource conservation include fishing, forestry, and agriculture.

Natural cycles involve the production, transport and breakdown of an enormous mass of materials. Borrowing materials from natural resources and returning them at the end of their use (through biodegradation) does not affect the overall balance of nature. This can reduce overall environmental impacts since synthetic materials involve large amounts of fuels and create nonbiodegradable emissions and wastes.

Plastic's combination of toughness and resilience is a drawback as well as a benefit. Some plastics are so durable that may remain unchanged in landfills for thousands of years. New plastics made from agricultural products such as corn or beets may be biodegradable. Cargill and Dow Corporations plan to jointly build a plant in Nebraska to make plastics from corn or wheat grains. The new plastic, called polylactide, is versatile and strong enough to compete with plastics now used for clothing, carpets, and food containers.

Another possibility is to derive chemicals from plants. These are called **agrochemicals** and are generally biodegradable and less toxic than chemicals derived from petroleum. Currently the price of agrochemicals is higher, but they may become competitive in the near future.

19.5 Service Extension

It is possible to reduce the service intensity of a product by extending its serviceable life. Service extension of a product is obtained by designing products with (1) increased durability, (2) improved repairability, (3) multi-functionality, and (4) shared use.

Long-lasting or durable products postpone the environmental impacts that result from product replacement. Durable products are the alternative to throw-away (disposable) products. For nonconsumable goods like cars, refrigerators, washing machines, or computers, it is important that products be designed for easy refurbishing and upgrading. Truly durable products are likely to be more expensive than throwaways. For some items, the upfront cost could be higher. However, the life-cycle costs may be less for a durable product.

It is important to ensure that a long-lived, durable product does not translate into an obsolete product. This calls for a modular approach that allows for easy updating of modules. Ultimately, durable products would lend themselves to remanufacturing. For products subject to high wear and tear, such as carpets, remanufacturing is crucial; they should be easy to take apart so as many of the components can be reused as possible.

19.6 Health and Environment Risk

It is important to reduce health and environmental risks. Such risks include long-term health effects from toxic materials use, emissions to the atmosphere, and accident risks. Effluents and wastes containing toxic chemicals and emissions are potential hazards.

For production processes, cleaner production includes conserving raw materials and energy, eliminating toxic raw materials, and reducing the quantity and quality of all emissions and wastes before they leave a process.

For products, the strategy focuses on reducing impacts along the entire life cycle of the product, from raw material extraction to the ultimate disposal of the product. Examples are electronics manufacturers who seek to reduce the uses of toxic materials in their processes. Emissions must be reduced to reduce risk for people. The focus of concern over environmental hazards to human health has traditionally been in relation to chemical and microbial contamination of air, water, soil, or food.

19.7 The Interface Corporation Case

Interface, Inc., is the world's largest producer of free-laying carpet tiles for office, commercial, and health care facilities. Their sales were about $1.3 billion in 2000. The Atlanta-based company is lead by its CEO, Ray Anderson. In the words of Ray Anderson in Interface's annual report for 1999:

> At Interface, we seek to become the first sustainable corporation in the world, and, following that, the first restorative company. It means creating the technologies of the future — kinder, gentler technologies that emulate nature's systems. I believe that's where we will find the right model. . . .

The goals of Interface are those listed in Table 19.1 and 19.2. They seek a model of operations that leads to zero waste with every material recycled or reused. They started in 1995 with waste minimization projects. They also shifted from new materials to 100% recycled fiber made from PET (polyethylene terephthalate), which comes from post-consumer soda bottles. Recycling materials also reduces energy usage.

As a first step, the company focused on the elimination of toxic effluents at its 26 manufacturing plants. The next goal is to reduce the energy intensity of its products by shifting to recycled materials. New nylon carpet is made from discarded carpet.

The company adopts the idea that the value to the customer is a service that includes flooring systems with desirable attributes. To transform a durable carpet into a service they introduced the Evergreen Lease. They lease the carpet to the building owner. As carpet tiles wear out and are replaced, the old ones are broken down and remanufactured into new tiles as part of the lease fee. The customer does not pay an installation cost, only a monthly fee for constantly fresh-looking and functional carpeting.

The Interface, Inc., model (see *www.ifsia.com*) is based on the use of natural materials that flow through its processes as well as compostable materials as the only discarded waste. Solar energy is the desired energy input and recycled modular products are part of the total service offered.