Chapter 13. Life-Cycle Concepts, Product Stewardship and Green Engineering

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Products, services, and processes all have a life cycle. For products, the life cycle begins when raw materials are extracted or harvested. Raw materials then go through a number of manufacturing steps until the product is delivered to a customer. The product is used, then disposed of or recycled. These product life-cycle stages are illustrated in Figure 13.1-1, along the horizontal axis. As shown in the figure, energy is consumed and wastes and emissions are generated in all of these life-cycle stages.

Processes also have a lifecycle. The life cycle begins with planning, research and development. The products and processes are then designed and constructed. A process will have an active lifetime, then will be decommissioned and, if necessary, remediation and restoration may occur. Figure 13.1-1, along its vertical axis, illustrates the main elements of this process life cycle. Again, energy consumption, wastes and emissions are associated with each step in the life cycle.

Traditionally, product and process designers have been concerned primarily with product life-cycle stages up to manufacturing. That focus is changing. Increasingly, chemical product designers must consider how their products will be recycled. They must consider how their consumers use their products. Process designers must avoid contamination of the sites at which their processes are located. Simply stated, design engineers must become stewards for their products and processes throughout their life cycles. These increased responsibilities for products and processes throughout their life cycles have been recognized by a number of professional organizations. Table 13.1-1 describes a Code of Product Stewardship developed by the Chemical Manufacturers' Association (now named the American Chemistry Council).

Effective product and process stewardship requires designs that optimize performance throughout the entire life cycle. This chapter provides an introduction to tools available for assessing the environmental performance of products and processes throughout their life cycle. The primary focus is on product life cycles, but similar concepts and tools could be applied to process life cycles. Sections 13.2 and 13.3 present quantitative tools used in product life cycles assessments (LCAs). Section 13.4 presents more qualitative tools. Section 13.5 describes a number of applications for these tools and Section 13.6 summarizes the main points of the chapter.

Table 13.1-1 The Chemical Manufacturers' Association (American Chemistry Council) Product Stewardship Code

The purpose of the Product Stewardship Code of Management Practices is to make health, safety and environmental protection an integral part of designing, manufacturing, marketing, distributing, using, recycling and disposing of our products. The Code provides guidance as well as a means to measure continuous improvement in the practice of product stewardship.

The scope of the Code covers all stages of a product's life. Successful implementation is a shared responsibility. Everyone involved with the product has responsibilities to address society's interest in a healthy environment and in products that can be used safely. All employers are responsible for providing a safe workplace, and all who use and handle products must follow safe and environmentally sound practices.

The Code recognizes that each company must exercise independent judgment and discretion to successfully apply the Code to its products, customers and business.

Relationship to Guiding Principles
Implementation of the Code promotes achievement of several of the Responsible Care Guiding Principles:

- ♦ To make health, safety and environmental considerations a priority in our planning for all existing and new products and processes;
- ♦ To develop and produce chemicals that can be manufactured, transported, used and disposed of safely;
- ♦ To extend knowledge by conducting or supporting research on the health, safety and environmental effects of our products, processes and waste materials;
- ♦ To counsel customers on the safe use, transportation and disposal of chemical products;
- ♦ To report promptly to officials, employees, customers and the public, information on chemical related health or environmental hazards and to recommend protective measures;
- ♦ To promote the principles and practices of Responsible Care by sharing experiences and offering assistance to others who produce, handle, use, transport or dispose of chemicals.

Figure 13.1-1 Product life cycles include raw material extraction, material processing, use and disposal steps, and are illustrated along the horizontal axis. Process life cycles include planning, research, design, operation and decommissioning steps and are shown along the vertical axis. In both product and process life cycles, energy and materials are used at each stage of the life cycle and emissions and wastes are created.

(Insert Figure here)

Chapter 13 Sample Example Problem

Example 13.2 Selected environmental indices from the Environmental Priority Strategies system.

In the EPS system, environmental indices are multiplied by the appropriate quantity of raw materials used or emissions released to arrive at Environmental Load Units (ELUs), which can then be added together to arrive at an overall ELU for the subject of the life-cycle study. Table 13.8 gives selected environmental weighting factors from the EPS system. Calculate the environmental load units due to air emissions from one kilogram of ethylene production. Emissions are 0.53 kg, 0.006 kg, 0.0009 kg, and 0.009 kg of carbon dioxide, nitrogen oxides, carbon monoxide, and sulfur oxides, respectively (Boustead, 1993).

Solution

Total ELUs due to air emissions are

$$0.53\ \text{kg}\ CO_2 \times 0.09\ \text{ELU/kg}\ CO_2$$
$$0.006\ \text{kg}\ NO_x \times 0.22\ \text{ELU/kg}\ NO_x$$
$$0.0009\ \text{kg CO} \times 0.27\ \text{ELU/kg CO}$$
$$0.009\ \text{kg}\ SO_x \times 0.10\ \text{ELU/kg}\ SO_x$$
$$= 0.05\ \text{ELU}.$$

Note that if quantities of raw materials or water emissions were given, the ELUs for these inputs would be added to the ELUs for the air emissions.

Chapter 13 Sample Homework Problem

1. (From Allen, et al., 1992) At the supermarket checkstand, customers are asked to choose whether their purchases should be placed in unbleached pape r grocery sacks or in polyethylene grocery sacks. Some consumers make their choice based on the perception of the relative environmental impacts of these two products. This problem will quantitatively examine life cycle inventory data on the energy use a nd air emissions for these two products.

Life cycle inventories for paper and polyethylene grocery sacks have resulted in the data given below, and these data will be used in comparing the two products. Assume that the functional unit to be used in thi s comparison is a defined volume of groceries to be transported, and that based on this functional unit, 2 plastic sacks are equivalent to one paper sack.

Air Emissions and Energy Requirements for Paper and Polyethylene Grocery Sacks (Allen, et al., 1992)

Life-cycle Stages	Paper sack air emissions (oz/sack)	Plastic sack air emissions (oz/sack)	Paper sack air energy req'd (Btu/sack)	Plastic sack air energy req'd (Btu/sack)
Materials manufacture plus product manufacture plus product use	0.0516	0.0146	905	464
Raw materials acquisition plus product disposal	0.0510	0.0045	724	185

Note: These data are based on past practices and may not be current.

a.) Using the data in the Table, determine the amount of energy required and the quantity of air pollutants released per plastic sack. Also determine the amount of energy required and the quantity of air pollutants released for the quantity of paper sacks capable of carrying the same volume of groceries as the plastic sack. Both the air emissions and the energy requirements are functions of the recycle rate, so perform your calculations at three recycle rates: 0%, 50% and 100% recycled. Note that a 50% recycle rate indicates that half of the sacks are disposed of and the other half are recycled after the product use stage of their life cycle.

b.) Plot the energy requirements calculated in Part a.) as a function of the recycle rate for both sacks. Do the same for the air emissions. Compare the energy requirements and air emissions of the sacks at different recycle rates.

c.) Discuss the relative environmental impacts of the two products. Do the results allow for a comprehensive comparison?

d.) The material and energy requirements of the plastic sacks are primarily derived from petroleum, a non-renewable resource. In contrast, the paper sacks rely on petroleum to only a limited extent and only for generating a small fraction of the manufacturing and transportation energy requirements. Compare the amount of petroleum required for the manufacture of two polyethylene sacks to the amount of energy necessary to provide 10% of the energy required in the manufacture of one paper sack. Assume 0% recycle and that 1.2 lb of petroleum is required to manufacture 1 lb of polyethylene. The higher heating value of petroleum is 20,000 BTU/lb.

e.) In this problem, we have assumed that 2 plastic sacks are equivalent to one paper sack. Does the uncertainty in the equivalency between paper and plastic sacks affect any of your conclusions?