13.1: Industrial Ecology and Industrial Ecosystems

Recall that the *anthrosphere* has been defined as a fifth sphere of the environment, the one made and modified by human activities. As such, it has developed in ways that are often in conflict with other spheres of the environment, including even the human denizens of the biosphere who have constructed the anthrosphere. This has given rise to the many environmental, resource, and sustainability problems that afflict the world today.

It is crucial for humankind and, indeed, the Earth as a whole, that the anthrosphere be brought into a state of compatibility with the other environmental spheres and with Earth. Green chemistry has a key role to play in this endeavor. In a sense, green chemistry is all about the greening of the anthrosphere. In order to understand how this may occur, it is necessary to introduce and explain the key concept of **industrial ecology**. Industrial ecology integrates the principles of science, engineering, and ecology in industrial systems through which goods and services are provided in away that minimizes environmental impact and optimizes utilization of resources, energy, and capital. In so doing, industrial ecology considers every aspect of the provision of goods and services from concept, through production, and to the final fate of products remaining after they have been used. Industrial ecology considers industrial systems in a closed-loop model rather than a linear one thereby emulating natural biological ecosystems, which are sustainable by nature. Industrial ecology is above all a **sustainable** means of providing goods and services.

Industrial ecology works through groups of industrial concerns, distributors, and other enterprises functioning to mutual advantage, using each others' products, recycling each others' potential waste materials, and utilizing energy as efficiently as possible. By analogy with natural ecosystems, such a system is an **industrial ecosystem**. Successful industrial ecosystems achieve the maximum possible degree of recycling. To quote Kumar Patel of the University of California at Los Angles, "The goal is *cradle to reincarnation*, since if one is practicing industrial ecology correctly there is no grave." As has been the case with natural ecosystems, the best means of assembling industrial ecosystems is through natural selection in which the various interests involved work out mutually advantageous relationships. However, with a knowledge of the feasibility of such systems, external input and various kinds of incentives can be applied to facilitate the establishment of industrial ecosystems. A key measure of the success of such a system can be given by the following relationship:

$$\frac{\text{Market value of products}}{\text{Consumption of material and energy}} \tag{13.1.1}$$

Just as organisms in natural ecosystems develop strong symbiotic relationships — the inseparable union of algae and fungi in lichens growing on rock surfaces, for example — concerns operating in industrial ecosystems develop a high degree of **industrial symbiosis**. It is the development of such mutually advantageous interactions between two or more industrial enterprises that result in the self-assembly of an industrial ecosystem in the first place. The recycling components of an industrial ecosystem are absolutely dependent upon symbiotic relationships with their sources of supply.

Figure 13.1 outlines a general industrial ecosystem. The major inputs to such a system are energy and virgin raw materials. A successful system minimizes use of virgin raw materials and maximizes efficiency of energy utilization. The materials processing sector produces processed materials such as sheet steel or synthetic organic polymers. These in turn go to a goods fabrication sector in which the processed materials are formed and assembled or, in the case of consumables such as detergents, formulated to give the desired product. Scrap materials, rejected

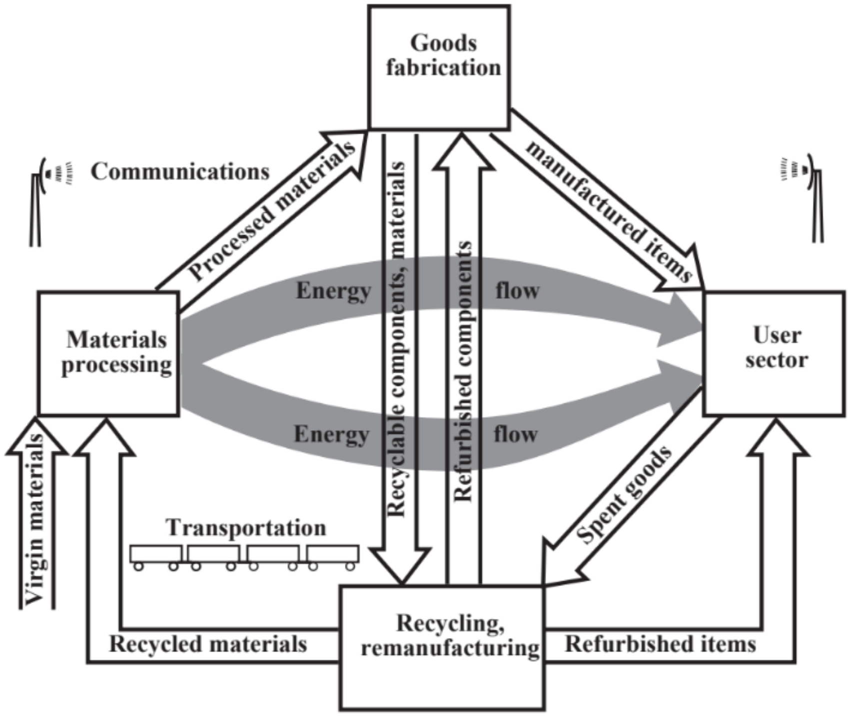

Figure 13.1. Outline of the major components of an industrial ecosystem.

components, and off-specification consumables generated during goods fabrication may go to recycling and remanufacturing. From goods fabrication, manufactured items or formulated substances are taken to a user sector, which includes consumers and industrial users. In a successful system of industrial ecology, waste materials from the user sector are minimized and, ideally, totally eliminated. Spent goods from the user sector are taken to recycling and remanufacturing to be introduced back into the materials flow of the system. Such items may consist of automobile components that are cleaned, have bearings replaced, and otherwise refurbished for the rebuilt automobile parts market. Another typical item is paper, which is converted back to pulp that is made into paper again. In some cases the recycling and remanufacturing sector salvages materials that go back to materials processing to start the whole cycle over. An example of such a material is scrap aluminum that is melted down and recast into aluminum for goods fabrication. Communications are essential to a successful industrial ecosystem, as is a reliable, rapid transportation system. It is especially important that these two sectors work well in modern manufacturing practice which calls for “just in time” delivery of materials and components to avoid the costs of storing such items.

An important characteristic of an industrial ecosystem is its **scope**. A regional scope large enough to encompass several industrial enterprises, but small enough for them to interact with each other on a constant basis is probably the most satisfactory scale to consider. Frequently such systems are based around transportation systems. Segments of interstate highways over which goods and materials move between enterprises by truck may constitute industrial ecosystems.