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AND ENVIRONMENTAL CHEMISTRY"

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2 THE ANTHROSPHERE, INDUSTRIAL ECOSYSTEMS, AND ENVIRONMENTAL CHEMISTRY

2.1. THE ANTHROSPHERE

The **anthrosphere** may be defined as *that part of the environment made or modified by humans and used for their activities*. Of course, there are some ambiguities associated with that definition. Clearly, a factory building used for manufacture is part of the anthrosphere as is an ocean-going ship used to ship goods made in the factory. The ocean on which the ship moves belongs to the hydrosphere, but it is clearly used by humans. A pier constructed on the ocean shore and used to load the ship is part of the anthrosphere, but it is closely associated with the hydrosphere.

During most of its time on Earth, humankind made little impact on the planet, and its small, widely scattered anthrospheric artifacts—simple huts or tents for dwellings, narrow trails worn across the land for movement, clearings in forests to grow some food—rested lightly on the land with virtually no impact. However, with increasing effect as the industrial revolution developed, and especially during the last century, humans have built structures and modified the other environmental spheres, especially the geosphere, such that it is necessary to consider the anthrosphere as a separate area with pronounced, sometimes overwhelming influence on the environment as a whole.

Components of the Anthrosphere

As discussed later in this book, the various spheres of the environment are each divided into several subcategories. For example, the hydrosphere consists of oceans, streams, groundwater, ice in polar icecaps, and other components. The anthrosphere, too, consists of a number of different parts. These may be categorized by considering where humans live; how they move; how they make or provide the things or services

they need or want; how they produce food, fiber, and wood; how they obtain, distribute, and use energy; how they communicate; how they extract and process nonrenewable minerals; and how they collect, treat, and dispose of wastes. With these factors in mind, it is possible to divide the anthrosphere into the following categories:

- Structures used for dwellings
- Structures used for manufacturing, commerce, education, and other activities
- Utilities, including water, fuel, and electricity distribution systems, and waste distribution systems, such as sewers
- Structures used for transportation, including roads, railroads, airports, and waterways constructed or modified for water transport
- Structures and other parts of the environment modified for food production, such as fields used for growing crops and water systems used to irrigate the fields
- Machines of various kinds, including automobiles, farm machinery, and airplanes
- Structures and devices used for communications, such as telephone lines or radio transmitter towers
- Structures, such as mines or oil wells, associated with extractive industries

From the list given above it is obvious that the anthrosphere is very complex with an enormous potential to affect the environment. Prior to addressing these environmental effects, several categories of the anthrosphere will be discussed in more detail.

2.2. TECHNOLOGY AND THE ANTHROSPHERE

Since the anthrosphere is the result of technology, it is appropriate to discuss technology at this point. **Technology** refers to the ways in which humans do and make things with materials and energy. In the modern era, technology is to a large extent the product of engineering based on scientific principles. Science deals with the discovery, explanation, and development of theories pertaining to interrelated natural phenomena of energy, matter, time, and space. Based on the fundamental knowledge of science, engineering provides the plans and means to achieve specific practical objectives. Technology uses these plans to carry out the desired objectives.

Technology has a long history and, indeed, goes back into prehistory to times when humans used primitive tools made from stone, wood, and bone. As humans settled in cities, human and material resources became concentrated and focused such that technology began to develop at an accelerating pace. Technological advances predating the Roman era include the development of **metallurgy**, beginning with native copper around 4000 B.C., domestication of the horse, dis-

covery of the wheel, architecture to enable construction of substantial buildings, control of water for canals and irrigation, and writing for communication. The Greek and Roman eras saw the development of **machines**, including the windlass, pulley, inclined plane, screw, catapult for throwing missiles in warfare, and water screw for moving water. Later, the water wheel was developed for power, which was transmitted by wooden gears. Many technological innovations such as printing with wood blocks starting around 740 and gunpowder about a century later, originated in China.

The 1800s saw an explosion in technology. Among the major advances during this century were widespread use of steam power, steam-powered railroads, the telegraph, telephone, electricity as a power source, textiles, the use of iron and steel in building and bridge construction, cement, photography, and the invention of the internal combustion engine, which revolutionized transportation in the following century.

Since about 1900, advancing technology has been characterized by vastly increased uses of energy; greatly increased speed in manufacturing processes, information transfer, computation, transportation, and communication; automated control; a vast new variety of chemicals; new and improved materials for new applications; and, more recently, the widespread application of computers to manufacturing, communication, and transportation. In transportation, the development of passenger-carrying airplanes has affected an astounding change in the ways in which people get around and how high-priority freight is moved. Rapid advances in biotechnology now promise to revolutionize food production and medical care.

The technological advances of the present century are largely attributable to two factors. The first of these is the application of electronics, now based upon solid state devices, to technology in areas such as communications, sensors, and computers for manufacturing control. The second area largely responsible for modern technological innovations is based upon improved materials. For example, special strong alloys of aluminum were used in the construction of airliners before World War II and now these alloys are being supplanted by even more advanced composites. Synthetic materials with a significant impact on modern technology include plastics, fiber-reinforced materials, composites, and ceramics.

Until very recently, technological advances were made largely without heed to environmental impacts. Now, however, the greatest technological challenge is to reconcile technology with environmental consequences. The survival of humankind and of the planet that supports it now requires that the established two-way interaction between science and technology become a three-way relationship including environmental protection.

Engineering

Engineering uses fundamental knowledge acquired through science to provide the plans and means to achieve specific objectives in areas such as manufacturing, communication, and transportation. At one time engineering could be divided conveniently between military and civil engineering. With increasing sophistication, civil engineering evolved into even more specialized areas such as mechanical engineering, chemical engineering, electrical engineering, and environmental engin-

ering. Other engineering specialties include aerospace engineering, agricultural engineering, biomedical engineering, CAD/CAM (computer-aided design and computer-aided manufacturing engineering), ceramic engineering, industrial engineering, materials engineering, metallurgical engineering, mining engineering, plastics engineering, and petroleum engineering. Some of the main categories of engineering are defined below:

- **Mechanical engineering**, which deals with machines and the manner in which they handle forces, motion, and power
- **Electrical engineering** dealing with the generation, transmission, and utilization of electrical energy
- **Electronics engineering** dealing with phenomena based on the behavior of electrons in vacuum tubes and other devices
- **Chemical engineering**, which uses the principles of chemical science, physics, and mathematics to design and operate processes that generate products and materials

The role of engineering in constructing and operating the various components of the anthroposphere is obvious. In the past, engineering was often applied without much if any consideration of environmental factors. As examples, huge machines designed by mechanical engineers were used to dig up and rearrange Earth's surface without regard for the environmental consequences, and chemical engineering was used to make a broad range of products without consideration of the wastes produced. Fortunately, that approach is changing rapidly. Examples of environmentally friendly engineering include machinery designed to minimize noise, much improved energy efficiency in machines, and the uses of earth-moving equipment for environmentally beneficial purposes, such as restoration of strip-mined lands and construction of wetlands. Efficient generation, distribution, and utilization of electrical energy based on the principles of electrical engineering constitute one of the most promising avenues of endeavor leading to environmental improvement. Automated factories developed through applications of electronic engineering can turn out goods with the lowest possible consumption of energy and materials while minimizing air and water pollutants and production of hazardous wastes. Chemical factories can be engineered to maximize the most efficient utilization of energy and materials while minimizing waste production.

2.3. INFRASTRUCTURE

The **infrastructure** is the utilities, facilities, and systems used in common by members of a society and upon which the society depends for its normal function. The infrastructure includes both physical components—roads, bridges, and pipelines—and the instruction—laws, regulations, and operational procedures—under which the physical infrastructure operates. Parts of the infrastructure may be publicly owned, such as the U.S. Interstate Highway system and some European railroads, or privately owned, as is the case with virtually all railroads in the U.S. Some of the major components of the infrastructure of a modern society are the following:¹

- Transportation systems, including railroads, highways, and air transport systems
- Energy generating and distribution systems
- Buildings
- Telecommunications systems
- Water supply and distribution systems
- Waste treatment and disposal systems, including those for municipal wastewater, municipal solid refuse, and industrial wastes

In general, the infrastructure refers to the facilities that large segments of a population must use in common in order for a society to function. In a sense, the infrastructure is analogous to the operating system of a computer. A computer operating system determines how individual applications operate and the manner in which they distribute and store the documents, spreadsheets, and illustrations created by the applications. Similarly, the infrastructure is used to move raw materials and power to factories and to distribute and store their output. An outdated, cumbersome computer operating system with a tendency to crash is detrimental to the efficient operation of a computer. In a similar fashion, an outdated, cumbersome, broken-down infrastructure causes society to operate in a very inefficient manner and is subject to catastrophic failure.

For a society to be successful, it is of the utmost importance to maintain a modern, viable infrastructure. Such an infrastructure is consistent with environmental protection. Properly designed utilities and other infrastructural elements, such as water supply systems and wastewater treatment systems, minimize pollution and environmental damage.

Components of the infrastructure are subject to deterioration. To a large extent this is due to natural aging processes. Fortunately, many of these processes can be slowed or even reversed. Corrosion of steel structures, such as bridges, is a big problem for infrastructures; however, use of corrosion-resistant materials and maintenance with corrosion-resistant coatings can virtually stop this deterioration process. The infrastructure is subject to human insult, such as vandalism, misuse, and neglect. Often the problem begins with the design and basic concept of a particular component of the infrastructure. For example, many river dikes destroyed by flooding should never have been built because they attempt to thwart to an impossible extent the natural tendency of rivers to flood periodically.

Technology plays a major role in building and maintaining a successful infrastructure. Many of the most notable technological advances applied to the infrastructure were made from 150 to 100 years ago. By 1900 railroads, electric utilities, telephones, and steel building skeletons had been developed. The net effect of most of these technological innovations was to enable humankind to “conquer” or at least temporarily subdue Nature. The telephone and telegraph helped to overcome isolation, high speed rail transport and later air transport conquered distance, and dams were used to control rivers and water flow.

The development of new and improved materials is having a significant influence on the infrastructure. From about 1970 to 1985 the strength of steel commonly used in construction nearly doubled. During the latter 1900s significant advances were made in the properties of structural concrete. Superplasticizers enabled mixing cement with less water, resulting in a much less porous, stronger concrete product. Polymeric and metallic fibers used in concrete made it much stronger. For dams and other applications in which a material stronger than earth but not as strong as conventional concrete is required, roller-compacted concrete consisting of a mixture of cement with silt or clay has been found to be useful. The silt or clay used is obtained on site with the result that both construction costs and times are lowered.

The major challenge in designing and operating the infrastructure in the future will be to use it to work with the environment and to enhance environmental quality to the benefit of humankind. Obvious examples of environmentally friendly infrastructures are state-of-the-art sewage treatment systems, high-speed rail systems that can replace inefficient highway transport, and stack gas emission control systems in power plants. More subtle approaches with a tremendous potential for making the infrastructure more environmentally friendly include employment of workers at computer terminals in their homes so that they do not need to commute, instantaneous electronic mail that avoids the necessity of moving letters physically, and solar electric-powered installations to operate remote signals and relay stations, which avoids having to run electric power lines to them.

Whereas advances in technology and the invention of new machines and devices enabled rapid advances in the development of the infrastructure during the 1800s and early 1900s, it may be anticipated that advances in electronics and computers will have a comparable effect in the future. One of the areas in which the influence of modern electronics and computers is most visible is in telecommunications. Dial telephones and mechanical relays were perfectly satisfactory in their time, but have been made totally obsolete by innovations in electronics, computer control, and fiber-optics. Air transport controlled by a truly modern, state-of-the-art computerized control system (which, unfortunately, is not yet fully installed in the U.S.) could enable present airports to handle many more airplanes safely and efficiently, thus reducing the need for airport construction. Sensors for monitoring strain, temperature, movement, and other parameters can be imbedded in the structural members of bridges and other structures. Information from these sensors can be processed by computer to warn of failure and to aid in proper maintenance. Many similar examples could be cited.

Although the payoff is relatively long term, intelligent investment in infrastructure pays very high returns. In addition to the traditional rewards in economics and convenience, properly designed additions and modifications to the infrastructure can pay large returns in environmental improvement as well.

2.4. DWELLINGS

The dwellings of humans have an enormous influence on their well-being and on the surrounding environment. In relatively affluent societies the quality of living

space has improved dramatically during the last century. Homes have become much more spacious per occupant and largely immune to the extremes of weather conditions. Such homes are equipped with a huge array of devices, such as indoor plumbing, climate control, communications equipment, and entertainment centers. The comfort factor for occupants has increased enormously.

The construction and use of modern homes and the other buildings in which people spend most of their time place tremendous strains on their environmental support systems and cause a great deal of environmental damage. Typically, as part of the siting and construction of new homes, shopping centers, and other buildings, the landscape is rearranged drastically at the whims of developers. Topsoil is removed, low places are filled in, and hills are cut down in an attempt to make the surrounding environment conform to a particular landscape scheme. The construction of modern buildings consumes large amounts of resources such as concrete, steel, plastic, and glass, as well as the energy required to make synthetic building materials. The operation of a modern building requires additional large amounts of energy, and of materials such as water. It has been pointed out that all too often the design and operation of modern homes and other buildings takes place “out of the context” of the surroundings and the people who must work in and occupy the buildings.²

There is a large potential to design, construct, and operate homes and other buildings in a manner consistent with environmental preservation and improvement. One obvious way in which this can be done is by careful selection of the kinds of materials used in buildings. Use of renewable materials such as wood, and non-fabricated materials such as quarried stone, can save large amounts of energy and minimize environmental impact. In some parts of the world sun-dried adobe blocks made from soil are practical building materials that require little energy to fabricate. Recycling of building materials and of whole buildings can save large amounts of materials and minimize environmental damage. At a low level, stone, brick, and concrete can be used as fill material upon which new structures may be constructed. Bricks are often recyclable, and recycled bricks often make useful and quaint materials for walls and patios. Given careful demolition practices, wood can often be recycled. Buildings can be designed with recycling in mind. This means using architectural design conducive to adding stories and annexes and to rearranging existing space. Utilities may be placed in readily accessible passageways rather than being imbedded in structural components in order to facilitate later changes and additions.

Technological advances can be used to make buildings much more environmentally friendly. Advanced window design that incorporates multiple panes and infrared-blocking glass can significantly reduce energy consumption. Modern insulation materials are highly effective. Advanced heating and air conditioning systems operate with a high degree of efficiency. Automated and computerized control of building utilities, particularly those used for cooling and heating, can significantly reduce energy consumption by regulating temperatures and lighting to the desired levels at specific locations and times in the building.

Advances in making buildings airtight and extremely well insulated can lead to problems with indoor air quality. Carpets, paints, paneling, and other manufactured components of buildings give off organic vapors such as formaldehyde, solvents, and monomers used to make plastics and fabrics. In a poorly insulated building that

is not very airtight, such indoor air pollutants cause few if any problems for the building occupants. However, extremely airtight buildings can accumulate harmful levels of indoor air pollutants. Therefore, building design and operation to minimize accumulation of toxic indoor air pollutants is receiving a much higher priority.

2.5. TRANSPORTATION

Few aspects of modern industrialized society have had as much influence on the environment as developments in transportation. These effects have been both direct and indirect. The direct effects are those resulting from the construction and use of transportation systems. The most obvious example of this is the tremendous effects that the widespread use of automobiles, trucks, and buses have had upon the environment. Entire landscapes have been entirely rearranged to construct highways, interchanges, and parking lots. Emissions from the internal combustion engines used in automobiles are the major source of air pollution in many urban areas.

The indirect environmental effects of the widespread use of automobiles are enormous. The automobile has made possible the “urban sprawl” that is characteristic of residential and commercial patterns of development in the U.S., and in many other industrialized countries as well. Huge new suburban housing tracts and the commercial developments, streets, and parking lots constructed to support them continue to consume productive farmland at a frightening rate. The paving of vast areas of watershed and alteration of runoff patterns have contributed to flooding and water pollution. Discarded, worn-out automobiles have caused significant waste disposal problems. Vast enterprises of manufacturing, mining, and petroleum production and refining required to support the “automobile habit” have been very damaging to the environment.

On the positive side, however, applications of advanced engineering and technology to transportation can be of tremendous benefit to the environment. Modern rail and subway transportation systems, concentrated in urban areas and carefully connected to airports for longer distance travel, can enable the movement of people rapidly, conveniently, and safely with minimum environmental damage. Although pitifully few in number in respect to the need for them, examples of such systems are emerging in progressive cities, showing the way to environmentally friendly transportation systems of the future.

A new development that is just beginning to reshape the way humans move, where they live, and how they live, is the growth of a **telecommuter society** composed of workers who do their work at home and “commute” through their computers, modems, FAX machines, and the Internet connected by way of high-speed telephone communication lines. These new technologies, along with several other developments in modern society, have made such a work pattern possible and desirable. An increasing fraction of the work force deals with information in their jobs. In principle, information can be handled just as well from a home office as it can from a centralized location, which is often an hour or more commuting distance from the worker’s dwelling. Within approximately the next 10 years, it is estimated that almost 20% of the U.S. work force, a total of around 30 million people, may be working out of their homes.

2.6. COMMUNICATIONS

It has become an overworked cliché that we live in an information age. Nevertheless, the means to acquire, store, and communicate information are expanding at an incredible pace. This phenomenon is having a tremendous effect upon society and has the potential to have numerous effects upon the environment.

The major areas to consider with respect to information are its acquisition, recording, computing, storing, displaying, and communicating. Consider, for example, the detection of a pollutant in a major river. Data pertaining to the nature and concentration of the pollutant may be obtained with a combination gas chromatograph and mass spectrometer. Computation by digital computer is employed to determine the identity and concentration of the pollutant. The data can be stored on a magnetic disk, displayed on a video screen, and communicated instantaneously all over the world by satellite and fiber-optic cable.

All the aspects of information and communication listed above have been tremendously augmented by recent technological advances. Perhaps the greatest such advance has been that of silicon integrated circuits. Optical memory consisting of information recorded and read by microscopic beams of laser light has enabled the storage of astounding quantities of information on a single compact disk. The use of optical fibers to transmit information digitally by light has resulted in a comparable advance in the communication of information.

The central characteristic of communication in the modern age is the combination of telecommunications with computers called **telematics**.³ Automatic teller machines use telematics to make cash available to users at locations far from the user's bank. Information used for banking, for business transactions, and in the media depends upon telematics.

There exists a tremendous potential for good in the applications of the "information revolution" to environmental improvement. An important advantage is the ability to acquire, analyze, and communicate information about the environment. For example, such a capability enables detection of perturbations in environmental systems, analysis of the data to determine the nature and severity of the pollution problems causing such perturbations, and rapid communication of the findings to all interested parties.

2.7. FOOD AND AGRICULTURE

The most basic human need is the need for food. Without adequate supplies of food, the most pristine and beautiful environment becomes a hostile place for human life. The industry that provides food is **agriculture**, an enterprise concerned primarily with growing crops and livestock.

The environmental impact of agriculture is enormous. One of the most rapid and profound changes in the environment that has ever taken place was the conversion of vast areas of the North American continent from forests and grasslands to cropland. Throughout most of the continental United States, this conversion took place predominantly during the 1800s. The effects of it were enormous. Huge acreages of

forest lands that had been undisturbed since the last Ice Age were suddenly deprived of stabilizing tree cover and subjected to water erosion. Prairie lands put to the plow were destabilized and subjected to extremes of heat, drought, and wind that caused topsoil to blow away, culminating in the Dust Bowl of the 1930s.

In recent decades, valuable farmland has faced a new threat posed by the urbanization of rural areas. Prime agricultural land has been turned into subdivisions and paved over to create parking lots and streets. Increasing urban sprawl has led to the need for more highways. In a vicious continuing circle, the availability of new highway systems has enabled even more development. The ultimate result of this pattern of development has been the removal of once productive farmland from agricultural use.

On a positive note, agriculture has been a sector in which environmental improvement has seen some notable advances during the last 50 to 75 years. This has occurred largely under the umbrella of soil conservation. The need for soil conservation became particularly obvious during the Dust Bowl years of the 1930s, when it appeared that much of the agricultural production capacity of the U.S. would be swept away from drought-stricken soil by erosive winds. In those times and areas in which wind erosion was not a problem, water erosion took its toll. Ambitious programs of soil conservation have largely alleviated these problems. Wind erosion has been minimized by practices such as low-tillage agriculture, strip cropping in which crops are grown in strips alternating with strips of summer-fallowed crop stubble, and reconversion of marginal cultivated land to pasture. The application of low-tillage agriculture and the installation of terraces and grass waterways have greatly reduced water erosion.

Food production and consumption are closely linked with industrialization and the growth of technology. It is an interesting observation that those countries that develop high population densities prior to major industrial development experience two major changes that strongly impact food production and consumption:⁴

1. Cropland is lost as a result of industrialization; if the industrialization is rapid, increases in grain crop productivity cannot compensate fast enough for the loss of cropland to prevent a significant fall in production.
2. As industrialization raises incomes, the consumption of livestock products increases, such that demand for grain to produce more meat, milk, and eggs rises significantly.

To date, the only three countries that have experienced rapid industrialization after achieving a high population density are Japan, Taiwan, and South Korea. In each case, starting as countries that were largely self-sufficient in grain supplies, they lost 20-30 percent of their grain production and became heavy grain importers over an approximately 30-year period. The effects of these changes on global grain supplies and prices was small because of the limited population of these countries — the largest, Japan, had a population of only about 100 million. Since approximately 1990, however, China has been experiencing economic growth at a rate of about 10% per year. With a population of 1.2 billion people, China's economic activity has an enormous effect on global markets. It may be anticipated that this economic

growth, coupled with a projected population increase of more than 400 million people during the next 30 years, will result in a demand for grain and other food supplies that will cause disruptive food shortages and dramatic price increases.

In addition to the destruction of farmland to build factories, roads, housing, and other parts of the infrastructure associated with industrialization, there are other factors that tend to decrease grain production as economic activity increases. One of the major factors is air pollution, which can lower grain yields significantly. Water pollution can seriously curtail fish harvests. Intensive agriculture uses large quantities of water for irrigation. If groundwater is used for irrigation, aquifers may become rapidly depleted.

The discussion above points out several factors that are involved in supplying food to a growing world population. There are numerous complex interactions among the industrial, societal, and agricultural sectors. Changes in one inevitably result in changes in the others.

2.8. MANUFACTURING

Once a device or product is designed and developed through the applications of engineering (see Section 2.2), it must be made—synthesized or manufactured. This may consist of the synthesis of a chemical from raw materials, casting of metal or plastic parts, assembly of parts into a device or product, or any of the other things that go into producing a product that is needed in the marketplace.

Manufacturing activities have a tremendous influence on the environment. Energy, petroleum to make petrochemicals, and ores to make metals must be dug from, pumped from, or grown on the ground to provide essential raw materials. The potential for environmental pollution from mining, petroleum production, and intensive cultivation of soil is enormous. Huge land-disrupting factories and roads must be built to transport raw materials and manufactured products. The manufacture of goods carries with it the potential to cause significant air and water pollution and production of hazardous wastes. The earlier in the design and development process that environmental considerations are taken into account, the more “environmentally friendly” a manufacturing process will be.

Three relatively new developments that have revolutionized manufacturing and that continue to do so are automation, robotics, and computers. These topics are discussed briefly below.

Automation

Automation uses automatic devices to perform repetitive tasks such as assembly line operations. The greatest application of automation is in manufacturing and assembly. Automation employs mechanical and electrical devices integrated into systems to replace or extend human physical and mental activities. Primitive forms of automation were known in ancient times, with devices such as floats used to control water levels in Roman plumbing systems. A key component of an automated system is the **control system**, which regulates the response of components of a system as a function of conditions, particularly those of time or location.

The simplest level of automation is **mechanization**, in which a machine is designed to increase the strength, speed, or precision of human activities. A backhoe for dirt excavation is an example of mechanization. **Open-loop, multifunctional** devices perform tasks according to preset instructions, but without any feedback regarding whether or how the task is done. **Closed-loop, multifunctional** devices use process feedback information to adjust the process on a continuous basis. The highest level of automation is **artificial intelligence** in which information is combined with simulated reasoning to arrive at a solution to a new problem or perturbation that may arise in the process.

Not all of the effects of automation on society and on the environment are necessarily good. One obvious problem is increased unemployment and attendant social unrest resulting from displaced workers. Another is the ability that automation provides to enormously increase the output of consumer goods at more affordable prices. This capability greatly increases demands for raw materials and energy, putting additional strain on the environment. To attempt to address such concerns by cutting back on automation is unrealistic, so societies must learn to live with it and to use it in beneficial ways. There are many beneficial applications of technology. Automated processes can result in much more efficient utilization of energy and materials for production, transportation, and other human needs. A prime example is the greatly increased gasoline mileage achieved during the last approximately 20 years by the application of computerized, automated control of automobile engines. Automation in manufacturing and chemical synthesis is used to produce maximum product from minimum raw material. Production of air and water pollutants and of hazardous wastes can be minimized by the application of automated processes. By replacing workers in dangerous locations, automation can contribute significantly to worker health and well-being.

Robotics

Robotics refers to the use of machines to simulate human movements and activities. **Robots** are machines that perform such functions using computer-driven mechanical components to grip, move, reorient, and manipulate objects. Modern robots are characterized by intricately related mechanical, electronic, and computational systems. A robot can perform a variety of functions according to pre-programmed instructions that can be changed according to human direction or in response to changed circumstances.

There are a variety of mechanical mechanisms associated with robots. These are servomechanisms in which low-energy signals from electronic control devices are used to direct the actions of a relatively large and powerful mechanical system. Robot arms may bend relative to each other through the actions of flexible joints. Specialized end effectors are attached to the ends of robot arms to accomplish specific functions. The most common such device is a gripper used like a hand to grasp objects.

Sensory devices and systems are crucial in robotics to sense position, direction, speed, and other factors required to control the functions of the robot. Sensors may be used to respond to sound, light, and temperature. One of the more sophisticated

types of sensors involves a form of vision. Images captured by a video camera can be processed by computer to provide information required by the robot to perform its assigned task.

Robots interact strongly with their environment. In addition to sensing their surroundings, robots must be able to respond to it in desired ways. In so doing, robots rely on sophisticated computer control. Rapid developments in computer hardware, power, and software continue to increase the ability of robots to interact with their environment. Commonly, instructions to robots are provided by computer software programmed by humans. It is now possible in many cases to lead a robot through its desired motions and have it “learn” the sequence by computer.

Robots are now used for numerous applications. The main applications are for moving materials and objects, and performing operations in manufacturing, assembly, and inspection. A promising use of robots is in surroundings that are hazardous to humans. For example, robots can be used to perform tasks in the presence of hazardous substances that would threaten human health and safety.

Computers

The explosive growth of digital computer hardware and software is one of the most interesting and arguably the most influential phenomenon of our time. Computers have found applications throughout manufacturing. The most important of these are outlined here.

Computer-aided design (CAD) is employed to convert an idea to a manufactured product. Whereas innumerable sketches, engineering drawings, and physical mockups used to be required to bring this transition about, computer graphics are now used. Thus computers can be used to provide a realistic visual picture of a product, to analyze its characteristics and performance, and to redesign it based upon the results of computer analysis. The capabilities of computers in this respect are enormous. As an example, Boeing’s large, extremely complex 777 passenger airliner, which entered commercial service in 1995, was designed by computer and brought to production without construction of a full-scale mockup.

Closely linked to CAD is **computer-aided manufacturing (CAM)** which employs computers to plan and control manufacturing operations, for quality control, and to manage entire manufacturing plants. The CAD/CAM combination continues to totally change manufacturing operations to the extent that it may be called a “new industrial revolution.” Computerized control of manufacturing, production, and distribution has greatly increased the efficiency of these activities, enabling economic growth with price stability.

The application of computers has had a profound influence on environmental concerns. One example is the improved accuracy of weather forecasting that has resulted from sophisticated and powerful computer programs and hardware. Related to this are the uses of weather satellites, which could not be placed in orbit or operated without computers. Satellites operated by computer control are used to monitor pollutants and map their patterns of dispersion. Computers are widely used in modeling to mimic complex ecosystems, climate, and other environmentally relevant systems.

Computers and their networks are susceptible to mischief and sabotage by outsiders. The exploits of “computer hackers” in breaking into government and private sector computers have been well documented. Important information has been stolen and the operation of computers has been seriously disrupted by hackers with malicious intent. Most computer operations are connected with others through the Internet, enabling communication with employees at remote locations and instant contact with suppliers and customers. The problem of deliberate disruption is potentially so great that companies throughout the world have spent billions of dollars on outside experts in computer security. The U.S. Federal Bureau of Investigation (FBI) now trains its new agents in cyberspace crime, and maintains special computer crime squads in New York, Washington, and San Francisco.

Numerous kinds of protection are available for computer installations. Such protection comes in the form of both software and hardware. Special encryption software can be used to put computer messages in code that is hard to break. Hardware and software barriers to unauthorized corporate computer access, “firewalls,” continue to become more sophisticated and effective.

2.9. EFFECTS OF THE ANTHROSPHERE ON EARTH

The effects of the anthrosphere on Earth have been many and profound. Persistent and potentially harmful products of human activities have been widely dispersed and concentrated in specific locations in the anthrosphere as well as other spheres of the environment as the result of human activities. Among the most troublesome of these are toxic heavy metals and organochlorine compounds. Such materials have accumulated in the anthrosphere in painted and coated surfaces, such as organotin-containing paints used to prevent biofouling on boats; under and adjacent to airport runways; under and along highway paving; buried in old factory sites; in landfills; and in materials dredged from waterways and harbors that are sometimes used as landfill on which buildings, airport runways and other structures have been placed. In many cases productive topsoil used to grow food has been contaminated with discarded industrial wastes, phosphate fertilizers, and dried sewage sludge.

Some of the portions of the anthrosphere that may be severely contaminated by human activities are shown in [Figure 2.1](#). In some cases the contamination has been so pervasive and persistent that the effects will remain for centuries. Some of the most vexsome environmental and waste problems are due to contamination of various parts of the anthrosphere by persistent and toxic waste materials.

Potentially harmful wastes and pollutants of anthrospheric origin have found their way into water, air, soil, and living organisms. For example, chlorofluorocarbons (Freons) have been released to the atmosphere in such quantities and are so stable that they are now constituents of “normal” atmospheric air and pose a threat to the protective ozone layer in the stratosphere. Lake sediments, stream beds, and deltas deposited by flowing rivers are contaminated with heavy metals and refractory organic compounds of anthrospheric origin. The most troubling repository of wastes in the hydrosphere is groundwater. Some organisms have accumulated high enough levels of persistent organic compounds or heavy metals to do harm to themselves or to humans that use them as a food source.

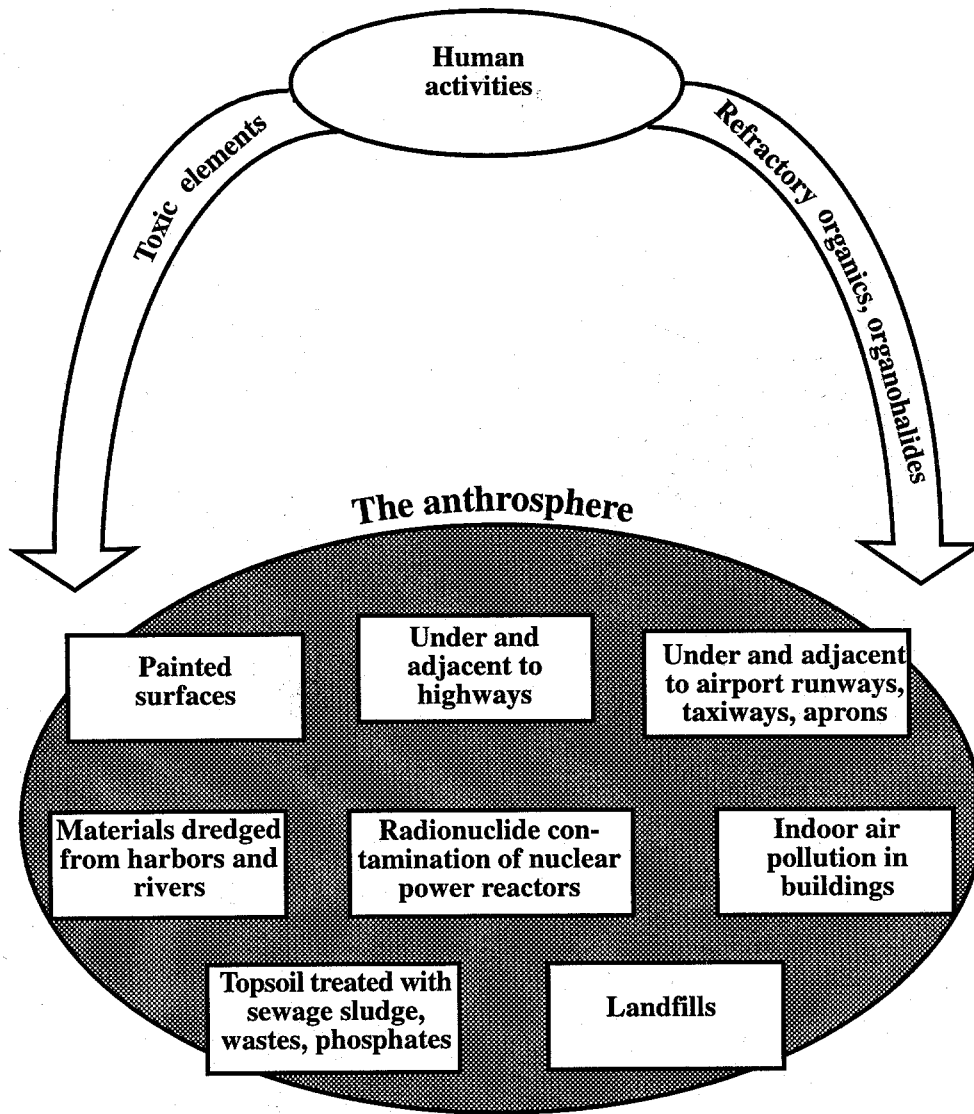


Figure 2.1. The anthrosphere is a repository of many of the pollutant by-products of human activities.

2.10. INTEGRATION OF THE ANTHROSPHERE INTO THE TOTAL ENVIRONMENT

Over the eons of Earth's existence, natural processes free from sudden, catastrophic disturbances (such as those that have occurred from massive asteroid impacts, for example) have resulted in a finely tuned balance among the systems composing Earth's natural environment. Fortuitously, these conditions—adequate water, moderate temperatures, an atmosphere that serves as a shield against damag-

ing solar radiation—have resulted in conditions amenable to various life forms. Indeed, these life forms have had a strong impact in changing their own environments. According to the **Gaia hypothesis** advanced by the British chemist James Lovelock, organisms on Earth have modified Earth's climate and other environmental conditions, such as by regulating the CO₂/O₂ balance in the atmosphere, in a manner conducive to the existence and reproduction of the organisms.

To a degree, the early anthrosphere created by pre-industrial humans integrated well with the other spheres of the environment and caused minimal environmental degradation. That this was so resulted less from any noble instincts of humankind toward nature than it did from the lack of power to alter the environment. In those cases where humans had the capability of modifying or damaging their surroundings, such as by burning forests to provide cropland, the effects on the natural environment could be profound and very damaging. In general, though, preindustrial humans integrated their anthrosphere, such as it was, with the natural environment as a whole.

The relatively harmonious relationship between the anthrosphere and the rest of the environment began to change markedly with the introduction of machines, particularly power sources, beginning with the steam engine, that greatly multiplied the capabilities of humans to alter their surroundings. As humans developed their use of machines and other attributes of industrialized civilization, they did so with little consideration of the environment and in a way that was out of synchronization with the other environmental spheres. A massive environmental imbalance has resulted, the magnitude of which has been realized only in recent decades. The most commonly cited manifestation of this imbalance has been pollution of air or water.

Because of the detrimental effects of human activities undertaken without due consideration of environmental consequences, significant efforts have been made to reduce the environmental impacts of these activities. [Figure 2.2](#) shows three stages of the evolution of the anthrosphere from an unintegrated appendage to the natural environment to a system more attuned to its surroundings. The first approach to dealing with the pollutants and wastes produced by industrial activities—particulate matter from power plant stacks, sulfur dioxide from copper smelters, and mercury-contaminated wastes from chlor-alkali manufacture—was to ignore them. However, as smoke from uncontrolled factory furnaces, raw sewage, and other by-products of human activities became more troublesome, “end-of-pipe” measures were adopted to prevent the release of pollutants after they were generated. Such measures have included electrostatic precipitators and flue gas desulfurization to remove particulate matter and sulfur dioxide from flue gas; physical processes used in primary sewage treatment; microbial processes used for secondary sewage treatment; and physical, chemical, and biological processes for advanced (tertiary) sewage treatment. Such treatment measures are often very sophisticated and effective. Another kind of end-of-pipe treatment is the disposal of wastes in a supposedly safe place. In some cases, such as municipal solid wastes, radioactive materials, hazardous chemicals, power plant ash, and contaminated soil, disposal of sequestered wastes in a secure location is practiced as a direct treatment process. In other cases, including flue-gas desulfurization sludge, sewage sludge, and sludge from chemical treatment of industrial wastewater, disposal is practiced as an adjunct to other end-of-pipe meas-

ures. Waste disposal practices later found to be inadequate have spawned an entirely separate end-of-pipe treatment called **remediation** in which discarded wastes are dug up, sometimes subjected to additional treatment, and then placed in a more secure disposal site.

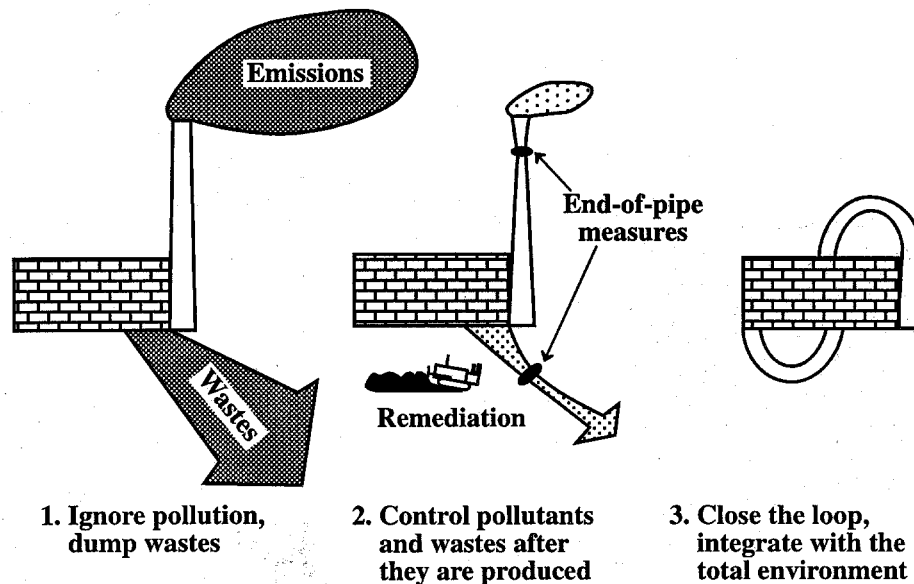


Figure 2.2. Steps in evolution of the anthroposphere to a more environmentally compatible form.

Although sometimes unavoidable, the production of pollutants followed by measures taken to control or remediate them to reduce the quantities and potential harmfulness of wastes are not very desirable. Such measures do not usually eliminate wastes and may, in fact, transfer a waste problem from one part of the environment to another. An example of this is the removal of air pollutants from stack gas and their disposal on land, where they have the potential to cause groundwater pollution. Clearly, it is now unacceptable to ignore pollution and to dump wastes, and the control of pollutants and wastes after they are produced is not a good permanent solution to waste problems. Therefore, it has become accepted practice to “close the loop” on industrial processes, recycling materials as much as possible and allowing only benign waste products to be released to the environment. Such an approach is the basis of industrial ecology discussed in the following section.

2.11. THE ANTHROSPHERE AND INDUSTRIAL ECOLOGY

Industrial ecology is an approach based upon systems engineering and ecological principles that integrates the production and consumption aspects of the design, production, use, and termination (decommissioning) of products and services in a manner that minimizes environmental impact. Industrial ecology functions within groups of enterprises that utilize each others’ materials and by-products such

that waste materials are reduced to the absolute minimum. Such a system is an **industrial ecosystem**, which is analogous to a natural ecosystem. In a manner analogous to natural ecosystems, industrial ecosystems utilize energy and process materials through a process of **industrial metabolism**. In such systems, products, effluents, and wastes are not regarded as leaving the system when a product or service is sold to a consumer, but are regarded as remaining in the system until a complete cycle of manufacture, use, and disposal is completed.

The first clear delineation of modern industrial ecology can be traced to a 1989 article by Frosch and Gallopoulos.⁵ In fact, industrial ecology in at least a very basic form has been practiced ever since industrial enterprises were first developed. That is because whenever a manufacturing or processing operation produces a by-product that can be used by another enterprise for a potential profit, somebody is likely to try to do so. Potentially, at least, modern industrial ecosystems are highly developed and very efficient in their utilization of materials and energy. The recognition that such systems can exist and that they have enormous potential to reduce environmental pollution in a cost-effective manner should result in the design of modern, well-coordinated industrial ecosystems, and the establishment of economic and regulatory incentives for their establishment.

The components of an industrial ecosystem are strongly connected by linkages of time, space, and economics. Such a system must consider the industrial ecosystem as a whole, rather than concentrating on individual enterprises. It also considers the total impact of the system on material use, energy consumption, pollution, and waste and by-product generation rather than regarding each of these aspects in isolation from the rest.

Industrial Ecosystems

A group of interrelated firms functioning together in the practice of industrial ecology constitutes an industrial ecosystem (see [Figure 2.3](#)). As noted above, such a system functions in a manner analogous to natural ecosystems. Each constituent of the system consumes energy and materials, and each produces a product or service. A well-developed industrial ecosystem is characterized by a very high level of exchange of materials among its various segments. It is often based upon a firm that is a primary producer of materials or energy. To the greatest extent possible, materials are kept within the industrial ecosystem and few wastes (ideally none) are produced that require disposal.

A functioning system of industrial ecology has at least five main constituents. The first of these is a primary materials producer, which generates the materials used throughout the rest of the system. Also required is a source of energy that keeps the system operating. The energy enters the system as high-grade energy that is used as efficiently as possible throughout the system before it is dissipated as waste heat. Another segment of the system is a materials processing and manufacturer sector, usually consisting of a number of firms. There is a large and diverse consumer sector. And finally there is a well-developed waste processing sector. It is this last kind of enterprise that distinguishes a functional industrial ecosystem from conventional industrial systems.

A key to the success of a sustainable industrial ecosystem is the symbiotic relationships that occur among various constituents of the system. Such relationships are analogous to symbiosis among organisms in a natural ecosystem. In a natural ecosystem the essential interdependencies among various biological species constituting the system have developed through long periods of evolution. Similarly, mutually advantageous relationships evolve naturally in functional industrial ecosystems.

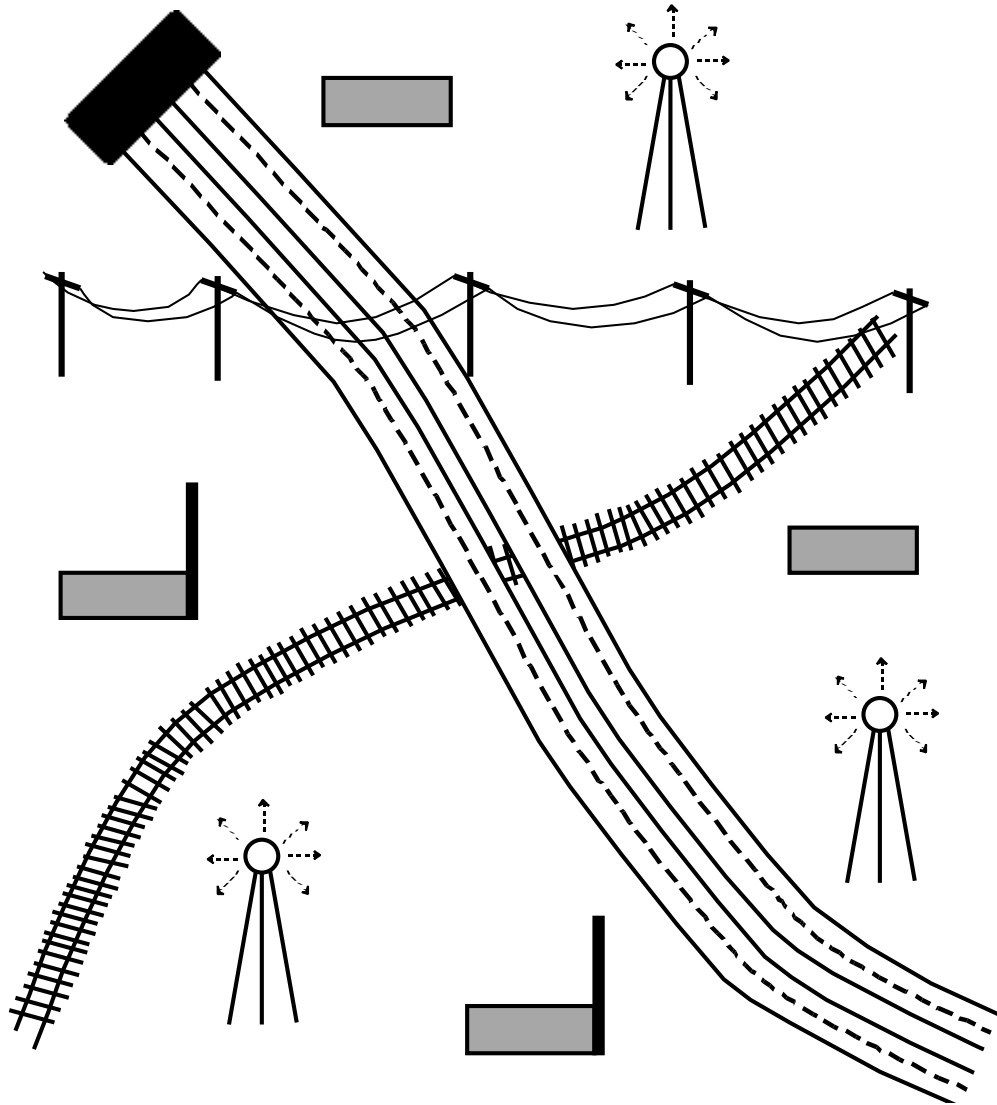


Figure 2.3. An industrial ecosystem consists of a variety of enterprises linked together by transportation and communications systems and processing materials in a manner that maximizes the efficient utilization of materials and minimizes wastes.

An essential key to the success of an industrial ecosystem is the facile exchange of materials and information in the system. Because of the central importance of materials exchange, industrial ecosystems tend to be clustered in relatively small geographic areas. Furthermore, they are often centered around a transportation system, such as a navigable river, a railroad line, or an interstate highway network. For high-value goods that can be shipped economically by air, a major airport is essential, and the constituents of the industrial ecosystem may be separated by great distances. Usually, several, or even all, of the constituents of a transportation system mentioned above are utilized in a functional industrial ecosystem.

In the modern “information age,” information is an increasingly valuable commodity. Therefore, the facile exchange of information among the constituents of an industrial ecosystem is essential for it to function properly. At the present time industrial ecosystems are developing in which information is the major commodity involved. Such systems are aided by modern developments in high-speed data transmission and computers. Industrial ecosystems based on information can be geographically highly dispersed with a scope that is truly worldwide.

Despite the advances of modern communication systems, the oldest form of communication, direct human contact, remains essential for the establishment and functioning of an industrial ecosystem. Thus it is essential to have a functioning social system conducive to the establishment of mutually interacting relationships in an industrial ecosystem.

Industrial Applications of Industrial Ecology

According to a survey conducted by the Rand Science and Technology Policy Institute, industrial concerns are increasing their use of the principles of industrial ecology to curtail pollution and to provide more environmentally friendly products and services.⁶ A detailed report dealing with industrial priorities in environmentally related research has shown that companies have a relatively low interest in funding research dealing with the traditional pollution control measures of remediation, effluent treatment, and pollutant monitoring and analysis.⁷ Instead, interest lies in research to increase production efficiency, produce environmentally friendly products, and provide environmentally beneficial services. The emphasis is increasing on research that deals with environmental concerns at an early stage of development, and “end-of-pipe” measures are receiving less emphasis. Basically, this means increasing emphasis upon the principles of industrial ecology.

There are a number of promising examples of how large companies are using the principles of industrial ecology to reduce environmental impact. Some of the best news is that such efforts can actually increase profitability. Xerox has greatly reduced disposal problems for photocopiers and components with a vigorous program to recycle parts and refurbish photocopiers, while simultaneously saving hundreds of millions of dollars per year. DuPont emphasizes market opportunities in the environmental area, such as the enzymatic production from cornstarch of intermediates required to make polyesters. The company also advises purchasers of hazardous chemicals on ways to reduce inventories of such chemicals, and in some cases even ways to produce the materials on site to reduce the transportation of

hazardous materials. Intel, which is a world leader in the rapidly changing semiconductor industry, completely retools its product line every two years. In so doing, the concern attempts to avoid triggering environmental permit requirements by designing processes that keep emissions low. It has been a leader in programs to conserve and recycle water, especially at a new facility in Arizona, where water is always a critical issue. Monsanto, arguably the world's leading concern in transgenic crops, is developing crops that are selectively resistant to Monsanto herbicides and that produce their own insecticides using genetic material transferred from bacteria that produce a naturally occurring insecticide.

Scenario Creation to Avoid Environmental Problems

A major concern with rapidly developing new technologies, of which transgenic biotechnology is a prime example, is the emergence of problems, often related to public concern, that were unforeseen in the development of the technologies. In order to avoid such problems, increasing use is being made of **scenario creation**, popularly known as story building, to visualize problems and take remedial action before they become unmanageable. Such an approach has been employed by members of the World Business Council for Sustainable Development to consider potential problems with newly emerging biotechnologies.⁸ In a remark attributed to Patricia Solaro of Germany's Hoechst A. G., the job of a panel on scenario creation is "to think the unthinkable and speak the unspeakable, not to say what we think will or should happen." That statement is supported by the fact that scenario creation was developed by the Rand Corporation in the 1950s under sponsorship by U. S. Federal Government to explore scenarios under which nuclear warfare might break out.

Several scenarios have been considered related to biotechnology. One of these is that biotechnology is entirely positive, leading to an abundance of products that lengthen life and improve its quality. Even with this positive scenario, problems could develop, such as those resulting from a much increased population of the elderly made possible by improved drugs and nutrition. Another possible course could result from some relatively small, unforeseen event such as human illness attributed to consumption of food from transgenic plants. The bad publicity resulting from such an event could cause a cascade of opposition that would result in onerous regulation that would seriously cripple efforts in biotechnology. Such an event would be an example of chaos theory, which holds that complex systems can be altered drastically by small perturbations which cause a catastrophic ripple effect in the system. A third scenario is that potential producers and users of biotechnology conclude that the benefits are not worth the effort, costs, and risks, so the technology simply fades away. Such an outcome is similar to that which has occurred with the nuclear power industry in the U. S. and most of Europe. (It could be argued, as well, that the course of the nuclear power industry illustrates chaos theory, with the Chernobyl nuclear power plant disaster the event that triggered a cascade of events leading to its demise.) Obviously, the development of computers and powerful computer programs have been extremely useful in scenario creation. In the late 1990s scenario creation was applied to possible problems created by the "Y2K bug" in which older computer programs had difficulty recognizing the year 2000.

2.12. ENVIRONMENTAL CHEMISTRY

In Chapter 1, environmental chemistry was defined as *the study of the sources, reactions, transport, effects, and fates of chemical species in water, soil, air, and living environments and the effects of technology thereon*. This definition is illustrated for a typical environmental pollutant in Figure 2.4. Pollutant sulfur dioxide is generated in the combustion of sulfur in coal, transported to the atmosphere with flue gas, and oxidized by chemical and photochemical processes to sulfuric acid. The sulfuric acid, in turn, falls as acidic precipitation, where it may have detrimental effects such as toxic effects on trees and other plants. Eventually the sulfuric acid is carried by stream runoff to a lake or ocean where its ultimate fate is to be stored in solution in the water or precipitated as solid sulfates.

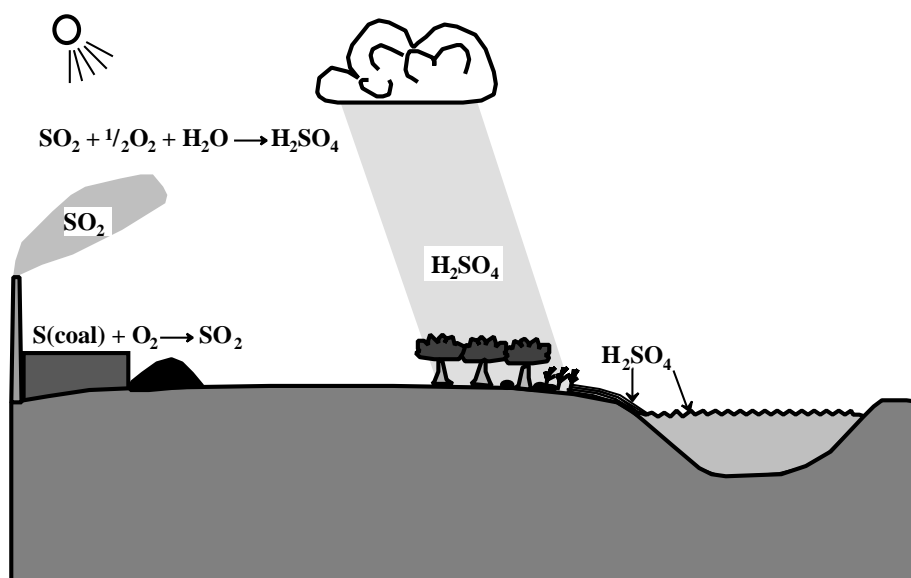


Figure 2.4. Illustration of the definition of environmental chemistry by the example of pollutant sulfuric acid formed by the oxidation of sulfur dioxide generated during the combustion of sulfur-containing coal.

Some idea of the complexity of environmental chemistry as a discipline may be realized by examining Figure 2.5, which shows the interchange of chemical species among various environmental spheres. Throughout an environmental system there are variations in temperature, mixing, intensity of solar radiation, input of materials, and various other factors that strongly influence chemical conditions and behavior. Because of its complexity, environmental chemistry must be approached with simplified models.

Potentially, environmental chemistry and industrial ecology have many strong connections. The design of an integrated system of industrial ecology must consider the principles and processes of environmental chemistry. Environmental chemistry must be considered in the extraction of materials from the geosphere and other

environmental spheres to provide the materials required by industrial systems in a manner consistent with minimum environmental impact. The facilities and processes of an industrial ecology system can be sited and operated for minimal adverse environmental impact if environmental chemistry is considered in their planning and operation. Environmental chemistry clearly points the way to minimize the environmental impacts of the emissions and by-products of industrial systems, and is very helpful in reaching the ultimate goal of a system of industrial ecology, which is to reduce these emissions and by-products to zero.

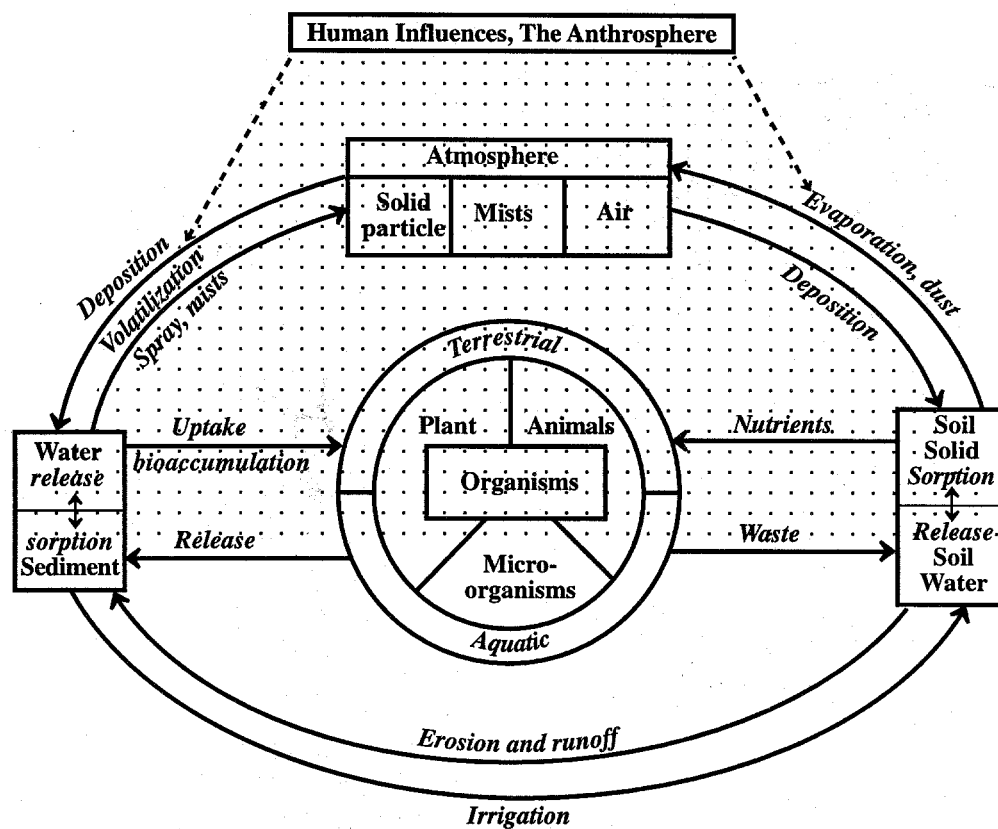


Figure 2.5. Interchange of environmental chemical species among the atmosphere, hydrosphere, geosphere, and biosphere. Human activities (the anthrosphere) have a strong influence on the various processes shown.

Environmental chemistry can be divided into several categories. The first of these addressed in this book is **aquatic chemistry**, the branch of environmental chemistry that deals with chemical phenomena in water. To a large extent, aquatic chemistry addresses chemical phenomena in so-called “natural waters,” consisting of water in streams, lakes, oceans, underground aquifers, and other places where the water is rather freely exposed to the atmosphere, soil, rock, and living systems. Aquatic chemistry is introduced in Chapter 3, “Fundamentals of Aquatic Chemistry,” which discusses some of the fundamental phenomena that apply to

chemical species dissolved in water, particularly acid-base reactions and complexation. Oxidation-reduction phenomena in water are addressed in Chapter 4, "Oxidation-Reduction." Many important aquatic chemical interactions occur between species dissolved in water and those in gaseous, solid, and immiscible liquid phases, the subject of Chapter 5, "Phase Interactions." One thing that clearly distinguishes the chemistry of natural waters from water isolated, contained, and purified by humans is the strong influence of microorganisms on aquatic chemistry, the topic of Chapter 6, "Aquatic Microbial Biochemistry." Water Pollution is discussed in Chapter 7, and Water Treatment in Chapter 8.

As the name implies, **atmospheric chemistry** deals with chemical phenomena in the atmosphere. To understand these processes it is first necessary to have a basic knowledge of the structure and composition of the atmosphere as given in Chapter 9, "The Atmosphere and Atmospheric Chemistry." This chapter also introduces the unique and important concepts of atmospheric chemistry, particularly photochemistry. Photochemical reactions occur when electromagnetic radiation from the sun energizes gas molecules forming reactive species that initiate chain reactions that largely determine key atmospheric chemical phenomena. Particles in the atmosphere are discussed in Chapter 10, and gaseous inorganic air pollutants, such as carbon monoxide, nitrogen oxides, and sulfur oxides, in Chapter 11. Organic species in the atmosphere result in some important pollution phenomena that also influence inorganic species. Organic air pollutants are the topic of Chapter 12, and the most important effect of organic air pollution, photochemical smog, is explained in Chapter 13. Some potentially catastrophic atmospheric pollution effects are outlined in Chapter 14, "The Endangered Global Atmosphere."

The **geosphere** is the topic of two chapters. The first of these, Chapter 15, "The Geosphere and Geochemistry," outlines the physical nature and chemical characteristics of the geosphere and introduces some basic geochemistry. Soil is a uniquely important part of the geosphere that is essential to life on earth. Soil chemistry is covered in Chapter 16, "Soil Environmental Chemistry."

Human activities have such a profound effect on the environment that it is convenient to invoke a fifth sphere of the environment called the "anthrosphere." Much of the influence of human activity on the environment is addressed in Chapters 1-16, particularly as it relates to water and air pollution. Specific environmental aspects of the anthrosphere addressed from the perspective of industrial ecology are covered in Chapter 17, "Principles of Industrial Ecology," and Chapter 18, "Industrial Ecology, Resources, and Energy." A unique environmental problem arising from anthropospheric activities is that of hazardous wastes, which is discussed in Chapter 19, "Nature, Sources, and Environmental Chemistry of Hazardous Wastes," and Chapter 20, "Industrial Ecology for Waste Minimization, Utilization, and Treatment."

The **biosphere** related to environmental chemistry is mentioned in various contexts throughout the book as it relates to environmental chemical processes in water and soil and it is the main topic of discussion of three chapters. The first of these, Chapter 21, "Environmental Biochemistry," covers general aspects of biochemical phenomena in the environment. The second, Chapter 22, "Toxicological Chemistry," deals specifically with the chemistry and environmental chemistry of

toxic substances. The third of the biologically oriented chapters is Chapter 23, "Toxicological Chemistry of Chemical Substances," which covers the toxicological chemistry of specific chemical substances and classes of substances.

Analytical chemistry is uniquely important in environmental chemistry. As it applies to environmental chemistry, it is summarized in Chapter 24, "Chemical Analysis of Water and Wastewater;" Chapter 25, "Chemical Analysis of Wastes and Solids;" Chapter 26, "Air and Gas Analysis;" and Chapter 27, "Chemical Analysis of Biological Materials and Xenobiotics.

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QUESTIONS AND PROBLEMS

1. Much of The Netherlands consists of land reclaimed from the sea that is actually below sea level as the result of dredging and dike construction. Discuss how this may relate to the anthrosphere and the other spheres of the environment.
2. With a knowledge of the chemical behavior of iron and copper, explain why copper was used as a metal long before iron, even though iron has some superior qualities for a number of applications.

3. How does engineering relate to basic science and to technology?
4. Suggest ways in which an inadequate infrastructure of a city may contribute to environmental degradation.
5. In what sense are automobiles not part of the infrastructure whereas trains are?
6. Discuss how the application of computers can make an existing infrastructure run more efficiently.
7. Although synthetic materials require relatively more energy and nonrenewable resources for their fabrication, how may it be argued that they are often the best choice from an environmental viewpoint for construction of buildings?
8. What is a telecommuter society and what are its favorable environmental characteristics?
9. What are the major areas to consider with respect to information?
10. What was the greatest threat to farmland in the U.S. during the 1930s, and what was done to alleviate that threat? What is currently the greatest threat, and what can be done to alleviate it?
11. What typically happens with regard to food production and demand in a country that acquires a high population density and then becomes industrialized?
12. What is the distinction between automation and robotics?
13. What is the function of a sensory device such as a thermocouple on a robot?
14. What is the CAD/CAM combination?
15. What are some of the parts of the anthrosphere that may be severely contaminated by human activities?
16. What largely caused or marked the change between the “relatively harmonious relationship between the anthrosphere and the rest of the environment” that characterized most of human existence on Earth, and the current situation in which the anthrosphere is a highly perturbing, potentially damaging influence?
17. What are three major stages in the evolution of industry with respect to how it relates to the environment?
18. How is an industrial facility based on the principles of industrial ecology similar to a natural ecological system?
19. Describe, with an example, if possible, what is meant by “end of pipe” measures for pollution control. Why are such measures sometimes necessary? Why are they relatively less desirable? What are the alternatives?
20. Discuss how at least one kind of air pollutant might become a water pollutant.
21. Suggest one or two examples of how technology, properly applied, can be “environmentally friendly.”

Answers to Questions, Chapter 2

1. Answer: In a sense, the reclaimed land is part of the anthrosphere because it was “made” by humans. Landfill composed of dredged materials is also part of the geosphere. The hydrosphere has been modified by pushing back its boundaries to provide additional land.

2. Answer: Chemically, copper has much more of a tendency to be in the elemental form and could be found in some locations as the native elemental metal. In order to utilize iron, it was necessary to discover how elemental iron can be reduced from iron oxide minerals.

3. Answer: Science is more concerned with the acquisition of fundamental knowledge, though usually directed toward some practical application. Engineering uses scientific knowledge to provide the plans to make and do things. Technology is the mechanism by which engineering enterprises are actually carried out.

4. Answer: Inadequate road systems and poor public transportation result in congestion, air pollution from idling and accelerating vehicles, and a general deterioration in esthetics. A poor electrical distribution system can cause inefficient utilization of electricity and the extra air pollution that results. Poor refuse collection causes direct problems with solid wastes. Substandard sewage treatment results in water pollution.

5. Answer: Automobiles are generally used by individuals, whereas trains are available to the public as a whole.

6. Answer: Computerized transportation systems, such as in scheduling bus routes and schedules to meet demand, can be optimized to provide maximum services with minimum use of the system. Electrical power generation can be optimized to meet demand with minimum energy consumption. Computers can aid in laying out streets in new subdivisions for most efficient service to residents.

7. Answer: Properly formulated, some synthetic materials have a practically unlimited lifetime in buildings. Another advantage is that synthetic materials can be designed with properties, such as insulating ability, that contribute markedly to their environmentally favorable performance.

8. Answer: A telecommuter society is one in which people whose jobs deal primarily with information work out of their homes and “commute” by means of communications lines interfaced with computers. The obvious advantage from the environmental viewpoint is that such workers do not have to commute physically with all of the environmental degradation associated with commuting, particularly by private automobile.

9. Answer: Acquisition, recording, computing, storing, display, and communication.

10. Answer: Erosion and deterioration of soil used to be the greatest threats, but have largely been alleviated by good soil conservation practices. At the current time, the greatest threat is probably removal of good farmland from production by urbanization and industrialization. Land zoning requirements and incentives that encourage redevelopment of previously developed areas and development on terrain not suitable for farming can be employed to alleviate this threat.

11. Answer: The demand for food and particularly livestock products increase while the capability of producing the food decreases. The result is that countries formerly self-sufficient in food tend to become food importers.

12. Answer: Automation uses machines to do repetitive tasks, whereas robotics uses machines to duplicate the actions of humans. There is potential overlap between the two areas

13. Answer: Such devices sense position, direction, speed, temperature, and other factors involved with the operation or control of a robot.

14. Answer: It refers to the use of computers in both the design (CAD) and manufacture (CAM) of manufactured products.

15. Answer: Painted surfaces; soil under and adjacent to paved surfaces, such as roadways or airport runways; landfill dredged from harbors and rivers; nuclear reactor components contaminated by radioactivity; air inside of buildings contaminated by “indoor air pollution;” topsoil used as a repository for various wastes, such as sludges; landfills.

16. Answer: The development of machines, such as gargantuan earth-moving equipment with the potential to significantly alter the other environmental spheres.

17. Answer: (1) Essentially no consideration of or control of emissions and wastes, (2) control and treatment of emissions and wastes after they are generated, (3) application of an approach based upon industrial ecology so that few, if any, emissions or wastes are generated.

18. Answer: Both require a major source of energy to make them run, as well as at least one major, as well as several minor sources of materials. Both kinds of systems

are diverse and operate such that various components make use of what would otherwise be the waste products of other sectors. Minimal unusable waste is produced from either kind of ecosystem.

19. Answer: Kinds of materials that will minimize wastes or that can be reused or recycled, recyclable components, alternate pathways for making goods or providing services that are more sound from the environmental viewpoint.

20. Answer: (1) Dematerialization, (2) material substitution, (3) recycling, (4) waste mining.