CHAPTER 1

NANOTECHNOLOGY/ ENVIRONMENTAL OVERVIEW

1.1 INTRODUCTION

Nanotechnology is concerned with the world of invisible miniscule particles that are dominated by forces of physics and chemistry that cannot be applied at the macro- or human-scale level. These particles have come to be defined by some as nanomaterials, and these materials possess unusual properties not present in traditional and/or ordinary materials.

Regarding the word *nanotechnology*, it is derived from the words *nano* and *technology*. Nano, typically employed as a prefix, is defined as one billionth of a quantity or term that is represented mathematically as 1×10^{-9}, or simply as 10^{-9}. Technology generally refers to "the system by which a society provides its members with those things needed or desired." The term *nanotechnology* has come to be defined as those systems or processes that provide goods and/or services that are obtained from matter at the nanometer level, that is, from sizes at or below one billionth of a meter. The new technology thus allows the engineering of matter by systems and/or processes that deal with atoms; or as Drexler (whom some view as the godfather of this industry) put it: "... entails the ability to build molecular systems with atom-by-atom precision yielding a variety of nanomachines." One of the major problems that remain is the development of nanomachines that can produce other nanomachines in a manner similar to what many routinely describe as mass production.

The classic laws of science are different at the nanoscale. Nanoparticles possess large surface areas and essentially no inner mass, that is, their surface-to-mass ratio is extremely high. This new "science" is based on the knowledge

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that particles in the nanometer range, and nanostructures or nanomachines that are developed from these nanoparticles, possess special properties and exhibit unique behavior. These special properties, in conjunction with their unique behavior, can significantly impact physical, chemical, electrical, biological, mechanical, and functional qualities. These new characteristics can be harnessed and exploited by applied scientists to engineer “Industrial Revolution II” processes. Present-day and future applications (to be discussed in more detail in the next section) include chemical products—to be parts, plastics, specialty metals, and powders; computer chips, computer systems, and miscellaneous parts; and pollution prevention areas that can include energy conservation, environmental control, and health/safety issues; plus crime and terrorism concerns. In effect, the sky’s the limit regarding efforts in this area, and as far as the environment is concerned, this new technology can terminate pollution as it is known today.

The authors believe that nanotechnology is the second coming of the industrial revolution, or as one of the authors[1] has described it, “Industrial Revolution II.” It promises to make that nation (hopefully ours) that seizes the nanotechnology initiative the technology capital of the world. One of the main obstacles to achieving this goal will be to control, reduce, and ultimately eliminate environmental and environmental-related problems associated with this technology; the success or failure of this new use may well depend on the ability to address these environmental issues. Only time will provide answers to three key environmental questions:

1. What are the potential environmental concerns associated with this new technology?
2. Can industries and society expect toxic/hazardous material to be released into the environment during either the manufacture or use of nanoproducts?
3. Could nanoapplications lead to environmental degradation, particularly from bioaccumulation of nanoparticles in living tissue?

Regarding these three questions, it is important to note that the environmental health and hazard risks associated with both nanoparticles and the applications of nanotechnology for industrial uses are at present not fully known. Some early studies indicate that nanoparticles can serve as environmental poisons that accumulate in organs. Although these risks may prove to be either minor, avoidable, or both, the engineer and scientist is duty bound to determine if there are in fact any health, safety, and environmental impacts associated with nanotechnology. These concerns served as the driving force for the writing of this book.

Note that Sections 1.2 to 1.4 discuss nanotechnology while Sections 1.5 to 1.8 address environmental issues.

1.2 SURVEY OF NANOTECHNOLOGY APPLICATIONS

> The extreme surface-to-volume ratio of nanoparticles is a key attribute that accounts for their range of superior performance characteristics. As the functional advantages of ultra-small particles continue to be deciphered, and processes are perfected to make and manipulate then, there seems to be no limit to what nanomaterials can do.

> Once an academic curiosity, nanotechnology has sweeping implications for many electronic, optical, magnetic, catalytic, and medical-therapeutic applications. Nanomaterials are being used to produce composite materials with improved electroconductivity and catalytic activity, hardness, scratch resistance, and self-cleaning capabilities. And, they are being exploited to improve the performance of gas sensors and other devices, the way drugs reach targets in the human body, and the aesthetic appeal and efficiency of consumer products.
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> A diverse array of ultra-small-scale materials, including metal oxides, ceramics and polymeric materials, and wide-ranging processing methods including techniques that employ 'self-assembly' on a molecular scale, are either in use today or are being groomed for commercial-scale use.[2]

Examples of nanotechnology in actual commercial use, under serious investigation, or on the verge of commercialization include:

- Semiconductor chips and other microelectronics applications
- High surface-to-volume catalysts, which promote chemical reactions more efficiently and selectively
- Ceramics, lighter-weight alloys, metal oxides, and other metallic compounds
- Coatings, paints, plastics, fillers, and food-packaging applications
- Polymer–composite materials, including tires, with improved mechanical properties
- Transparent composite materials, such as sunscreens containing nanosize titanium dioxide and zinc oxide particles
- Use in fuel cells, battery electrodes, communications applications, photographic film developing, and gas sensors
- Nanobarcodes
- Tips for scanning probe microscopes
- Purification of pharmaceuticals and enzymes

Promising medical applications encompass diagnostic and drug delivery systems, including specific targeting of cancer cells. However, these appear to be many years away from commercialization because of lengthy approval procedures by the Food and Drug Administration (FDA) in the United States and its counterpart agencies overseas.[3]

Other examples, in various stages of development, focused on pollution prevention and treatment are listed below:

- Sensing of pollutants, pH, and chemical warfare agents
- Ultraviolet light (UV)-activated catalysts for treatment of environmental contaminants
- Removal of environmental contaminants from various media, including in situ remediation of pesticides, polychlorinated biphenyls (PCBs), and chlorinated organic solvents, such as trichloroethylene (TCE)

- Posttreatment of contaminated soils, sediments, and solid wastes
- Sorption of contaminants for air and water pollution control, in a manner said to be vastly superior to activated carbon
- Chelating agents for polymer-supported ultrafiltration
- Oil–water separation
- Destruction of bacteria (including anthrax)
- Purification of drinking water, without the need for chlorination

Further details can be found in the references cited below. The reader is encouraged to stay abreast of the latest developments in this rapidly changing field.[3]

1. Baum, R. M., editor-in-chief, "Biotech and Nanotech," *Chemical & Engineering News (C&EN)*, **82**(15), 3 (April 12, 2004).
2. Dagani, R., "Nanotech Hoopla," *Chemical & Engineering News (C&EN)*, **82**(15), 31 (April 12, 2004).
3. Masciangioli, T. and W. Zhang, "Environmental Technologies at the Nanoscale," *Environmental Science & Technology*, **37**(5), 102A–108A (Mar. 1, 2003).
4. Shelley, S., "Carbon Nanotubes: A Small-Scale Wonder," *Chemical Engineering*, **110**(1), 27–29 (Jan. 2003).
5. Various Authors, "Nanotechnology," *Chemical Engineering Progress*, **99**(11), 34S–48S (Nov. 2003).
6. Zhang, W., "Nanoscale Iron Particles for Environmental Remediation: An Overview," *Journal of Nanoparticle Research*, **5**, 323–332 (2003).

In addition to the publications cited above, possible sources of additional information include (1) NanoFocus page of C&EN *Online*, (2) *Small*, a Wiley-VCH journal scheduled for start-up on January 2005, and (3) The American Chemical Society's *Nano Letters.*

It has been reported that market opportunities for nanoparticles as materials are limited; the present real value of the nanos are in their future application. In time, these applications will increase, probably at an exponential rate. Once these opportunities have been identified by the engineer and applied scientist, the appropriate nanotechnology fit will be made. Normally, this will involve successfully engineering the interface between the aforementioned nanoparticles and other materials. In the meantime, there are the areas briefly described above to which industry is currently applying nanoparticles and nanotechnology to real-world applications. Shelley,[2] in an outstanding review article provides additional information on some of the above applications. These are detailed in the next chapter.

Two current and specific nanotechnology projects follow. The first is an industrial application with academic ties. The second involves a government-sponsored project. These are detailed in the following paragraphs.

Project (1): NanoScale Materials, Inc., has developed scaled-up production processes for FAST-ACT (First Applied Sorbent Treatment Against Chemical Threats), an advanced nanoengineered family of products designed to provide first responders, Hazmat teams, and other emergency personnel with a single technology to counteract a variety of chemical warfare agents and toxic industrial chemicals. Nontoxic, noncorrosive, and nonflammable, FAST-ACT is particularly useful when response personnel are confronted with a chemical spill whose exact nature is unknown. While substances such as activated carbon only physically absorb toxic substances, FAST-ACT neutralizes, destroys, and renders them harmless. The material's large surface area gives it the ability to capture and destroy toxic chemicals. Just 25 g (a little less than an ounce) has the surface area of almost three football fields. Independent testing by chemical warfare experts showed that FAST-ACT removed more than 99 percent of such agents as VX, soman, and mustard gas from surfaces in less than 90 s. The initial research that led to FAST-ACT was conducted by the Kansas State University laboratory of Kenneth Klabunde. The National Science Foundation (NSF) Small Business Innovation Research (SBIR) program supported NanoScale's research to make the production processes commercially viable. This scaling-up required dramatic process changes, development of quality control standards and testing to confirm the safety and efficacy of FAST-ACT.

Project (2): Mercury pollution is widely recognized as a growing risk to both the environment and public health. It is estimated that coal-burning power plants contribute about 48 tons of mercury to the U.S. environment each year. The Centers for Disease Control and Prevention (CDC) estimate that one in eight women have mercury concentrations in their bodies that exceed safety limits. The U.S. Environmental Protection Agency (EPA) is currently reconsidering proposed rules on the release of mercury from coal-burning power plant effluents and may impose greater restrictions. Mercury found in liquid effluents comes from water-based processes the facilities used to scrub, capture, and collect the toxic material.

Scientists at the Department of Energy's Pacific Northwest National Laboratory (PNNL) have developed a novel material that can remove mercury and other toxic substances from coal-burning power plant wastewater. PNNL's synthetic material features a nanoporous ceramic substance with a specifically tailored pore size and a very high surface area. The surface area of one teaspoon of this substance is equivalent to that of a football field. This material has proven to be effective for absorbing mercury. Pore sizes can be tailored for specific tasks. The material relies on technology previously developed at PNNL—self-assembled monolayers on mesoporous support, or SAMMS. SAMMS integrates a nanoporous silica-based substrate with an innovative method for attaching monolayers, or single layers of densely packed molecules that can be designed to attract mercury or other toxic substances. In recent tests at PNNL, a customized version of SAMMS with an affinity of mercury, referred to as thiol-SAMMS, was developed. According to Shas Mattigod, lead chemist at PNNL, test results revealed mercury-absorbing capabilities that surpassed the devel-opers' expectations. After three successive treatments, 99.9 percent of the mercury in the simulated wastewater was captured, reducing levels from

145.8 to 0.04 parts per million (ppm). This is below the EPA's discharge limit of 0.2 ppm. The mercury-laden SAMMS also passed Washington State's dangerous waste regulatory limit of 0.2 ppm, allowing for safe disposal of the test solution directly to the sewer. Tests have shown that the mercury-laden SAMMS also passed EPA requirements for land disposal. This technology may result in huge savings to users who are faced with costly disposal of mercury in the waste stream. It appears that SAMMS technology can be easily adapted to target other toxins such as lead, chromium, and radionuclides.

With regard to economics and finance, the latest reports indicate that worldwide research and development (R&D) spending is now up to approximately $12 billion, with the biggest increases occurring in defense and security projects. Expenditures/investments also continue to increase in:

1. Information technology
2. Life sciences
3. Food
4. Energy
5. Water

The nanotechnology market is expected to grow by 30 percent annually in this decade. This growth will be further fueled as individuals become more aware of the impact nanotechnology will have on society. Additional details are provided in the next chapter.

1.3 LEGAL CONSIDERATIONS FOR NANOTECHNOLOGY

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A new area of technological research and development is rapidly emerging. It is called *nanotechnology* because it pertains to technology operating at the scale of nanometers. For the present, the full implications of the meaning of the term must remain speculative. Nanotechnology is being introduced into a society with an existing legal framework. Nevertheless, because of the potential of this technology to introduce changes as to what human beings can do and expect in the realm of materials, mechanics, information systems, and biological systems, the legal system may have a difficult time catching up with the vast new potentials. Not the least of the reasons for this difficulty is that technological development begets more technological development. More technological development has occurred in the past 30 years than in the previous century. Twenty years ago it was relatively uncommon for a household to have a personal computer. Now, most households in the United States have personal computers. In the early 1990s the Internet was just becoming popular and there was conflict over its commercialization. Now, even grade-school children communicate over the Internet and "surf the net" for research or amusement.

Technology affects almost every area of human activity in one way or another. And so one can expect that the legal relations between people will have to be taken into account. Even though anticipated developments in nanotechnology may yet be in the realm of speculation, those involved with nanotechnology and those involved with law should consider how nanotechnology and law might interact.

One area of law with which the nanotechnologist must be concerned is intellectual property law. Technological development is all about ideas. Ideas have commercial value only if they can be protected by excluding others from exploiting those ideas. Typically, the way to protect ideas is through intellectual property rights such as patents, trademarks, copyrights, trade secrets, and maskworks. Patents can be used to protect useful inventions, ornamental designs, and even botanical plants. The patent allows the owner of the patent the right to prevent anyone else from making, using, or selling the invention covered by the claims of the patent. Trademarks are distinctive marks associated with a product or service (these are usually referred to as service marks), which the owner of the mark can use exclusively to identify himself as the source of the product or service. Copyrights protect the expression of an idea, rather than the idea itself, and are typically used to protect literary works and visual and performing arts, such as books, photographs, paintings and drawings, sculpture, movies, songs, and the like. Trade secret law protects technical or business information that a company uses to gain a competitive business advantage by virtue of the secret being unknown to others. Customer or client lists, secret formulations, or methods of manufacture are typical business secrets. Maskwork protection is for original circuit designs in a chip layout.

Of these intellectual property rights, the most pertinent for nanotech inventions are patents. (Recent patent activity is discussed in the next section.) A patent can protect, for example, a composition of matter, an article of manufacture, or a method of doing something.

It is incumbent upon those engaged in any area of technological development to acquire a basic understanding of patent law because the patent portfolio of a company, particularly one focused on research and development, may represent its most valuable asset(s). Certain activities, such as premature sale or public disclosure, can jeopardize one's right to obtain a patent. Patents are creatures of the national law of the issuing country and are enforceable only in that country. Thus, a U.S. patent is enforceable only in the United States. To protect one's invention in foreign countries, one must apply in the countries in which protection is sought. One can obtain a general idea of the developmental progress of a new technological field by monitoring the number of patents issued in that field.

Patent rights are private property rights. Infringement of a patent is a civil offense, not criminal. The patent owner must come to his or her own defense through litigation, if necessary. And this is a very expensive undertaking. Lawsuits costing more than a million dollars are not unusual. But at stake can be exclusive rights to technology worth a hundred times as much.

Another legal area that will be relevant to nanotechnology is contract law. Any time two or more parties agree upon something, the principles of contract law come into play. The essential components of a contract are parties competent to enter into a contractual agreement, subject matter (what the contract is about), legal consideration (the inducement to contract such as the promises or payment exchanged, or some other benefit or loss or responsibility incurred by the parties), mutuality of agreement, and mutuality of contract. While oral contracts can be legally binding, in the event of a dispute it may be difficult to establish in court who said what. It is far better to memorialize the agreement in the form of a written contract.

One of the basic principles of contract law is that the parties should have a meeting of minds. That is, they should have a common understanding of what the terms of the contract mean. Sometimes it is not so clear what particular terms mean, or the meaning or its implications may change in time. What, for example, qualifies as "nanotechnology?" Not only is nanotechnology not well defined now, in the future it may encompass things that are not even imagined today.

Generally, contracts are employed with the sale and licensing of exclusive rights to a technology. Also, there are agreements to fund technological research and development.

Who are the entities engaged in the contract? Typically, these are business entities. So one must also consider whether there may be some peripheral issues of corporation or partnership law.

Another area of concern is government regulations. Environmental regulations, in particular, have become a central concern for technological development. In fact, in many technologies it is the increasingly stringent clean air and water regulations that drive new technological development. This is particularly true, for example, in the automotive industry and in heavy industries where emissions are released into the atmosphere or water. What effects will nanotechnology have on the environment? This is yet unknown because the field is still, relatively speaking, in its infancy. One can only speculate. But suppose, for example, nanoproducts are developed, products that are so small they can be ingested or inhaled, and that act upon the interior organs of the human body. Suppose now that such products are released into the environment. They might be carried by the air within the state or across state lines. The state and federal environmental regulatory agencies would understandably be taking a great interest in the environmental impact of such a release.

Also, one can imagine that nanotechnology intended for medical applications will arouse the interest of the Food and Drug Administration. Perhaps there may be a court case in the future in which a question to be decided is whether a dose of nanomachines qualifies as medical instrumentation or a drug.

Statutory regulations are prospective. They deal with the future. Vague regulations are not enforceable. And, generally speaking, one cannot be accused of violating a law or regulation that was not in effect when the act in question was performed. Hence, it is usually (but not always) the case that regulations and laws are put into effect only after some disaster has occurred.

But there is a branch of law that can address retrospectively certain situations in which property or people are harmed. That is tort law. A tort is a civil wrong, other than a breach of contract, for which the law provides a remedy. One can recover damages under tort law if a legal duty has been breached that causes foreseeable harm. These duties are created by law other than duties under criminal law, governmental regulations, or those agreed to under a contract. Tort law can be very encompassing.

Nanotechnologists have to consider the possibilities of reasonably foreseeable harm arising from their developments and take prudent precautions to avert such harm. In the event that a technology is inherently dangerous, nanotechnologists may be held to a standard of strict liability for any harm caused by the technology regardless of whether an accident was foreseeable.

Sometimes a very unexpected series of events can arise that cause harm. In the *Palsgraf v. Long Island Railroad* case the plaintiff, Mrs. Palsgraf, was standing on the platform of the station after buying a ticket to go to Rockaway Beach. A train bound for another destination stopped at the station and a man carrying a package under his arm jumped aboard the car. A railroad employee, a guard who was holding the door, reached out to help the man in. But the package was dislodged and fell onto the tracks. Unknown to the guard, the package happened to contain fireworks. Upon hitting the ground the fireworks exploded, treating the bystanders to a dazzling, if violent, pyrotechnic display. Unfortunately, the shock of the explosion knocked over a scale that fell upon the hapless Mrs. Palsgraf. She was injured and sued the Long Island Railroad. The court dealt with issues of causation and foreseeability, and ultimately decided in favor of the defendant. Nevertheless, the fact that the defendant in this case was the Long Island Railroad and not the gentleman with the fireworks leads to the conclusion that, insofar as the plaintiff is concerned, causal linkage between an act and an injury is not unrelated to the depth of pockets of a prospective defendant.

Most nanotechnologists are not at all interested in deliberately causing harm. But some will be. As described earlier, nanotechnology can have military applications, and governments may be interested in developing nanoweapons. To take the example given earlier, let us suppose that nanoproducts, perhaps nanomachines, are developed that can invade the human body and do harm. Is a cloud of such nanomachines to be considered a poison gas? Or is it a collection of antipersonnel mechanical implements, like shrapnel? How will nanomachines as weapons be treated under the Geneva convention? And suppose such a cloud of nanoweapons drifts over, or is released over, a civilian population? The devastating effect of land mines, which remain lethal long after hostilities are ended and which wreak havoc upon unsuspecting civilians wandering into mine fields, has been amply documented. Will nanoweapons remain harmful years after their deployment? What responsibilities do governments have morally, and under international law?

But suppose these nanoproducts are not designed to cause harm but simply to obtain and transmit information. For example, suppose such nanoproducts, if ingested, provide information about bodily functioning. Or suppose they enable a person to be tracked wherever he or she goes. Larger devices are already known that enable a person to be tracked by global positioning satellites. These devices are worn voluntarily. There are also implantable devices. But nanomachines would be undetectable and could very well be implanted in a person without his or her knowledge or consent. Under what circumstances should such invasions of privacy be allowed or forbidden?

Then there is the matter of the criminal use of nanotechnology. The past decade has already seen the growth of a new area of crime: computer crime. For example, in addition to conventional theft, law enforcement agencies must now become technologically proficient to handle computer fraud, identity theft, theft of information, embezzlement, copyright violation, computer vandalism, and like activities, all accomplished over the computer network under conditions such that not only is the criminal hard to trace but even the crime may go undetected. The computer criminals are technologically very savvy and willing to exploit the potentials of any new technology. About the only thing one can expect is that if nanotechnology provides great new potentials, someone will use those potentials for criminal purposes, and the laws will again be forced to play catch-up in response to the crimes, after the harm has occurred.

These speculations presume the feasibility of such futuristic devices. And one comes back to the original point that it is not known what will be feasible in 10 or 20 years, not only with respect to nanotechnology but with respect to the convergence of nanotechnology with other technologies such as biotechnology, information technology, wireless technology, materials science, and quantum physics.

It would be prudent for those involved in nanotechnology and those involved in law to interact constructively, and to share knowledge and expertise to avoid blindly traveling along a road whose features and direction are yet unknown. As always, the question is whether human beings will control technology for their own constructive uses, and that depends upon whether people can control themselves. The alternative is to be mastered by one's own creations.

1.4 RECENT PATENT ACTIVITY[2]

The publication of patent applications by the U.S. Patent and Trademark Office (USPTO) has given researchers in both academia and industry a means of following new developments in their particular fields of interest. This is particularly true in nanotechnology. The following survey, developed with the assistance of Examiner Vivek Koppikar of the U.S. Patent and Trademark Office, a chemical engineer and member of the American Institute of Chemical Engineers (AIChE), shows some of the new directions in the field while suggesting opportunities for further exploration and future patent protection.

In terms of issued patents alone, the USPTO reports that those involving nanotechnology have increased by over 600 percent in the last 5 years, from 370 in 1997 to 2650 in 2002. While these patents made up only 2 percent of all patents issued in 2002, this compares to a figure of 0.3 percent in 1997. New filings of nanotechnology-related patent applications are evenly split between process inventions and product inventions, as is typical for all patent applications. Most of these applications (approximately 90 percent) come from private corporations, with

Hewlett-Packard, Texas Instruments, 3M, and Motorola filing the largest number. Universities are filing approximately 7 percent, with the University of California and Stanford University in the lead. About 3 percent are being filed by agencies of the U.S. government and collaboration research centers such as the Department of Energy, the Department of Defense, and Sandia National Laboratories. Most of the inventions in these applications are refinements to known technology, but a significant number can be considered "revolutionary" or pioneering in nature. The following is a sampling of what has appeared in published patent applications, showing the wide diversity of chemical engineering disciplines utilizing nanotechnology.

In heat transfer and reaction engineering, the extremely high surface area of nanoparticles has been known to raise reaction rate coefficients and ultimately reduce the energy requirements for a reactor. Patent application no. 2002/0100578 now discloses that nanoparticles are also useful in heat transfer fluids where the high surface area of the particles raises the convective heat transfer coefficients and heat capacities of the fluids and produces a greater degree of collision-induced motion, all of which produce significant energy and cost savings for heat transfer and exchanger systems.

In fiber chemistry, nanoparticle-containing fibers formed by melt-spinning resins containing nanoparticle dispersions are improved upon by the invention of patent application no. 2003/0083401. In this invention, the fibers are formed by nanoparticles that are surface-derivatized with functional groups that allow the nanoparticles themselves to link together in a "polymerization" reaction. The resulting fiber is claimed to benefit from reduced agglomeration of the particles and greater control of their size, both of which enhance product uniformity.

Drug delivery has also benefited from nanotechnology, including nanoparticles, nanotubes, and nanowires. Among the new patent applications are those claiming nanowire compositions for specific treatments and therapies. Orally administered nanowires (termed *nanorobots*), for example, are disclosed for delivering antibodies to specific cells in the body and for probing and manipulating biomolecules at the cellular and subcellular level. In application no. 2002/0187504, nanowires are made to act as antibodies themselves by functionalizing one end of a nanowire with a ligand to bind to a specific target molecule and the other end with a ligand that attracts immune cells.

Nanoparticles are also used for controlled-release drug delivery. In application no. 2003/0095928, the drug itself is formed into nanoparticles with the assistance of a surface stabilizer. The drug in this application is insulin, and the resulting nanoparticle offers both a rapid onset of insulin activity and prolonged activity. Other applications disclose the use of nanotechnology to deliver Taxol, antigens, and antibiotics such as penicillin.

In soaps, detergents, and industrial cleaners, nanoparticles have been used to provide controlled release of fragrances, biocides, and antifungals on textiles by adhering to the textile fibers. Application no. 2003/0013369, discloses "textile-reactive" nanoparticles that bind to the textile fiber through a covalent bond. Nanoscale polymers have been disclosed for use in hair and skin care cleansing preparations to increase the stability and consistency of the preparations. Recent improvements are disclosed in patent applications nos. 2003/0086894, 2003/0059385, and 2003/0003070, in which nanoscale polymers with a mean diameter of 10 to 500 nm provide increased dermatological compatibility and improved sensory properties on skin and hair due to the high compatibility of these polymers with keratin.

In coatings technology, nanoparticle hardcoats have been applied to the surfaces of glass, quartz, wood, and metal, as well as thermoset and thermoplastic materials such as acrylics and polycarbonates, providing protection of the substrate in each case. Application no. 2003/0068486 discloses that smudge resistance can be increased by using nanoparticles with exposed reactive groups that covalently attach to smudge-resistant moieties.

The use of nanoparticles in separation technology has seen numerous improvements as well. In application no. 2003/0038083, for example, superparamagnetic nanoparticles are placed in contact with a liquid or gaseous medium to bind to specified targets in the medium. A magnetic field then separates the target-laden nanoparticles from the medium. The advantage of nanoparticles is their lack of retention of magnetism after the magnetic field is removed, since retained magnetism causes the laden nanoparticles to aggregate, which inhibits separation.

In composite materials, recent patent applications disclose the incorporation of nanoparticles to add novel properties to macrosized materials without altering other, favorable properties of the materials. One example is application no. 2003/0099834 in which silver nanoparticles are embedded in glass to make the glass photochromic, that is, capable of light-induced, reversible darkening. The nanoparticles are incorporated into the glass at room temperature without the need for annealing or other processing steps at higher temperatures. Another example is application no. 2003/0037443, which discloses the incorporation of metallic nanoparticles in plastic forks and spoons to add luster.

As with any invention, the qualities that make nanotechnology-related inventions patentable are novelty, nonobviousness, and utility. While many unique properties of nanotechnology are already known, more are being discovered as are new ways of exploiting known properties, all of which can lead to patentable inventions. The growth of patents in nanotechnology is a clear indication of the industry's recognition of the potential in this field.

1.5 ENVIRONMENTAL IMPLICATIONS[5,6]

Any technology can have various and imposing effects on the environment and society. Nanotechnology is no exception, and the results will be determined by the extent to which the technical community manages this technology. This is an area that has, unfortunately, been seized upon by a variety of environmental groups.

There are two thoughts regarding the environmental implications of nanotechnology: One is positive and the other is potentially negative. Some of the positive features of this new technology are discussed in this section. Much of this has been drawn from an excellent report that recently appeared in the literature.[7] Additional details are provided in Section 2.7.

The other implication of nanotechnology has been dubbed by many in this diminutive field as "potentially negative." The reason for this label is as simple as it is obvious: The technical community is dealing with a significant number of unforeseen effects that could have disturbingly disastrous impacts on society. Fortunately, it appears that the probability of such dire consequences actually occurring is near zero . . . but *not* zero. This finite, but differentially small, probability is one of the reasons this book was written; and it is the key topic that is addressed in the pages that follow. Air, water, and land (solid waste) concerns with emissions from nanotechnology operations in the future, as well companion health and hazard risks, receive extensive treatment. All of these issues arose earlier with the Industrial Revolution, the development/testing/use of the atomic bomb, the arrival of the Internet, Y2K, and so forth; and all were successfully (relatively speaking) resolved by the engineers and scientists of their period. An example of how the U.S. EPA chose to address the impacts of toxic air pollution (TAP) concerns of the 1980s is presented in the next paragraph.

Basic air pollutant toxicology, or the science that treats the origins of toxics, must be considered in terms of entering the body through inhalation. This makes the respiratory tract the first site of attack. Among the primary air pollutants, only lead and carbon monoxide exert their major effects beyond the lung. The more reactive a compound, the less likely it is to penetrate the lung. However, many individuals breathe a mixture of air contaminants, and many of the TAP compounds are known to cause cancer. The total nationwide cancer incidence due to outdoor concentrations of air toxics in the United States was estimated to range from approximately 1700 to 2700 excess cancer cases per year. This is roughly equivalent to between 7 and 11 annual cancer cases per million population (data obtained from a 1986 population of 240 million). The U.S. EPA initiated a broad "scoping" study with a goal of gaining a better understanding of the size and causes of the health problems caused by outdoor exposure to air toxics. This broad scoping study was referred to as the Six-Month Study. The objective was to assess the magnitude and nature of the air toxics problem by developing quantitative estimates of the cancer risks posed by selected air pollutants and their sources from a national and regional perspective. The main conclusion of the Six-Month Study was that the air toxics problem is widely thought to be related to the elevated cancer mortality. Table 1.1 provides a summary of the estimated annual cancer cases by pollutant.[8] The EPA classifications used in this report were: A = proven human carcinogen; B = probable human carcinogen (B1 indicates limited evidence from human studies and sufficient evidence from animal studies; B2 indicates sufficient evidence from animal studies, but inadequate evidence from human studies); C = possible human carcinogen.

To the authors knowledge there are no documented nano human health hazards. Statements in the literature refer to *potential* health problems. A typical recent study follows.

Günter Oberdörster, professor of Toxicology in Environmental Medicine at the University of Rochester (UR) and director of the university's EPA Particulate Matter Center, has already completed one study showing that inhaled nanosized

TABLE 1.1 Summary of Estimated Annual Cancer Cases by Pollutant

Pollutant	EPA Classification[a]	Estimated Annual Cancer Cases
1. Acrylonitrile	B	113
2. Arsenic	A	68
3. Asbestos	A	88
4. Benzene	A	181
5. 1,3-Butadiene	B	2266
6. Cadmium	B	110
7. Carbon tetrachloride	B	241
8. Chloroform	B	2115
9. Chromium (hexavalent)	A	147–265
10. Coke oven emissions	A	7
11. Dioxin	B	22–125
12. Ethylene dibromide	B	268
13. Ethyl dichloride	B	245
14. Ethlene oxide	B	1–26
15. Formaldehyde	B	1124
16. Gasoline vapors	B	219–276
17. Hexachlorobutadiene	C	9
18. Hydrazine	B	26
19. Methylene chloride	B	25
20. Perchloroethylene	B	26
21. PIC[b]		438–1120
22. Radionuclides	A	3
23. Radon[c]	A	2
24. Trichloroethylene	B	27
25. Vinyl chloride	A	25
26. Vinylidene chloride	C	10
27. Miscellaneous[d]		15
Totals		1726–2706

[a]For a discussion of how EPA evaluates suspect carcinogens and more information on these classifications, refer to "Guidelines for Carcinogen Risk Assessment" (51 *Federal Register* 33992).
[b]EPA has not developed a classification for the group of pollutants that compose products of incomplete combustion (PICs), although EPA has developed a classification for some components, such as benzo(*a*)pyrene (BaP), which is a B2 pollutant.
[c]From sources emitting significant amounts of radionuclides (and radon) to outdoor air. Does not include exposure to indoor concentrations of radon due to radon from soil gases entering homes through foundations and cellars.
[d]Includes approximately 68 other individual pollutants, primarily from the TSDF study and the Sewage Sludge Incinerator study.

particles accumulate in the nasal cavities, lungs, and brains of rats. Scientists speculate this buildup could lead to harmful inflammation and the risk of brain damage or central nervous system disorders. "I'm not advocating that we stop using nanotechnology, but I do believe we should continue to look for adverse health effects," says

Oberdörster, who also leads the UR Division of Respiratory Biology and Toxicology. "Sixty years ago scientists showed that in primates, nanosized particles traveled along nerves from the nose and settled into the brain. But this has mostly been forgotten. The difference today is that more nanoparticles exist, and the technology is moving forward to find additional uses for them—and yet we do not have answers to important questions of the possible health impact." Oberdörster is leading a 5-year study employing a multidisciplinary team from 10 departments at three universities (UR, University of Minnesota, and University of Washington at St. Louis). They plan to test a hypothesis that the chemical characteristics of nanoparticles determine how they will ultimately interact with human or animal cells. A negative cellular response may indicate impaired function of the central nervous system. In previous studies, Oberdörster showed that nanosized particles depositing in the nose of rats traveled into the olfactory bulb. At this point the team is not entirely opposed to nanotechnology, Oberdörster explains. In fact, researchers hope to work with industry, as well as with the American and Canadian governments, to seek solutions if problems arise. Another goal is to develop an educational program so that future engineers, and scientists will understand the health consequences of nanotechnology. For decades, Oberdörster has studied how the body interacts with ambient ultrafine particles, including automotive and power plant emissions and dust from the World Trade Center disaster. What's different about nanotechnology is that these particles appear to seep all the way into the mitochondria, or energy source, of living cells. "We must consider many different issues before we come to a judgment on risk," he says. "Foremost is an assessment of potential human and environmental exposure by different routes: inhalation, ingestion, dermal. Then, what is their fate in the organism? And what are the risks of cumulative effects, given that these particles are being mass produced? At this point we're trying to balance the tremendous opportunity that nanotechnology presents with any potential harm."

It should be noted that nanoenvironmental concerns are starting to be taken seriously around the globe. There are a variety of studies going on into the health and environmental impacts of many applications of nanotechnology. It is in everyone's interest to ensure that any new compound is fully characterized and the long-term implications studied before it is commercialized. Class action suits in the United States against both tobacco companies and engineering companies, coupled with a new era of corporate responsibility, have ensured that most companies are well aware of this need. Now that potential risks that may have been overlooked are becoming widely known, these companies are more inclined to be proactive than they have been with risks in the past.[7]

Returning to the positive features of this new activity, nanotechnology will be one of the key technologies used in the quest to improve the global environment in the 21st century. While there will be some direct effects, much of the technology's influence on the environment will be through indirect applications of nanotechnology. Although any technology, whether nanotechnology or a box of matches, can always be put to both positive and negative uses, there are many areas in which the positive aspects of nanotechnology look promising. These extend from pollution reduction through environmental remediation to sustainable development.

There has already been a considerable shift in both public and corporate attitudes to the environment. Major scandals such as Enron and WorldCom have led not only to tighter corporate governance but also to calls for greater corporate responsibility. The end result of this shift will be to make companies focus on the environment, and look to leveraging nanotechnology as a way of not only improving efficiency and lowering costs, but doing this by reducing energy consumption and minimizing waste. A typical example would be in the use of nanoparticle catalysts that are not only more efficient, owing to more of the active catalyst being exposed, but also require less precious metal (thus reducing cost), are more tightly bound to the support (increasing the lifetime of the catalyst) and may also increase selectivity, that is, produce more of the desired reaction product, rather than by-products.

Though nanotechnology could have some significant effects on environmental technologies, environmental considerations have not historically been given anywhere near the priority in new developments that commercial considerations are given, and this balance, though swinging gradually more toward environmental considerations, still largely dominates. Many of the direct applications of nanotechnology relate to the removal of some element or compound from the environment, through, for example, the use of nanofiltration, nanoporous sorbents (absorbents and adsorbents), catalysts in cleanup operations, and filtering, separating, and destroying environmental contaminants in processing waste products. Most effects, as with other technologies, are likely to be indirect.

The application of nanotechnology to the environment is already being hailed by some as the "killer application," offering companies a chance to enhance their green credentials without hurting their balance sheets and also creating some huge new markets. Improved efficiency of energy production and supply has both commercial and environmental advantages. One is likely to see the biggest impacts in this area, in savings through lighter composite materials, growth of the use of alternative energy (e.g., through improved economic viability of solar and wind energy generation), and the advent of commercially viable fuel cells in a number of applications. Such technologies certainly have the ability to help considerably in the reduction of global carbon emissions, and other emissions, but probably the most dramatic effects, from the point of view of the daily lives of many individuals in both developed and developing countries, will come with clean water and a reduction in health costs. Further, air in cities around the world could become as unpolluted as the air in the country. Some, including the authors of this work, have concluded that the major environmental nanotechnology breakthroughs will occur naturally through pollution prevention principles.[10]

Pollution prevention in the EPA's definition involves the reduction, to the extent feasible, of generated waste. It includes any source reduction or closed-loop recycling activity undertaken by a generator that results in either: (1) the reduction of the total volume or quantity of waste or (2) the reduction of toxicity of the waste, or both, so long as such reduction is consistent with the goal of minimizing present and future threats to human health and the environment.[11] Source reduction is defined as any activity that reduces or eliminates the generation of waste at the source, usually within a process. A material is "recycled" if it is used, reused, or reclaimed (40 CFR 261.1 [c][7]). A material is "used or reused" if it is either: (1) employed as an ingredient to make a product, including its use as an intermediate (however, a material will not satisfy this condition if distinct components of the material are recovered as separate end products, as when metals are recovered from metal containing secondary materials), or (2) employed in a particular function as an effective substitute for a commercial product (40 CFR 261.1 [c][5]). A material is "reclaimed" if it is processed to recover a useful product or if it is regenerated. Examples include the recovery of lead from spent batteries and the regeneration of spent solvents (40 CFR 261.1 [c][4]). (The reader should note that the working definition of pollution prevention in this text also includes energy conservation and health, safety, and accident management considerations. All these effects are considered in more detail later in this book.) Because of the very nature of nanotechnology, applications will lead to and produce less waste/pollution because this new technology involves exact and/or perfect manufacturing.

There are other areas of environmental advances currently in progress. Areas include:

1. Sensors
2. Treatment
3. Remediation

Some details of these topics are provided below.[12]

Sensors—Novel Sensing Technologies or Devices for Pollutant and Microbial Detection Protection of human health and ecosystems requires rapid, precise sensors capable of detecting pollutants at the molecular level. Major improvement in process control, compliance monitoring, and environmental decision making could be achieved if more accurate, less costly, more sensitive techniques were available. Examples of research in sensors include the development of nanosensors for efficient and rapid in situ biochemical detection of pollutants and specific pathogens in the environment; sensors capable of continuous measurement over large areas, including those connected to nanochips for real-time continuous monitoring; and sensors that utilize lab-on-a-chip technology. Research also may involve sensors that can be used in monitoring or process control to detect or minimize pollutants or their impact on the environment.

Treatment—Technologies to Effectively Treat Environmental Pollutants Cost-effective treatment poses a challenge for the EPA and others in the development of effective risk management strategies. Pollutants that are highly toxic, persistent, and difficult to treat, present particular challenges. EPA supports research that addresses new treatment approaches that are more effective in reducing contaminant levels and more cost effective than currently available techniques. For example, nanotechnology research that results in improved treatment options might include removal of the finest contaminants from water (under 300 nm) and air (under 50 nm) and "smart" materials or reactive surface coatings that destroy or immobilize toxic compounds.

Remediation—Technologies to Effectively Remediate Environmental Pollutants Cost-effective remediation techniques also pose a major challenge for the EPA in the development of adequate remedial techniques that protect the public and safeguard the environment. EPA supports research that addresses new remediation approaches that are more effective in removing contamination in a more cost-effective manner than currently available techniques. Substances of significant concern in remediation of soils, sediment, and groundwater, because of both their cancer and noncancer hazards, include heavy metals (e.g., mercury, lead, cadmium) and organic compounds (e.g., benzene, chlorinated solvents, creosote, toluene). Reducing releases to the air and water, providing safe drinking water, and reducing quantities and exposure to hazardous wastes also are areas of interest.

1.6 CURRENT ENVIRONMENTAL REGULATIONS[5,6,13]

Many environmental concerns are addressed by existing health and safety legislation; most countries require a health and safety assessment for any new chemical before it can be marketed, with the European Union (EU) recently introducing the world's most stringent labeling system. Prior experience with materials such as PCBs and asbestos, and a variety of unintended effects of drugs such as thalidomide, mean that both companies and governments have an incentive to keep a close watch on potential negative health and environmental effects.[12]

It is very difficult to predict future nanoregulations. In the past, regulations have been both a moving target and confusing. What can be said for certain is that there will be regulations, and the probability is high that they will be contradictory and confusing. Past and current regulations provide a measure of what can be expected. And, it is for this reason that this section is included in this book.

Introductory Comments

Environmental regulations are not simply a collection of laws on environmental topics. They are an organized system of statutes, regulations, and guidelines that minimize, prevent, and punish the consequences of damage to the environment. This system requires each individual—whether an engineer, field chemist, attorney, or consumer—to be familiar with its concepts and case-specific interpretations. Environmental regulations deal with the problems of human activities and the environment, and the uncertainties the law associates with them.

With the onset of the Industrial Revolution, environmental law has increased in popularity due to an interest in public health and safety and the environment.

Companies are concerned with exposing themselves to future potentially disastrous liabilities by polluting the environment where their operations are located. Businesses are now taking a proactive approach to environmental compliance. The recent popularity of environmental issues with public and private interest groups has brought about changes in legislation and subsequent advances in technology.

The EPA's authority is increasingly broadening. It is the largest administrative agency in the federal government and accounts for nearly one-seventh of the federal budget. The agency has nearly 20,000 employees and churns out more pages of regulation than any other administrative agency. The EPA's comprehensive environmental programs encompass regulations for air pollution, hazardous waste management, solid waste management, drinking water standards, emergency management, and permitting requirements for discharges to the air, land, or waters of the United States and its territories and districts.

Most major environmental statutes stem from dramatic and highly publicized incidents such as Love Canal, New York, where hazardous substances from an abandoned dump site polluted a nearby community in 1970; Union Carbide Corporation's Bhopal, India, methyl isocyanate release from a chemical plant in 1984; and the *Exxon Valdez* oil spill off the coast of Alaska in 1988. As a result, the focus on environmental issues has been magnified as official government policies on the environment can be the swing vote in an election year.

Legislation, such as the Clean Air Act Amendments of 1990, is requiring members of society to familiarize themselves with its myriad provisions or become lost in the proverbial shuffle. Who would have thought the federal government would be telling citizens not to drive our cars to work, wash cars in one's yard, or to retrofit automobiles with air conditioning units that use a nonchlorofluorocarbon coolant? Even sellers of new homes are required to identify whether there is radon, lead, asbestos, drinking water pollution, or a leaking underground oil storage tank.

This is by far the longest section in the book ... and for good reason. Environmental regulations usually play a key role in any environmental management issue. For this reason, this section attempts to explain some of the major topics in environmental regulation (along with its seemingly never-ending list of acronyms!). With society moving toward almost a state of total litigiousness it may pay, by saving exorbitant attorney fees, to examine in more detail than presented here, those environmental regulations that most affect each individual or organization. As a general rule, based on the authors' experience as environmental professionals, using common sense (unfortunately) in environmental regulation does not always render the appropriate choice. Much of the material to follow as well as the writing style has been drawn from the *Federal Register.*

Air Pollution

The American Cancer Society says it is a matter of life and breath. On November 15, 1990, President George Bush signed into law the Clean Air Act Amendments

(CAAA) of 1990. This section will key on the 1990 amendments. Details regarding the entire amendments are available in 40 Code of Federal Regulations (CFR) 50 through 99. It is the major piece of legislation that today applies to the air. The CAAA build upon the regulatory framework of the earlier Clean Air Act's programs and their amendments and expands their coverage to many more industrial and commercial facilities. The CAAA established a new permit program, substantially tightened requirements for air pollution emission controls, and dramatically increased the potential civil and criminal liability for noncompliance for individuals and companies. A brief overview of the 10 titles of the 1990 CAAA is presented below.

Title I: Provisions for Attainment and Maintenance of National Ambient Air Quality Standards This provision of the CAAAs provides a new strategy for controls of urban air pollution problems of tropospheric ozone, carbon monoxide (CO), and particulate matter (PM-10). (The troposphere extends upward from the surface of Earth to approximately 12 km and is the air one breathes.) The new law mandates that the federal government, which in turn empowers the states, address the problem of urban air pollution by designating geographical locations according to the extent of their contamination of ozone, CO, and NO_X (oxides of nitrogen) as "nonattainment" areas, that is, areas that cannot meet specified air quality standards.

The CAAA require states to revise their State Impementation Plans (SIPs) to include more sources of ozone, both mobile and stationary. For the pollutant ozone, nonattainment areas are further categorized as to the severity of the ozone contamination. Each nonattainment area is classified, as shown in Table 1.2 by the area's "ozone design value," as either extreme, severe, serious, moderate, or marginal.

States with nonattainment areas have to enact various control measures to reduce these emissions, depending on the classification of the areas. An area that is classified as marginal nonattainment will require less control measures than an area classified as extreme to bring it into compliance.

Carbon monoxide nonattainment areas are designated as either "moderate" or "serious." Moderate areas are those that have a CO concentration of 9.1 to 16.4 ppm. Serious areas are those that have CO concentrations of 16.5 ppm or greater. Moderate areas were to meet milestones for CO reductions by 1995 and

TABLE 1.2 Ozone Nonattainment Classifications Specified by the Act

Area Class	Ozone Design Value (ppm)	Number of Metropolitan Areas	Attainment Date
Marginal	0.121–0.138	41	11/15/93
Moderate	0.138–0.160	32	11/15/96
Serious	0.160–0.180	18	11/15/99
Severe	0.180–0.280	8	11/15/2005[a]
Extreme	>0.280	1	11/15/2010

[a]11/15/2007 for Chicago, Houston, and New York.

serious areas had until 2000 to attain the standard. The statute specifically requires controls for CO by enhanced vehicle inspection and maintenance and clean fuels for fleet vehicles, both mobile source controls.

The PM-10 nonattainment areas (PM-10 is particulate matter with an aerodynamic diameter less than or equal to 10 μm) are designated as either "moderate" or "serious." Moderate areas had until 1994, while serious areas had until 2001 to meet the standard. States must develop attainment plans that will require implementation of control measures to attain the standard. Depending upon their classifications, PM-10 areas will have to implement reasonably available control measures (RACMs) or best available control measures (BACMs), among other requirements.

Title I also contains provisions for emissions offset requirements at new and modified sources for ozone, PM-10, and CO. Sources will be required to use the lowest achievable control technology (LEAR). Any resulting increase in emissions must be offset by equivalent or greater emissions reductions elsewhere (P.L. 101–549, 1990; 40 CFR, December 10, 1993).

Title II: Provisions Relating to Mobile Sources Cars and trucks in many nonattainment areas account for over 50 percent of the precursors to ground-level ozone (different from stratospheric ozone), volatile organic carbons (VOCs), NO_X, and over 90 percent of CO emissions. It has been speculated that this was brought about by an unexpected growth in motor vehicle emissions. A summary of the major requirements is presented below.

The CAAAs establish emissions standards applicable to heavy- and light-duty trucks and conventional motor vehicles. These standards will help reduce tailpipe emissions of hydrocarbons, CO, NO_X, and PM-10. The EPA will also regulate evaporative emissions from all gasoline-fueled vehicles both during operation and during periods of nonuse. CO emissions from light-duty vehicles may not exceed 10.0 g per mile when operated at 20°F.

Title II also contains provisions to establish rules for reformulated gasoline in specific nonattainment areas. Methyl tertiary butyl ether (MTBE) is used in some cities. The clean fuel fleet program requires that states revise their SIPs to include a clean fuel program for fleets. The program impacts anyone owning a fleet that is capable of being centrally fueled. Fleet owners and operators who purchase additional new vehicles had to do so according to the earlier schedule in Table 1.3.

Each of these provisions is aimed at decreasing pollution in nonattainment areas that are in excess of the guideline values. The degree of control placed on industrial sources of CO, VOCs, and NO_X will depend on reductions of these pollutants achieved through Title II programs (P.L. 101–549, 1990).

Title III: Air Toxics In its prime, the federal air toxics program, known as the National Emissions Standards for Hazardous Air Pollutants (NESHAP), only encompassed seven toxic air pollutants. Prior to the CAAAs, NESHAP regulated emissions for arsenic, asbestos, beryllium, mercury, radionuclides, benzene, and vinyl chloride. Title III was revamped to give the EPA the authority to establish

TABLE 1.3 Clean Fuel Fleet Program: Clean Fuel Vehicle Phase-in

Model Year	Light-Duty Vehicles	Heavy-Duty Vehicles
1988	30%	50%
1999	50%	50%
2000	70%	50%

an elaborate program to regulate emissions of air toxics from sources that emit hazardous air pollutants (HAPs).

The EPA has identified, via an industry-specific list, major sources of HAPs. These industries are categorized by the amount of pollutants they emit. A "major source" is defined as a source that emits 10 tons or more per year of any one of the list of 189 HAPs, or 25 tons per year or more of any combination of HAPs. The regulations also empower the federal government and states to regulate sources that emit less than the aforementioned levels if they are found to pose a "threat of adverse effects to health and the environment." Dry cleaners using perchloroethylene as a cleaning solvent would fall under this category.

The EPA requires each of these affected sources to comply with maximum achievable control technology (MACT) standards. These technology-based emissions standards are enacted to consider not only emissions control technology that removes pollutants at the point of discharge but also "measures, processes, methods, systems or techniques which:"

1. Reduce or eliminate emissions through process changes, materials substitution, or other changes
2. Enclose processes to monitor emissions
3. Are design, equipment, work practice, or operational standards, including operator training and certification

Title III also establishes a new and comprehensive accidental release program modeled in part after New Jersey's Toxic Catastrophic Prevention Act. The Process Safety Management Regulation and the Accidental Release and Emergency Preparedness Regulation, respectively, are regulations required to be promulgated by the EPA and the Occupational Safety and Health Administration (OSHA) under Title III. These new regulations provide for accidental release prevention and define consequences within and external to a facility that has in excess of a threshold quantity of 100 substances that are known to cause, or may be reasonably anticipated to cause, death, injury, or serious adverse health effects to human health and the environment (P.L. 101–549, 1990; 40 CFR, October 20, 1993).

Title IV: Acid Deposition Control Title IV mandates controls to reduce the deposition of acidic sulfates and nitrates by reducing emissions of sulfur dioxide (SO_2) and nitrogen oxides (NO_X), which are precursors of acid rain. Sulfur emissions are attributed largely to coal burning at electric utilities that contain sulfur as an impurity.

Congress set a two-phased goal for utility emissions reduction. The first phase requires 110 fossil-fuel-fired public power plants to reduce their emissions to a level equivalent to the product of an emissions rate of 2.5 lb of SO_2/MMBtu times the average of their 1985 to 1987 fuel usage. The second phase requires approximately 2000 utilities to reduce their emissions to a level equivalent to the product of an emissions rate of 1.2 lb of SO_2/MMBtu times the average of their 1985 to 1987 fuel use.

Title IV also mandates a program in which allowances are created as market shares, which utilities are allowed to buy and sell in order to meet reductions of emissions. These shares currently have a value of approximately $2000. The regulation also contains requirements for reduction of NO_X from tangentially fired boilers and dry bottom wall-fired boilers by 1995 and all other utility boilers by 1997.

Affected sources will be required to perform continuous emissions monitoring, permit their sources, and keep records of their activities. Continuous emissions monitoring devices must be installed on all affected sources. The permit application must include a compliance plan for the source to comply with the requirements of Title IV. Affected sources are also required to pay an annual fee of $2000 per ton for emissions in excess of allowance levels (P.L. 101–549. 1990).

Title V: Permits Under Title V, the EPA has attempted to model the permit requirements from the Clean Water Act (CWA). (See a later section on Water Pollution for additional details on the CWA.) The CWA permitting system is known as the National Pollution Discharge Elimination System (NPDES). The permitting program is enacted to ensure compliance with various portions of the program. States were required to submit a proposed program to the EPA by November 1993 for issuing permits to certain significant sources of air emissions.

The Title V operating permit program requires all affected sources under the CAAAs to submit a permit application to the appropriate permitting authority within one year of the effective date of the state program. The operating permit program applies to the following major sources:

1. Air toxic sources as defined under Title III, with the potential to emit 10 tons per year (tpy) or more of a single HAP or 25 tpy or more of the aggregate of HAPs or a lesser quantity if the administrator so specifies.
2. Sources emitting more than 100, 50, 25, or 10 tons per year depending on their nonattainment designation; that is, marginal, moderate, severe, or extreme.
3. Sources of air pollutants with the potential to emit 100 tpy or more of any pollutant.
4. Any other source, including an area source, subject to a hazardous air pollutant standard under Title III.
5. Any affected source under the acid rain program under Title IV.

6. Any source required to have a preconstruction permit pursuant to the requirements of the prevention of significant deterioration (PSD) program under Title I, or the nonattainment new source review (NSR) program under Title I.
7. Any other stationary source in a category the EPA designates in whole or in part by regulation after notice and comment.

Once subject to the operating permit program for one pollutant, a major source must submit a permit application including all emissions of all regulated pollutants from all emissions units located at the plant, except that only a generalized list needs to be included for insignificant events or emissions levels. The program applies to all geographic areas within each state, regardless of their attainment status (P.L. 101–549, 1990).

Title VI: Stratospheric Ozone and Global Climate Protection Title VI requires the EPA to promulgate controls pertaining to the protection of stratospheric ozone. In response to growing evidence that chlorine and bromine could destroy stratospheric ozone on a global basis, many members of the international community concluded that an international agreement to reduce the global production of ozone-depleting substances was needed. Because releases of chlorofluorocarbons (CFCs) from all areas mix in the atmosphere to affect stratospheric ozone globally, efforts to reduce emissions from specific products by only a few nations could quickly be offset by increases in emissions from other nations, leaving the risk to the ozone layer unchanged. In September 1987 the United States and 22 other countries signed the Montreal Protocol on Substances that Deplete the Ozone Layer. The Montreal Protocol called for a freeze in the production and consumption of certain CFCs. The Montreal Protocol was the main thrust for Title VI, although in response to recent scientific evidence indicating a hole in the ozone layer, the EPA has adopted a phase-out schedule more aggressive than the protocol.

The CAAAs established a phase-out schedule as fast as, and in some instances faster than, the 1990 Amendments to the Montreal Protocol. Specifically this Title required the United States to phase out production and consumption of class I substances, that is, CFCs, Halons, carbon tetrachloride, and methyl chloroform by 1996, 1994, 1996, and 1996, respectively. In addition, the CAAAs require a freeze in the production of class II chemicals—hydrochlorofluorocarbons (HCFCs)—by the year 2015, and a phaseout by 2030. The phaseout includes exemptions for certain uses that the administrator of the EPA deems essential, such as CFC as a propellant in metered-dose inhalers (an asthma prescription pharmaceutical). As of January 1, 1994, methyl bromide and hydrobromofluorocarbons (HBFCs) were added to the list of class I chemicals. Recently the EPA has accelerated the phase out of HCFC-22, HCFC-141b, and HCFC-142b, three relatively heavily weighted ozone depleters. Production and consumption will be frozen in 2010 with a complete phaseout by 2020.

The Safe New Alternatives Program (SNAP) evaluates the overall effects on human health and the environment of the potential substitutes for ozone-depleting substances. SNAP will render it unlawful to replace an ozone-depleting substance with a substitute chemical or technology that may present adverse effects to human health and the environment if the Administrator determines that some other alternative is commercially available and that this alternative poses a lower overall threat to human health and the environment. The SNAP program is a powerful tool to assure that safe alternatives are developed.

The refrigerant recycling regulations promulgated May 14, 1993, require recycling, emissions reduction, and disposal for ozone-depleting refrigerants. The regulations require technicians servicing and disposing of air-conditioning and refrigeration equipment to observe certain service practices, to be certified by an EPA-approved organization for technicians servicing equipment. They also establish reclaimer certification programs.

Other Title VI provisions require the EPA to promulgate additional controls pertaining to the protection of stratospheric ozone for banning nonessential products, such as party streamers and noise horns, and mandating warning labels for products manufactured with containers of, and products containing, specific ozone-depleting substances (P.L. 101–549, 1990; 40 CFR, December 10, 1993 and February 11, 1993; "Complying with the Refrigerant Recycling Rule," June 1993).

Title VII: Provisions Relating to Enforcement The 1990 provisions bring with them penalties unlike other environmental laws. Congress has taken several measures in order to make air quality violations felonies or crimes, punishable by jail sentences, where previously they were misdemeanors that were punishable by fines. Under the CAAAs there are now four classes of criminal offenses: negligent; knowing; knowing endangerment; falsification, failure to make required reports, and tampering with monitors. Each of these offences is detailed below.

1. Negligent: Anyone who negligently releases any of the 189 hazardous air pollutants designated under section 112, as well as the 360 or so extremely hazardous substances listed under 40 CFR Part 350 into the ambient air is subject to criminal prosecution. In order to be a criminal offense, the negligent release must place another person in imminent danger of death or serious bodily injury. Violators may be imprisoned for up to one year.

2. Knowing Violations: Any knowing violations of a state implementation plan, a nonattainment provision, an air toxics law, and a standard associated with the permits, acid rain, or stratospheric ozone titles has been upgraded to a felony. These violations are now punishable by a fine and 5 years imprisonment. The CAAAs also increase the maximum fine associated with criminal knowing violations to $250,000 for individuals and $500,000 for organizations. It is also a criminal offense to knowingly fail to pay any fee owed to the United States under Titles I to VI. Violators may be imprisoned for up to one year and fined.

3. Knowing Endangerment: Anyone who knowingly releases any of the 189 hazardous air pollutants designated under section 112, as well as the 360 or so extremely hazardous substances listed under 40 CFR Part 350 is subject to criminal

prosecution. In order to be a criminal offense, the knowing release must place another person in imminent danger of death or serious bodily injury. This is a felony offense punishable by a fine and/or 15 years in prison. The statute authorizes a $1 million maximum fine for organizations and companies.

4. Falsifications, Failures to Report, and Tampering: Knowing actions to falsify reports, failure to keep necessary monitoring records, and material omissions from such reports and records as well as failures to report or notify as required by the CAAAs or failure to properly install the monitoring equipment are criminal violations. The CAAAs also increase the maximum fine associated with criminal knowing violations to $250,000 for individuals and $500,000 for organizations.

Citizens will be allowed to sue violators for penalties that will go to the U.S. Treasury fund for the EPA in compliance and enforcement activities. Administrative enforcement now includes provisions for issuance of field citations for violations observed in the field (this is like receiving a speeding ticket). These citations may not exceed $5000 for each day that the violation continues. Administrative penalties are capped at $200,000. The CAAAs authorize the EPA to issue administrative compliance orders with compliance schedules of up to one year. The EPA may act in emergency situations to protect public health and the environment. Companies can pay fines of up to $25,000 per day for failure to comply with an emergency order. Knowing violations of an emergency order are punishable by a fine and 5 years in prison.

The act also includes other titles that are not included here. It is suggested that the interested reader contact his or her specific EPA region for information and literature, call the stratospheric ozone hot line for specific questions, or refer directly to the CAAA (P.L. 101–549, 1990).

Hazardous and Solid Waste

Resource Conservation and Recovery Act Defining what constitutes "solid waste" and "hazardous waste" requires consideration of both legal and scientific factors. The basic definition is derived from the Resource Conservation and Recovery Act (RCRA) of 1976 and the subsequent Hazardous and Solid Waste Amendments (HSWA) of 1984. Hazardous substances are regulated under the Comprehensive Environmental Response Compensation and Liability Act (CERCLA) of 1980 and the subsequent Superfund Amendments and Reauthorization Act (SARA) of 1986. These two governing bodies regulate management of currently generated hazardous waste and remediation of hazardous waste sites, respectively.

The first comprehensive federal effort to deal with the solid waste problem in general, and hazardous waste specifically, came with the passage of RCRA. The act provides for the development of federal and state programs for otherwise unregulated disposal of waste materials and for the development of resource recovery programs. It regulates anyone engaged in the creation, transportation, treatment, and disposal of "hazardous wastes." It also regulates facilities for the disposal of all solid waste and prohibits the use of open (essentially uncontrolled) dumps for solid wastes in favor of sanitary (essentially controlled) landfills.

The hazardous waste management program identifies specific hazardous wastes either by listing them or identifying characteristics that render them hazardous. Under RCRA, a solid waste that is not excluded as a hazardous waste is a hazardous waste if it exhibits any of the characteristics of reactivity, corrosivity, ignitability, or toxicity under 40 Code of Federal Regulations (CFR) 261.21–261.24, or it is listed hazardous waste under 40 CFR Parts 261.31–261.33. The EPA has established three lists:

1. "K" Listed Wastes—These hazardous wastes are from specific sources, that is, those wastes generated in a specific process that is specific to an industry group. Examples include wastewater treatment sludge from the production of chrome yellow and orange pigments and still bottoms from the distillation of benzyl chloride.
2. "F" Listed Wastes—These hazardous wastes are from nonspecific sources, that is, those wastes that are generated by a nonspecific industry that are generated from a standard operation that is part of a particular manufacturing process. Examples include spent solvent mixtures and blends used in degreasing containing, before use, a total of 10 percent or more (by volume) of various solvents.
3. "P" and "U" Listed Wastes—The third list has been broken into two distinct subsets. The "U" list contains chemicals that are deemed toxic and the "P" list contains chemicals that are deemed acutely hazardous. These hazardous wastes are discarded commercial chemical products, off-specification products, container residues, and spill residues. Examples include beryllium, fluorine, and methyl isocyanate.

As mentioned above, those wastes that are not listed in either the F, K, P, U lists may still be a hazardous waste if they exhibit one or more of the four following characteristics: reactivity, ignitability, corrosivity, or toxicity. These are listed below.

1. Reactivity—The waste will react violently with or release toxic gases or fumes when mixed with water, or is susceptible to explosions or detonations
2. Ignitability—A solid liquid or gas that is easily ignitable
3. Corrosivity—Alkaline or acidic material normally having a pH in the range of less than 2 and greater than 12.5
4. Toxicity—Wastes that have the ability to bioaccumulate in various aquatic species

Facilities generating these wastes are required to notify the EPA of such activity, as well as comply with the standards authorized by RCRA under Subtitle C. Facilities that generate hazardous waste are classified as either large-quantity generators, small-quantity generators, or conditionally exempt small-quantity generators. Large-quantity generators receive this classification if they generate more than 1000 kg in a calendar month. Small-quantity generators receive this classification if they generate less than 1000 kg but more than 100 kg in any calendar month. Both large- and small-quantity generators are subject to all EPA hazardous waste regulations, except small-quantity generators are not required to have formal training programs for employees; an RCRA contingency plan and accumulation time is determined differently. Conditionally exempt small-quantity generators, generating no more than 100 kg of hazardous waste in a calendar month, are not subject to EPA regulations, except that all waste(s) generated must be disposed of at a site approved by state or federal authority.

Generators are allowed to accumulate waste on site in two related circumstances. First, the generator is allowed to accumulate up to 55 gallons of a hazardous waste in a satellite accumulation area, provided the waste container is properly marked and compatible with the waste, and is removed to a storage area within three days of reaching the 55-gal limit. Second, generators may store waste on site for 90 days or less in storage areas and containers that adhere to strict requirements. Small-quantity generators may store waste on site for up to 180 days (270 days if the waste must be transferred 200 miles or more). Conditionally exempt small-quantity generators are conditionally exempt under RCRA but must still meet certain minimum requirements (40 CFR, Part 261, July 1, 1992).

Comprehensive Environmental Response, Compensation, and Liability Act Congress enacted the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA) commonly known as "Superfund." Superfund establishes two related funds to be used for the immediate removal of hazardous substances released into the environment. Superfund is intended to establish a mechanism of response for the immediate cleanup of hazardous waste contamination from accidental spills and from chronic environmental damage such as associated with abandoned hazardous waste disposal sites. CERCLA works in concert with RCRA to provide full coverage of present and past hazardous waste activities.

A hazardous substance under CERCLA is any substance the EPA has designated for special consideration under the CAA, CWA, Toxic Substance Control Act (TSCA), as well as any hazardous waste under RCRA. Furthermore, the EPA must designate additional substances as hazardous that may present substantial danger to health and the environment. A list of these hazardous substances is found in 40 CFR Part 302.

Under CERCLA, the EPA is empowered to undertake removal and/or remedial action where the pollutant may present an imminent and substantial danger. Potentially responsible parties (PRPs) are those private parties that are encouraged by the EPA to clean up sites on the National Priorities List (NPL). Only NPL sites are eligible for fund-financed remedial action. Sites make the list by undergoing evaluation and scoring under the hazard ranking system (HRS), which estimates the degree of risk each suspected site poses to human health and the environment. Factors such as waste volume, toxicity, and potential pathways are evaluated and combined to form a single numbered HRS score. If this HRS score is over 28.5 the site will be included on the NPL.

Spill reporting under CERCLA covers releases to all environmental media: air, surface water, groundwater, and soil. The EPA assigns reportable quantities, that is, the exceeding of the assigned value of a hazardous substance released within any 24-h period for which the CERCLA reporting requirements are triggered, to all hazardous substances. Immediately after a person in charge of the facility has knowledge of a release in excess of a reportable quantity, that person must immediately contact the National Response Center (NRC) to relay telephone information on the details of the release. Written follow-up information is required for establishing the details of cleanup mitigation efforts.

In response in part to the Bhopal, India, tragedy, the Emergency Planning and Community Right to Know Act (EPCRA) was enacted under the Superfund Amendments and Reauthorization Act of 1986. Under EPCRA, state and local governments are required to develop emergency response plans for unanticipated releases of a number of acutely toxic materials known as extremely hazardous substances. EPCRA mandates the formation of State Emergency Response Commissions (SERC) and Local Emergency Planning Committees (LEPC), which are in charge of developing and implementing emergency response plans.

The EPCRA also establishes reporting provisions for informing the public of hazardous substances being used, as indicated below.

1. Material Safety Data Sheets (MSDS) Reporting—Facilities for which hazardous chemicals are present in excess of a threshold quantity are required to submit MSDSs to the SERC, LEPC, and local fire departments.
2. Tier I or Tier II Reporting—Facilities for which hazardous substances are present are required to provide information on the annual and daily inventory information on the quantities of those materials and their locations on site. Tier I reports provide the required information on hazardous chemicals grouped by hazard category and Tier II reports provide the information on individual hazardous chemicals. Tier II may be submitted in lieu of Tier I reports.
3. Toxic Release Inventory (TRI)—Facilities that manufacture, process, or otherwise use a toxic chemical in excess of a threshold quantity are required to provide annual reports on the quantities released (40 CFR, Parts 300–372, July 1, 1992).

Solid Waste Under RCRA, 40 CFR 261.4(a), a solid waste is defined as any material that is discarded, abandoned, recycled, or inherently wastelike. To gain further insight into the meaning of solid waste, the RCRA Section 1004(27) definition is:

> A solid waste is defined as any garbage, refuse, sludge from a waste treatment plant, water supply treatment plant, or air pollution control facility and other discarded material, including solid, liquid, semisolid, or contained gaseous material resulting

from industrial, commercial, mining, and agricultural operations and community activities, but does not include solid or dissolved material in domestic sewage (P.L. 80–272, 1965).

A material can be considered a solid waste if it is recycled in a manner constituting disposal. This type of recycling includes materials used to produce products that are applied to the land, burned for energy recovery, or accumulated speculatively before recycling. A material that fits the definition of a solid waste may be regulated as a hazardous waste if it poses a threat to human health or the environment. The definitions of solid waste and hazardous waste interlock, which results in EPA regulating a plethora of materials that may not be commonly thought of as wastes for certain industries.

The following materials are excluded from the definition of solid waste:

1. Domestic sewage
2. Industrial wastewater discharges that are point-source discharges subject to regulation under section 402 of the Clean Water Act (This exclusion applies only to point-source discharges. It does not exclude industrial wastewaters while they are being collected, stored, or treated before discharge, nor does it exclude sludges that are generated by industrial wastewater treatment.)
3. Irrigation return flows
4. Source, special nuclear, or by-product material as defined by the Atomic Energy Act
5. Materials subjected to in situ mining techniques that are not removed from the ground as part of the extraction process
6. Pulping liquors (i.e., black liquor) that are reclaimed in a pulping liquor recovery furnace and then reused in the pulping process, unless it is accumulated speculatively
7. Spent sulfuric acid used to produce virgin sulfuric acid, unless it is accumulated speculatively
8. Secondary materials that are reclaimed and returned to the original process or processes in which they were generated where they are reused in the production process provided (This exemption has limitations stipulating closed processes, reclamation not involving controlled flame combustion, accumulation, use as fuel, and not used in a manner constituting disposal.)

Obviously, solid waste is far less regulated, which, when translated by hazardous waste generators, means a savings on disposal costs. Certain materials are not regulated as a solid waste when recycled. These include materials shown to be recycled by being:

1. Used or reused as ingredients in an industrial process to make a product, provided the materials are not being reclaimed
2. Used or reused as effective substitutes for commercial products

3. Returned to the original process from which they are being generated, without first being reclaimed. The material must be returned as a substance for raw material feedstock, and the process must use raw materials as principal feedstock.

Certain materials may still be considered solid wastes, that is, RCRA-regulated, even if the recycling involves use, reuse, or return to the original process. This includes:

1. Materials used in a manner constituting disposal, or used to produce products that are applied to the land; or materials burned for energy recovery, used to produce a fuel, or contained in fuels
2. Materials accumulated speculatively
3. Hazardous waste numbers F020, F021 (unless used as an ingredient to make a product at the site of generation), F022, F023, F026, and F028.

It is important to examine the manner of recycling and the material being recycled in determining whether the waste is considered a solid waste.

Once a material is found to be a solid waste, the next question is whether it is a hazardous waste. The EPA automatically exempts certain solid waste from being hazardous waste. A few examples are household waste, including household waste that has been collected, transported, stored, treated, disposed, recovered (e.g., refuse-derived fuel), or reused; solid waste generated in the growing and harvesting of agricultural crops that is returned to the soil as fertilizer; fly ash waste; bottom ash waste, slag waste; flue gas emissions control waste generated primarily from the combustion of fossil fuels; and cement kiln dust. (Cement kiln dust is under attack by private interest groups to be regulated as a hazardous waste.)

The EPA may also grant a variance from classification as a solid waste on a case-by-case basis. Eligible materials include those that are reclaimed and then reused within the original primary production process in which they were generated, reclaimed partially, but require further processing by being completely recovered, and accumulating speculatively with less than 75 percent of the volume having the potential for recycling (40 CFR, Part 261, July 1, 1992).

Water Pollution Control

Congress put the framework together for water pollution control by enacting the Federal Water Pollution Control Act (FWPCA), the Marine Protection, Research and Sanctuaries Act (MPRSA), the Safe Drinking Water Act (SDWA), and the Oil Pollution Control Act (OPA). Each statute provides a variety of tools that can be used to meet the challenges and complexities of reducing water pollution in the nation. These are discussed below.

Federal Water Pollution Control Act In 1977, Congress renamed the FWPCA the Clean Water Act (CWA) and substantially revamped and revised the control of toxic water pollutants. The CWA has two basic components: a statement of goals and objectives and a system of regulatory mechanisms calculated to achieve these goals and mechanisms. The objective of the program as outlined in section 101 of the CWA is to “restore and maintain the chemical, physical and biological integrity of the nation’s waters.” To achieve this, the CWA provides water quality for protection of fish, shellfish, and wildlife for recreational use and eliminates the discharge of pollutants into the waters of the United States.

The system of achieving these goals and objectives has six basic elements:

1. A two-stage system of technology-based effluent limits establishing base level or minimum treatment required to prevent industries and publicly owned treatment works (POTW) from discharging pollutants.
2. A program for imposing more stringent limits in permits where such limits are necessary to achieve water quality standards or objectives.
3. A permit program known as the National Pollution Discharge Elimination Program (NPDES). The NPDES permit requires the dischargers to disclose the volume and nature of their dischargers as well as monitor and report the results to the authorizing agency. The NPDES permit program authorizes the EPA and citizens enforcement in the case of noncompliance.
4. A set of specific deadlines for compliance or noncompliance with the limitations, with attached enforcement provisions for the EPA and citizens.
5. A set of provisions applicable to certain toxic and other pollutant discharges of particular concern, e.g., stormwater and oil spills.
6. A loan program to help fund POTW attainment of the applicable requirements.

Effluent limitations have been established for various categories of point sources that include but are not limited to the chemical, pharmaceutical, paper manufacturing, and pesticide manufacturing industries. The CWA is far more than the six-part framework indicates. The reader is referred to 40 CFR Subchapter N, “Effluent Guidelines and Standards” for more information on how a specific industry is regulated (40 CFR, Part 401, July 1, 1992).

Safe Drinking Water Act The Safe Drinking Water Act (SDWA) was originally passed in 1974 to ensure that public water supplies are maintained at high quality by setting national standards for levels of contaminants in drinking water, by regulating underground injection-wells, and by protecting sole source aquifers.

The SDWA requires the EPA to establish maximum contamination level goals (MCLGs) and national primary drinking water regulations (NPDWR) for contaminants that, in the judgment of the EPA Administrator, may cause any adverse effect on the health of persons and that are known or anticipated to occur in public water systems. The NPDWRs are to include maximum contamination levels (MCLs) and “criteria and procedures to assure a supply of drinking water that dependably complies” with such MCLs. If it is not feasible to ascertain the level of a contaminant in drinking water, the NPDWRs may require the use of a treatment technique instead of an MCL. The EPA is mandated to establish MCLGs and promulgate NPDWRs for 83 contaminants in public water systems. (The SDWA was amended in 1986 by establishing a list of 83 contaminants for which EPA is to develop MCLGs and NPDWRs). MCLGs and MCLs were to be promulgated simultaneously.

The MCLGs do not constitute regulatory requirements that impose any obligation on public water systems. Rather, MCLGs are health goals that are based solely upon consideration of protecting the public from adverse health effects of drinking water contamination. The MCLGs reflect the aspirational health goals of the SDWA that the enforceable requirements of NPDWRs seek to attain. MCLGs are to be set at a level where "no known or anticipated adverse effects on the health of persons occur and which allows an adequate margin of safety."

The House Report on the bill that eventually became the SDWA of 1974 provides congressional guidance on developing MCLGs:

> [T]he recommended maximum contamination level [renamed maximum contamination level goal in the 1986 amendments to the SDWA] must be set to prevent the occurrence of any known or anticipated adverse effect. It must include an adequate margin of safety, unless there is no safe threshold for a contaminant. In such a case, the recommended maximum contamination level would be set at the zero level (40 CFR, Parts 141 and 142, June 7, 1991).

The NPDWRs include either MCLs or treatment technique requirements as well as compliance monitoring requirements. The MCL for a contaminant must be set as close to the MCLG as feasible. Feasible means "feasible with the use of the treatment techniques and other means which the Administrator of the EPA finds, after examination for efficacy under field conditions and not solely under laboratory conditions, are available (taking cost into consideration)." A treatment technique must "prevent known or anticipated adverse effects on the health of a person to the extent feasible." A treatment technique requirement can be set only if the EPA administrator makes a finding that "it is not economically or technically feasible to ascertain the level of the contaminant." Also the SDWA requires the EPA to identify the best available technology (BAT) for meeting the MCL for each contaminant.

The EPA sets national secondary drinking water regulations (NSDWRs) to control water color, odor, appearance, and other characteristics affecting consumer acceptance of water. The secondary regulations are not federally enforceable but are considered guidelines for the states (40 CFR, Parts 141 and 142, June 7, 1991).

Oil Pollution Control Act The Oil Pollution Control Act (OPA) of 1990 was enacted to expand prevention and preparedness activities, improve response capabilities, ensure that shippers and oil companies pay the costs of spills that do occur, and establish and expand research and development programs. This was all in response to the *Exxon Valdez* oil spill in Prince William Sound in 1989.

The OPA establishes a new Oil Spill Liability Trust Fund, administered by the U.S. Coast Guard. This fund replaces the fund established under the CWA and other oil pollution funds. The new act mandates prompt and adequate compensation for those harmed by oil spills and an effective and consistent system of assigning liability. The act also strengthens requirements for the proper handling, storage, and transportation of oil and for the full and prompt response in the event discharges occur. The act does so in part by amending section 311 of the CWA.

There are eight titles codified under the act, details of which are available in the literature (40 CFR, Part 112, July 1, 1992; 40 CFR, February 17, 1993).

Occupational Safety and Health Act

The Occupational Safety and Health Act (OSH Act) was enacted by Congress in 1970 and established the Occupational Safety and Health Administration (OSHA), which addressed safety in the workplace; at the same time, EPA was created. Both EPA and OSHA are mandated to reduce the exposure of hazardous substances over land, sea, and air. The OSH Act is limited to conditions that exist in the workplace, where its jurisdiction covers both safety and health. Frequently, both agencies regulate the same substances but in a different manner. In effect, they are overlapping environmental organizations.

Congress intended that OSHA be enforced through specific standards. Employers would follow these standards in an effort to achieve a safe and healthful working environment. A “general duty clause” was added to attempt to cover those obvious situations that were admitted by all concerned but for which no specific standard existed. The OSHA standards are an extensive compilation of regulations, some that apply to all employers—such as eye and face protection—and some that apply to workers who are engaged in a specific type of work, such as welding or crane operation. Employers are obligated to familiarize themselves with the standards and comply with them at all times.

Health issues, most importantly, contaminants in the workplace, have become OSHA’s primary concern. Health hazards are complex and difficult to define. Because of this, OSHA has been slow to implement health standards. To be complete, each standard requires medical surveillance, record keeping, monitoring, and physical reviews. On the other side of the ledger, safety hazards are aspects of the work environment that are expected to cause death or serious physical harm immediately or before the imminence of such danger can be eliminated.

Probably one of the most important safety and health standards ever adopted is the OSHA hazard communication standard, more popularly known as the “right-to-know” laws. The hazard communication standard requires employers to communicate information to the employee on hazardous chemicals that exist within the workplace. The program requires employers to craft a written hazard communication program, keep material safety data sheets (MSDSs) for all hazardous chemicals at the workplace and provide employees with training on those hazardous chemicals, and assure that proper warning labels are in place.

The Hazardous Waste Operations and Emergency Response Regulation enacted in 1989 by OSHA addresses the safety and health of employees involved in cleanup operations at uncontrolled hazardous waste sites being cleaned up under government mandate, and in certain hazardous waste treatment, storage, and disposal operations conducted under RCRA. The standard provides for employee protection during initial site characterization and analysis, monitoring activities, training, and emergency response.

Four major areas are under the scope of the regulation:

1. Cleanup operations at uncontrolled hazardous waste sites that have been identified for cleanup by a government health or environmental agency
2. Routine operations at hazardous waste TSD (Transportation, Storage, and Disposal) facilities or those portions of any facility regulated by 40 CFR Parts 264 and 265
3. Emergency response operations at sites where hazardous substances have or may be released
4. Corrective actions at RCRA sites

The regulation addresses three specific populations of workers at the above operations. First, it regulates hazardous substance response operations under CERCLA, including initial investigations at CERCLA sites before the presence or absence of hazardous substance has been ascertained; corrective actions taken in cleanup operations under RCRA; and those hazardous waste operations at sites that have been designated for cleanup by state or local government authorities. The second worker population to be covered is those employees engaged in operations involving hazardous waste TSD facilities. The third employee population to be covered is those employees engaged in emergency response operations for releases or substantial threat of releases of hazardous substances, and postemergency response operations to such facilities (29 CFR, March 6, 1989; 29 CFR, February 24, 1992).

Toxic Substance Control Act

The Toxic Substance Control Act (TSCA) of 1976 provides EPA with the authority to control the risks of thousands of chemical substances, both new and old, that are not regulated as drugs, food additives, cosmetics, or pesticides. TSCA essentially mandates testing of chemical substances to regulate their uses in industrial, commercial, and consumer products. TSCA fills in the gaps and supplements other laws regulating toxic substances, such as the Clean Air Act, the Occupational Safety and Health Act, and the Federal Water Pollution Control Act. TSCA allows EPA to tailor its regulation to specific sources of risk.

The TSCA essentially contains two sections: requirements for information on the substance to identify risks to health and the environment from chemical substances [a premanufacturing notification (PMN)]; and regulations on the production and distribution of new chemicals and regulations on the manufacturing, processing, distribution, and use of existing chemicals (recordkeeping and reporting requirements).

TSCA Inventory No person may manufacture a new chemical substance, or manufacture or process an existing chemical substance for a significant new use, without EPA approval. (Note: This will apply to nanochemicals and products.) There are two kinds of chemical substances—"new chemical substances" and "existing chemical substances." A chemical substance that is not on the TSCA inventory (an inventory of existing chemical substances) is a "new chemical substance." Notification is required before a chemical substance can be put to a significant new use.

The TSCA inventory was initially compiled in 1977 but is updated by EPA to include new chemical substances for which manufacturers have filed Notices of Commencement. Every 4 years, beginning in 1986, manufacturers (and importers) of certain chemicals must submit updated information including chemical identity, plant site, whether the substance is manufactured or imported, whether the substance is distributed offsite for commercial purposes, and production volume on their TSCA-regulated chemicals. Manufacturers of polymers, microorganisms, naturally occurring substances, and inorganics are exempt from inventory updating. Any company that manufactures (or imports) more than 10,000 lb of any chemical substances (except those excluded) in the latest complete fiscal year preceding a reporting period must submit updated information.

Premanufacturing Notification Any company that wishes to manufacture (or import) a chemical substance must first determine whether the chemical substance is on the TSCA inventory. If it is not on the inventory, a manufacturer must file a PMN with the EPA. The PMN must be filed 90 days prior to manufacture of the chemical substance. If a PMN is not necessary, EPA will notify the submitter that submissions are not necessary. Companies may request a 90-day extension if EPA determines there is good cause to extend the notice.

If the EPA takes no action by the end of the review period, the submitter may begin to manufacture. Within 30 days after the first day of manufacturing, the manufacturer must submit a Notice of Commencement (NOC). The NOC essentially places the chemical substance on the TSCA inventory. Companies are exempt from the PMN reporting requirements for the following reasons: The chemical is not a "chemical substance," e.g., a nuclear material, tobacco, foods, and drugs; any chemical substance that is manufactured or imported in small quantities solely for research and development, provided certain conditions are met; any chemical substances that will be manufactured or imported solely for test-marketing purposes under an exemption granted pursuant to 40 CFR 720.38; any new chemical substance manufactured solely for export provided certain requirements are met; any new chemical substance that is manufactured or imported under the terms of a rule promulgated under section 5(h) (4) of TSCA, e.g., certain chemicals used for instant photographic and peel-apart film articles; any by-product if its only commercial purpose is for use by a public or private organization that burns it as fuel, disposes of it as waste, or extracts chemical substances from it for commercial purposes; certain chemical substances described in 40 CFR 720(h), e.g., any impurity or by-product, provided it is not used or manufactured for commercial purposes; and any chemical substance that is manufactured solely for noncommercial research and development purposes.

Recordkeeping and Reporting Requirements Section 8 of TSCA contains a variety of reporting requirements to fulfill the statute's information-gathering objectives. The scope of chemicals and regulated entities changes between sections. Sections 8(a) and (d) apply only to chemicals listed by regulation. Sections 8(c) and (e) cover the full spectrum of TSCA chemicals. Section 8(a) reporting requirements consist of two reports: the Comprehensive Assessment Information Rule (CAIR) and the Preliminary Assessment Information Rule (PAIR). Manufacturers, importers, and processors must report on each substance such that the EPA can formulate risk assessments and develop regulatory strategies. CAIR requires companies to report on listed substances under 40 CFR 704.200 Subparts C and D. PAIR requires manufacturers and importers to report on each listed substance during the reporting period for that substance as given in the rule (see 40 CFR Part 712). Ultimately, PAIR is to be replaced by CAIR.

Section 8(c) requires affected companies to maintain records of allegations of significant adverse reactions to health or the environment caused by the substances. Section 8(d) sets forth requirements for the submission of health studies on chemical substances and mixtures selected for priority consideration testing rules under Section 4(a) of TSCA and on other substances on which EPA requires health and safety studies. Section 8(e) requires affected companies to inform the administrator of the EPA or any chemical substance that presents a substantial risk of injury to health or the environment as soon as this information is discovered.

The TSCA also specifically regulates PCBs, CFCs, and asbestos (40 CFR, Parts 700–766, July 1, 1992).

Nanotechnology Environmental Regulations Overview

Completely new legislation and regulatory rulemaking will almost certainly be necessary for environmental control of nanotechnology. However, in the meantime, one may speculate on how the existing regulatory framework might be applied to the nanotechnology area as this emerging field develops over the next several years. One experienced Washington, D.C., attorney has done just that, as summarized below.[14–16] The reader is encouraged to consult the cited references as well as the text of the laws that are mentioned and the applicable regulations derived from them.

As indicated above, commercial applications of nanotechnology are likely to be regulated under TSCA, which authorizes EPA to review and establish limits on the manufacture, processing, distribution, use, and/or disposal of new materials that EPA determines to pose "an unreasonable risk of injury to human health or the environment." The term *chemicals* is defined broadly by TSCA. Unless qualifying for an exemption under the law [R&D (a statutory exemption requiring no further approval by EPA), low-volume production, low environmental releases along with low volume, or plans for limited test marketing], a prospective manufacturer is subject to the full-blown PMN procedure. This requires submittal of said notice, along with toxicity and other data to EPA at least 90 days before commencing production of the chemical substance.

Approval then involves recordkeeping, reporting, and other requirements under the statute. Requirements will differ, depending on whether EPA determines that a particular application constitutes a "significant new use" or a "new chemical substance." EPA can impose limits on production, including an outright ban when it is deemed necessary for adequate protection against "an unreasonable risk of injury to health or the environment." EPA may revisit a chemical's status under TSCA and change the degree or type of regulation when new health/environmental data warrant. EPA is expected to be issuing several new TSCA test rules in 2004.[17] If the experience with genetically engineered organisms is any indication, there will be a push for EPA to update regulations in the future to reflect changes, advances, and trends in nanotechnology.[18]

Workplace exposure to chemical substances and the potential for pulmonary toxicity is subject to regulation by the OSHA under the OSH Act, including the requirement that potential hazards be disclosed on MSDS. (An interesting question arises as to whether carbon nanotubes, chemically carbon but with different properties because of their small size and structure, are indeed to be considered the same as or different from carbon black for MSDS purposes.) Both governmental and private agencies can be expected to develop the requisite threshold limit values (TLVs) for workplace exposure. Also, EPA may once again utilize TSCA to assert its own jurisdiction, appropriate or not, to minimize exposure in the workplace.

Another likely source of regulation would fall under the provisions of the Clean Air Act (CAA) for particulate matter less than 2.5 μm ($PM_{2.5}$). Additionally, an installation manufacturing nanomaterials may ultimately become subject as a "major source" to the CAA's Section 112 governing hazardous air pollutants (HAPs).

A waste from a commercial-scale nanotechnology facility would be captured under RCRA, provided that it meets the criteria for a RCRA waste. RCRA requirements could be triggered by a listed manufacturing process or the RCRA's specified hazardous waste characteristics. The type and extent of regulation would depend on how much hazardous waste is generated and whether the wastes generated are treated, stored, or disposed of onsite.

Finally, opponents of nanotechnology, especially, may be able to use the National Environmental Policy Act (NEPA) to impede nanotechnology research funded by the U.S. government. A "major Federal action significantly affecting the quality of the human environment" is subject to the environmental impact provision under NEPA. (Various states also have environmental impact assessment requirements that could delay or put a stop to construction of nanotechnology facilities.) Time will tell.

1.7 CLASSIFICATION AND SOURCES OF POLLUTANTS[5,6,19]

It is relatively safe to say that there will be two classifications of nanoemissions: particulates and gases. Additional details cannot be provided at this time since many of these new processes, and their corresponding emissions, have yet to be formulated. Nonetheless, it seems reasonable to conclude that many of these emissions will be similar in classifications to what presently exits. The classification and sources of pollutants of necessity have to be emitted to "traditional" contaminants. At the time of this writing, very little could be said about those pollutants generated from nanoapplications.

Not long ago, the nation's natural resources were exploited indiscriminately. Waterways served as industrial pollution sinks, skies dispersed smoke from factories and power plants, and the land proved to be a cheap and convenient place to dump industrial and urban wastes. However, society is now more aware of the environment and the need to protect it. The American people have been involved in a great social movement known broadly as "environmentalism." Society has been concerned with the quality of the air one breathes, the water one drinks, and the land on which one lives and works. While economic growth and prosperity are still important goals, opinion polls show overwhelming public support for pollution controls and a pronounced willingness to pay for them. This section presents the reader with information on pollutants and categorizes their sources by the media they threaten.

Air Pollutants

Since the Clean Air Act was passed in 1970, the United States has made impressive strides in improving and protecting air quality. As directed by this Act, the EPA set National Ambient Air Quality Standards (NAAQS) for those pollutants commonly found throughout the country that posed the greatest overall threats to air quality. These pollutants, termed *criteria pollutants* under the act, include: ozone, carbon monoxide, airborne particulates, sulfur dioxide, lead, and nitrogen oxide. Although the EPA has made considerable progress in controlling air pollution, all of the six criteria except lead and nitrogen oxide are currently a major concern in a number of areas in the country. The following subsections focus on a number of the most significant air quality challenges: ozone and carbon monoxide, airborne particulates, airborne toxics, sulfur dioxide, acid deposition, and indoor air pollutants.

Ozone and Carbon Monoxide Ozone is one of the most intractable and widespread environmental problems. Chemically, ozone is a form of oxygen with three oxygen atoms instead of the two found in regular oxygen. This makes it very reactive, so that it combines with practically every material with which it comes in contact. In the upper atmosphere, where ozone is needed to protect people from ultraviolet radiation, the ozone is being destroyed by manmade chemicals, but at ground level, ozone can be a harmful pollutant.

Ozone is produced in the atmosphere when sunlight triggers chemical reactions between naturally occurring atmospheric gases and pollutants such as volatile organic compounds (VOCs) and nitrogen oxides. The main source of VOCs and nitrogen oxides is combustion sources such as motor vehicle traffic.

Carbon monoxide is an invisible, odorless product of incomplete fuel combustion. As with ozone, motor vehicles are the main contributor to carbon monoxide formation. Other sources include wood-burning stoves, incinerators, and industrial processes. Since auto travel and the number of small sources of VOCs are expected to increase, even strenuous efforts may not sufficiently reduce emissions of ozone and carbon monoxide.

Airborne Particulates Particulates in the air traditionally include dust, smoke, metals, and aerosols. Major sources include steel mills, power plants, cotton gins, cement plants, smelters, and diesel engines. Other sources are grain storage elevators, industrial haul roads, construction work, and demolition. Wood-burning stoves and fireplaces can also be significant sources of particulates. Urban areas are likely to have wind-blown dust from roads, parking lots, and construction work.

Airborne Toxics Toxic pollutants are one of today's most serious emerging problems and found in all media. Many sources emit toxic chemicals into the atmosphere: industrial and manufacturing processes, solvent use, sewage treatment plants, hazardous waste handling and disposal sites, municipal waste sites, incinerators, and motor vehicles. Smelters, metal refiners, manufacturing processes, and stationary fuel combustion sources emit such toxic metals as cadmium, lead, arsenic, chromium, mercury, and beryllium. Toxic organics, such as vinyl chloride and benzene, are released by a variety of sources, such as plastics and chemical manufacturing plants, and gas stations. Chlorinated dioxins and furans are emitted by some chemical processes and the high-temperature burning of plastics in incinerators.

Sulfur Dioxide Sulfur dioxide can be transported long distances in the atmosphere because of its ability to bond to particulates. After traveling, sulfur dioxide combines with water vapor to form acid rain. Sulfur dioxide is released into the air primarily through the burning of coal and fuel oils. Today, two-thirds of all national sulfur dioxide emissions come from electric power plants. Other sources of sulfur dioxide include refiners, pulp and paper mills, smelters, steel and chemical plants, and energy facilities related to oil shale, syn (synthetic) fuels, and oil and gas production. Home furnaces and coal-burning stoves are sources that directly affect residential neighborhoods.

Acid Deposition Acid deposition is a serious environmental concern in many parts of the country. The process of acid deposition begins with the emissions of sulfur dioxide (primarily from coal-burning power plants) and nitrogen oxides (primarily from motor vehicles and coal-burning power plants). As described in the previous subsection, these pollutants interact with sunlight and water vapor in the upper atmosphere to form acidic compounds. During a storm, these compounds fall to Earth as acid rain or snow; the compounds may also join dust or other dry airborne particles and fall as "dry deposition."

Indoor Air Pollutants

Indoor air pollution is rapidly becoming a major health issue in the United States. Indoor pollutant levels are quite often higher than outdoors, particularly where buildings are tightly constructed to save energy. Since most people spend 90 percent of their time indoors, exposure to unhealthy concentrations of indoor air pollutants is often inevitable. The degree of risk associated with exposure to indoor pollutants depends on how well buildings are ventilated and the type, mixture, and amounts of pollutants in the building. Indoor air pollutants of special concern are described below.

Radon Radon is a unique environmental problem because it occurs naturally. Radon results from the radioactive decay of radium-226, found in many types of rocks and soils. Most indoor radon comes from the rock and soil around a building and enters structures through cracks or openings in the foundation or basement. Secondary sources of indoor radon are well water and building materials.

Environmental Tobacco Smoke Environmental tobacco smoke is smoke that nonsmokers are exposed to from smokers. This smoke has been judged by the Surgeon General, the National Research Council, and the International Agency for Research on Cancer to pose a risk of lung cancer to nonsmokers. Tobacco smoke contains a number of pollutants, including inorganic gases, heavy metals, particulates, VOCs, and products of incomplete combustion (PICs), such as polynuclear aromatic hydrocarbons.

Asbestos Asbestos has been used in the past in a variety of building materials, including many types of insulation, fireproofing, wallboard, ceiling tiles, and floor tiles. The remodeling or demolition of buildings with asbestos-containing materials frees tiny asbestos fibers in clumps or clouds of dust. Even with normal aging, materials may deteriorate and release asbestos fibers. Once released, these asbestos fibers can be inhaled into the lungs and can accumulate.

Formaldehyde and Other Volatile Organic Compounds The EPA has found formaldehyde to be a probable human carcinogen. The use of formaldehyde in furniture, foam insulation, and pressed wood products, such as some plywood, particle board, and fiberboard, makes formaldehyde a major indoor air pollutant.

The VOCs commonly found indoors include benzene from tobacco smoke and perchlorethylene emitted by dry-cleaned clothes. Paints and stored chemicals, including certain cleaning compounds, are also major sources of VOCs. VOCs can also be emitted from drinking water; 20 percent of water supply systems have detectable amounts of VOCs.

Pesticides Indoor and outdoor use of pesticides, including termiticides and wood preservatives, are another cause of concern. Even when used as directed, pesticides may release VOCs. In addition, there are about 1200 inert ingredients added to pesticide products for a variety of purposes. While not “active” in attacking the particular pest, some inert ingredients are chemically or biologically active and may cause health problems. EPA researchers are presently investigating whether indoor use of insecticides and subsurface soil injection of termiticides can lead to hazardous exposure.

Water Pollutants

The EPA, in partnership with state and local governments, is responsible for improving and maintaining water quality. These efforts are organized around three themes. The first is maintaining the quality of drinking water. This is addressed by monitoring and treating drinking water prior to consumption and by minimizing the contamination of the surface water and protecting against contamination of groundwater needed for human consumption. The second is preventing the degradation and destruction of critical aquatic habitats, including wetlands, nearshore coastal waters, oceans, and lakes. The third is reducing the pollution of free-flowing surface waters and protecting their uses. The following is a discussion of various pollutants categorized by these themes.

Drinking Water Pollutants The most severe and acute public health effects from contaminated drinking water, such as cholera and typhoid, have been eliminated in America. However, some less acute and immediate hazards remain in the nation's tap water. These hazards are associated with a number of specific contaminants in drinking water. Contaminants of special concern to the EPA are lead, radionuclides, microbiological contaminants, and disinfection by-products.

The primary source of lead in drinking water is corrosion of plumbing materials, such as lead service lines and lead solders, in water distribution systems and in houses and larger buildings. Virtually all public water systems serve households with lead solders of varying ages, and most faucets are made of materials that can contribute some lead to drinking water.

Radionuclides are radioactive isotopes that emit radiation as they decay. The most significant radionuclides in drinking water are radium, uranium, and radon, all of which occur in the natural environment. While radium and uranium enter the body by ingestion, radon is usually inhaled after being released into the air during showers, baths, and other activities, such as washing clothes or dishes. Radionuclides in drinking water occur primarily in those systems that use groundwater. Naturally occurring radionuclides seldom are found in surface waters (such as rivers, lakes, and streams).

Water contains many microbes—bacteria, viruses, and protozoa. Although some organisms are harmless, others can cause disease. The Centers for Disease Control reported 112 waterborne disease outbreaks from 1981 to 1983. Microbiological contamination continues to be a national concern because contaminated drinking water systems can rapidly spread disease.

Disinfection by-products are produced during water treatment by the chemical reactions of disinfectants with naturally occurring or synthetic organic materials present in untreated water. Since these disinfectants are essential to safe drinking water, the EPA is presently looking at ways to minimize the risks from by-products.

Critical Aquatic Habitat Pollutants Critical aquatic habitats that need special management attention include the nation's wetlands, near coastal waters, oceans, and lakes. In recent years, the EPA has been focusing on addressing the special problems of these areas. The following is a discussion of pollutants categorized by the habitats they affect.

Wetlands in urban areas frequently represent the last large tracts of open space and are often a final haven for wildlife. Not surprisingly, as suitable upland development sites become exhausted, urban wetlands are under increasing pressure for residential housing, industry, and commercial facilities.

Increasing evidence exists that our nation's wetlands, in addition to being destroyed by physical threats, also are being degraded by chemical contamination. The problem of wetland contamination received national attention in 1985 due to reports of waterfowl deaths and deformities caused by selenium contamination. Selenium is a trace element that occurs naturally in soil and is needed in small amounts to sustain life. However, for years it was being leached out of the soil and carried in agricultural drainwater used to flood the wildlife refuge's wetlands, where it accumulated to dangerously high levels.

Coastal water environments are particularly susceptible to contamination because they act as sinks for the large quantities of pollution discharged from municipal sewage treatment plants, industrial facilities, and hazardous waste disposal sites. In many coastal areas, non-point-source runoff from agricultural lands, suburban developments, city streets, and combined sewer and stormwater overflows poses an even more significant problem than point sources. This is due to the difficulty of identifying and then controlling the source of the pollution.

Physical and hydrological modifications from such activities as dredging channels, draining and filling wetlands, constructing dams, and building shorefront houses may further degrade near coastal environments. In addition, growing population pressures will continue to subject these sensitive coastal ecosystems to further stress.

The Great Lakes provide an inestimable resource to the 45 million people living in the surrounding basin. A 1970 study by the International Joint Commission identified nutrients and toxic problems in the lakes. They suffered from eutrophication problems caused by excessive nutrient inputs. Since then the United States and Canada have made joint efforts to reduce nutrient loadings, particularly phosphorus. However, contamination of the water and fish by toxics from pesticide runoff, landfill leachates, and in-place sediments remains a major problem.

Ocean dumping of dredged material, sewage sludge, and industrial wastes is a major source of ocean pollution. Sediments dredged from industrialized urban harbors are often highly contaminated with heavy metals and toxic synthetic organic chemicals like PCBs and petroleum hydrocarbons. Although ocean dumping of dredged material, sludge, and industrial wastes is now less of a threat, persistent disposal of plastics from land and ships at sea has become a serious problem. Debris on beaches from sewer and storm drain overflows or mismanagement of trash poses public safety and aesthetic concerns.

Surface Water Pollutants Pollutants in waterways come from industries or treatment plants discharging wastewater into streams or from waters running across urban and agricultural areas, carrying the surface pollution with them (nonpoint sources). The following is a discussion of surface water pollutants categorized by their main sources.

Raw or insufficiently treated wastewater from municipal and industrial treatment plants still threatens water resources in many parts of the country. In addition to harmful nutrients, poorly treated wastewater may contain bacteria and chemicals.

Sludge, the residue left from wastewater treatment plants, is a growing problem. Although some sludges are relatively "clean," or free from toxic substances, other sludges may contain organic, inorganic, or toxic pollutants and pathogens.

An important source of toxic pollution is industrial wastewater discharged directly into waterways or indirectly through municipal wastewater treatment plants. Industrial wastes discharged indirectly are treated to remove toxic pollutants. It is important that those wastes be treated because toxics may end up in sludge, making them harder to dispose of safely.

Nonpoint sources present continuing problems for achieving national water quality in many parts of the country. Sediment and nutrients are the two largest contributors to non-point-source problems. Nonpoint sources are also a major source of toxics, among them pesticide runoff from agricultural areas, metals from active or abandoned mines, gasoline, and asbestos from urban areas. In addition, the atmosphere is a source of toxics since many toxics can attach themselves to dust, later to be deposited in surface waters hundreds of miles away through precipitation.

Land Pollutants

Historically, land has been used as the dumping ground for wastes, including those removed from the air and water. Early environmental protection efforts focused on cleaning up air and water pollution. It was not until the 1970s that there was much public concern about pollution of the land. It is now recognized that contamination of the land threatens not only future uses of the land itself, but also the quality of the surrounding air, surface water, and groundwater. There are five different forms of land pollutants. These include:

1. Industrial hazardous wastes
2. Municipal wastes
3. Mining wastes
4. Radioactive wastes
5. Underground storage tanks

A short description of each is provided next.

Industrial Hazardous Wastes The chemical, petroleum, and transportation industries are major producers of hazardous industrial waste. Ninety-nine percent of the hazardous waste is produced by facilities that generate large quantities (more than 2200 lb) of hazardous waste each month.

A much smaller amount of hazardous waste, about one million tons per year, comes from small quantity generators (between 220 and 2200 lb of waste each month). These include automotive repair shops, construction firms, laundromats, dry cleaners, printing operations, and equipment repair shops. Over 60 percent of the these wastes are derived from lead batteries. The remainder includes acids, solvents, photographic wastes, and dry cleaning residue.

Municipal Wastes Municipal wastes include household and commercial wastes, demolition materials, and sewage sludge. Solvents and other harmful household and commercial wastes are generally so intermingled with other materials that specific control of each is virtually impossible.

Sewage sludge is the solid, semisolid, or liquid residue produced from treating municipal wastewater. Some sewage sludges contain high levels of disease-carrying microorganisms, toxic metals, or toxic organic chemicals. Because of the large quantities generated, sewage sludge is a major waste management problem in a number of municipalities.

Mining Wastes A large volume of all waste generated in the United States is from mining coal, phosphates, copper, iron, uranium, other minerals, and from ore processing and milling. These wastes consist primarily of overburden, the soil and rock cleared away before mining, and tailings, the material discarded during ore processing. Runoff from these wastes increases the acidity of streams and pollutes them with toxic metals.

Radioactive Wastes Radioactive materials are used in a wide variety of applications, from generating electricity to medical research. The United States has produced large quantities of radioactive wastes that can pose environmental and health problems for many generations.

Pollutants from Underground Storage Tanks Leaking underground storage tanks are another source of land contamination that can contribute to groundwater contamination. The majority of these tanks do not store waste but instead store petroleum products and some hazardous substances. Most of the tanks are bare steel and subject to corrosion. Many are old and near the end of their useful lives. Hundreds of thousands of these tanks are presently thought to be leaking, with more expected to develop leaks in the next few years.

Hazardous Pollutants

Before the early 1970s, the nation paid little attention to industrial production and the disposal of the waste it generated, particularly hazardous waste. As a result, billions of dollars must now be spent to clean up disposal sites neglected through years of mismanagement. The EPA often identifies a waste as hazardous if it poses a fire hazard (ignitable), dissolves materials or is acidic (corrosive), is explosive (reactive), or otherwise poses danger to human health or the environment (toxic). Most hazardous waste results from the production of widely used goods such as polyester and other synthetic fibers, kitchen appliances, and plastic milk jugs. A small percentage of hazardous waste (less than 1 percent) is comprised of the used commercial products themselves, including household cleaning fluids or battery acid.

Definitions of hazardous substances are not as straightforward as they appear. For purposes of regulation, Congress and the EPA have defined terms to describe wastes and other substances that fall under regulation. The definitions below show the complexity of the EPA's regulatory task.

1. Hazardous Substances [Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), or "Superfund"]—Any substance that, when released into the environment, may cause substantial danger to public health, welfare, or the environment. Designation as a hazardous substance grows out of the statutory definitions in several environmental laws: CERCLA, RCRA, CWA, CAA, and TSCA. Currently there are 717 CERCLA hazardous substances.

2. Extremely Hazardous Substance (CERCLA as amended)—Substances that could cause serious, irreversible health effects from a single exposure. For purposes of chemical emergency planning, EPA has designated 366 substances extremely hazardous. If not already so designated, these also will be listed as hazardous substances.

3. Solid Waste (RCRA)—Any garbage, refuse, sludge, or other discarded material. All solid waste is not solid; it can be liquid, semisolid, or contained gaseous material. Solid waste results from industrial, commercial, mining, and agricultural operations from community activities. Solid waste can be either hazardous or nonhazardous. However, it does not include solid or dissolved material in domestic sewage, certain nuclear material, or certain agricultural wastes.

4. Hazardous Waste (RCRA)—Solid waste, or combinations of solid waste, that because of its quantity, concentration, or physical, chemical, or infectious characteristics, may pose a hazard to human health or the environment.

5. Nonhazardous Waste (RCRA)—Solid waste, including municipal wastes, household hazardous waste, municipal sludge, and industrial and commercial wastes that are not hazardous.

Toxic Pollutants

Today's high standard of living would not be possible without the thousands of different chemicals produced. Most of these chemicals are not harmful if used properly. Others can be extremely harmful if people are exposed to them, even in minute amounts. The following is a discussion of four toxic chemicals under control of the Toxic Substance Control Act of 1976.

Polychlorinated biphenyls (PCBs) provide an example of the problems that toxic substances can present. PCBs were used in many commercial activities, especially in heat transfer fluids in electrical transformers and capacitors. They also were used in hydraulic fluids, lubricants, and dye carriers in carbonless copy paper, and in paints, inks, and dyes. Over time, PCBs accumulated in the environment, either from leaking electrical equipment or from other materials such as inks.

Like PCBs, *asbestos* was widely used for many purposes, such as fireproofing and pipe and boiler insulation in schools and other buildings. Asbestos was often mixed with a cementlike material and sprayed or plastered on ceilings and other surfaces. Now these materials are deteriorating, releasing the asbestos.

Dioxins refer to a family of chemicals with similar structure, although it is common to refer to the most toxic of these—2,3,7,8-tetrachlorodinitro-*p*-dioxin, or TCDD—as dioxin. Dioxin is an inadvertent contaminant of the chlorinated herbicides 2,4,5-T and silvex, which were used until recently in agriculture, forest management, and lawn care. It is also a contaminant of certain wood preservatives and the defoliant Agent Orange used in Vietnam. Dioxins and the related chemicals known as furans also are formed during the combustion of PCBs.

Several other sources of dioxin contamination have been identified in recent years. These include pulp and paper production and the burning of municipal wastes containing certain plastics or wood preserved by certain chlorinated chemicals.

In 1978, the use of *chlorofluorocarbons (CFCs)* as a propellent in aerosol cans and other nonessential uses were prohibited by the EPA. The EPA took this action as a result of evidence that CFCs caused a decrease in stratopsheric ozone.

1.8 EFFECTS OF POLLUTANTS[5,6]

As with the previous section, it is difficult to provide specific information on this topic since technical individuals are essentially dealing with unknown nanoemissions for unknown processes/sources. The material that follows, therefore, primarily addresses "traditional" pollutants. Detailing the effects of emissions from nanoapplications that would be described as pollutants is an order of magnitude more difficult than classifying then, as discussed in the previous section. However, the future looks bright for those individuals involved with toxicology and epidemiology studies of nanotechnology. This topic will be revisited in earnest in Chapter 7—Health Risk Assessment.

Pollutants are various noxious chemicals and refuse materials that impair the purity of the water, soil, and the atmosphere. The area most affected by pollutants is the atmosphere or air. Air pollution occurs when wastes pollute the air. Artificially or synthetically created wastes are the main sources of air pollution. They can be in the form of gases or particulates, which result from the burning of fuel to power motor vehicles and to heat buildings. More air pollution can be found in densely populated areas. The air over largely populated cities often becomes so filled with pollutants that it not only harms the health of humans, plants, and animals but also adversely affects materials of construction.

Water pollution occurs when wastes are dumped into the water. This polluted water can spread typhoid fever and other diseases. In the United States, water supplies are disinfected to kill disease-causing germs. The disinfection, in some instances, does not remove all the chemicals and metals that may cause health problems in the distant future.

Wastes that are dumped into the soil are a form of land pollution, which damages the thin layer of fertile soil that is essential for agriculture. In nature, cycles work to keep soil fertile. Wastes, including dead plants and wastes from animals, form a substance in the soil called humus. Bacteria then decays the humus and breaks it down into nitrates, phosphates, and other nutrients that feed growing plants.

This section will review the effects of air pollutants, water pollutants, and land (solid waste) pollutants on:

1. Humans
2. Plants
3. Animals
4. Materials of construction

For obvious reasons, the material will key on the effects on humans. It will also focus primarily on air pollutants since this has emerged as the leading environmental issue with the passage of the Clean Air Act Amendments of 1990.

Air Pollution

Humans Humans are in constant contact with pollutants, whether they are indoors or outdoors. The pollutants, primarily air pollutants, may have negative effects on human health. In some instances humans adapt and do not realize that they are being affected. For example, people living in smog-covered cities know that smog is bad for their health but just consider it "normal." There are still some who do not think that there is anything that can be done about it.

Indoors, which includes the home and the workplace, a definite correlation seems to exist between some of the most important indoor activities and the resulting pollutants that are generated. Some examples of these are smoking, the use of personal products, cleaning, cooking, heating, maintenance of hair and facial care, hobbies, and electrical appliances such as washing machines and dryers.[20,21] Fumes from these activities can get trapped in the home or workplace, and the buildup of these over time will cause health problems in the short- and long-term future.

When people go outside, they usually say they are going to "get some fresh air." This "fresh air" to them usually means breathing in the air from a different location. Although the common term for the air outside is "fresh air." the air may not necessarily be very "fresh." The outside air can be full of air pollutants that can cause negative effects on the health of humans.

The influence of air pollution on human productivity has not been firmly established. In addition, a number of authorities suspect (and some are convinced) that air pollution is associated with an increasing incidence of lung and respiratory ailments and heart disease.[21] Table 1.4 shows some of the health effects of the regulated air pollutants.

"Air toxics" is the term generally used to describe cancer-causing chemicals, radioactive materials, and other toxic chemicals not covered by the National

TABLE 1.4 Health Effects of the Regulated Air Pollutants

Pollutant	Health Concerns
Criteria Pollutants	
Ozone	Respiratory tract problems such as difficult breathing and reduced lung function. Asthma, eye irritation, nasal congestion, reduced resistance to infection, and possibly premature aging of lung tissue
Particulate matter	Eye and throat irritation, bronchitis, lung damage, and impaired visibility
Carbon monoxide	Ability of blood to carry oxygen impaired; cardiovascular, nervous and pulmonary systems affected
Sulfur dioxide	Respiratory tract problems, permanent harm to lung tissue
Lead	Retardation and brain damage, especially in children
Nitrogen dioxide	Respiratory illness and lung damage
Hazardous Air Pollutants	
Asbestos	A variety of lung diseases, particularly lung cancer
Beryllium	Primary lung disease, although also affects liver, spleen, kidneys, and lymph glands
Mercury	Several areas of the brain as well as the kidneys and bowels affected
Vinyl chloride	Lung and liver cancer
Arsenic	Causes cancer
Radionuclides	Cause cancer
Benzene	Leukemia

Ambient Air Quality Standards for conventional pollutants. Air toxics result from many activities of modem society, including driving a car, burning fossil fuel, and producing and using industrial chemicals or radioactive materials. The latter is one of the highest health risk problems with which the EPA is wrestling.[22]

Some major contributors to pollution that affect human health are: sulfur dioxide, carbon monoxide, nitrogen oxides, ozone, carcinogens, fluorides, aeroallergens, radon, smoking, asbestos, and noise. These are treated in separate paragraphs below.

Sulfur dioxide (SO_2) is a source of serious discomfort and in excessive amounts is a health hazard, especially to people with respiratory ailments. In the United States alone, the estimated amount of SO_2, emitted into the atmosphere is 23 million tons per year. SO_2 causes irritation of the respiratory tract; it damages lung tissue and promotes respiratory diseases. The taste threshold limit is 0.3 ppm and SO_2 produces an unpleasant smell at 0.5 ppm concentration. In fact, sulfur dioxides in general have been considered as prime candidates for an air pollution index. Such an index would be a measure reflecting the presence and action of harmful environmental conditions. This would aid in rendering meaningful analyses of the effect of air pollutants on human health, especially since health effects are most probably due to the complementing action of pollutants and meteorological variables. SO_2 is more harmful in a dusty atmosphere. This effect may be explained as follows: The respiratory tract is lined with hairlike cilia, which by means of regular sweeping action force out foreign substances entering the respiratory tract through the mouth. SO_2 and H_2SO_4 (sulfuric acid) molecules paralyze the cilia, rendering it ineffective in rejecting these particulates, causing them to penetrate deeper into the lungs. Alone, these molecules are too small to remain in the lungs; but, some SO_2 molecules are absorbed on larger particles, which penetrate into the lungs and settle there, bringing concentrated amounts of the irritant SO_2 into prolonged contact with the fine lung tissues. SO_2 and the other sulfur dioxide–particulate combinations are serious irritants of the respiratory tract. In high-pollution intervals they can cause death. Their action of severely irritating the respiratory tract may cause heart failure due to the excessive laboring of the heart in its pumping action to circulate oxygen through the body.

Carbon monoxide (CO) levels have declined in most parts of the United States since 1970, but the standards are still exceeded in many cities throughout the country. Carbon monoxide pollution is the basic concern in most large cities of the world where traffic is usually congested and heavy. CO cannot be detected by smell or sight, and this adds to its danger. It forms a complex with hemoglobin, called carboxy-hemoglobin (COHb). The formation of this complex reduces the capability of the bloodstream to carry oxygen by interfering with the release of the oxygen carried by remaining hemoglobin. Also, since the affinity of human hemoglobin is 210 times higher for CO than it is for oxygen, a small concentration of CO markedly reduces the capacity of the blood to act as an oxygen carrier. The threshold limit value (TLV), or maximum allowable concentration (MAC), of CO for industrial exposure is 50 ppm; concentrations of CO as low as 10 ppm produce effects on the nervous system and give an equilibrium level of COHb larger than 2 percent. A concentration of 30 ppm produces a level greater than 5 percent COHb, which affects the nervous system and causes impairment of visual acuity, brightness discrimination, and other psychomotor functions. Carbon monoxide concentrations of 50 to 100 ppm are commonly encountered in the atmosphere of crowded cities, especially at heavy-traffic rush hours. Such high concentrations adversely affect driving ability and cause accidents. In addition, an estimate of the average concentration of CO inhaled into the lungs from cigarette smoking is 400 ppm.[23]

Two major pollutants among *nitrogen oxides* (NO_X) are nitric oxide (NO), and nitrogen dioxide (NO_2). Emissions from stationary sources are estimated to be 16 million tons of NO_X per year. Mobile sources of NO_X pollution are automobiles emitting an estimated average of 10.7 million tons per year. NO is colorless, but it is photochemically converted to nitrogen dioxide, which is one of the components of smog. Nitrogen dioxide also contributes to the formation of aldehydes and ketones through the photochemical reaction with hydrocarbons of the atmosphere. Nitrogen dioxide is an irritant; it damages lung tissues, especially through the formation of nitric acid. Breathing nitrogen dioxide at 25 ppm for 8 hours could cause spoilage of lung tissues, while breathing it for one-half hour at 100 to 150 ppm could produce serious pulmonary edema, or swelling of lung tissues. A few breaths at 200 to 700 ppm may cause fatal pulmonary edema.

Ozone (O_3) is produced from the activation of sunlight on nitrogen dioxide, pollutants such as volatile organic compounds (VOCs), and atmospheric gases such as oxygen. It is an irritant to the eyes and lungs, penetrating deeper into the lungs than sulfur dioxide. In air it forms complex organic compounds; dominant among these are aldehydes and peroxyacetyl nitrate (PAN), which also causes eye and lung irritation. Rural areas have concentrations of 2 to 5 parts per hundred million (pphm) of ozone, which is distinguished by an odor of electrical shorting. A few good smells and the individual's sensitivity for this odor disappears. At 5 to 10 pphm, the odor is unpleasant and pungent. Exposure to ozone for 30 min at 10 to 15 pphm, which is normally encountered in large cities, causes serious irritation of the mucous membranes and reduces their ability to fight infection. At 20 to 30 pphm it affects vision, and exposure to concentrations of 30 pphm for a few minutes brings a marked respiratory distress with severe fatigue, coughing, and choking. When volunteers were exposed intermittently for 2 weeks to a 30-pphm ozone atmosphere, they experienced severe headaches, fatigue, wheezing, chest pains, and difficulty in breathing. It reduces the activity of individuals, especially those with previous heart conditions. Even young athletes tire on smoggy days.

Carcinogens, which are often polycyclic hydrocarbons inducing cancer in susceptible individuals, are present in the exhaust emissions of the internal combustion engine, be it diesel or gasoline. Two major carcinogens are benzopyrene, which is a strong cancer-inducing agent, and benzanthracene, which is a weak one. They are essentially nonvolatile organic compounds associated with solids or polymeric substances in the air. These compounds are not very stable, and they are destroyed at varying rates by other air pollutants and by sunlight. However, as a result of industrialization and urbanization, these substances are discharged into the atmosphere in significant quantities, reportedly causing a steady increase in the frequency of human lung cancer in the world.

Aeroallergens are airborne substances causing allergies. These are predominantly of natural origin, but some are industrial. Allergic reactions in sensitive persons are caused by allergens such as pollens, spores, and rusts. A large percentage of the population is affected by hay fever and asthma each year; ragweed pollen may be the worst offender—it is about 20 μm in diameter, and under normal conditions, nearly all of it will be deposited near the source. Organic allergens come from plants, yeasts, molds, and animal hair, fur, or feathers. Fine industrial materials in the air cause allergies; for example, the powdered material given off in the extraction of oil from castor beans causes bronchial asthma in people living near the factory.[23]

Radon (as described earlier) is a radioactive, colorless, odorless, naturally occurring gas that is found everywhere at very low levels. It seeps through the soil and collects in homes. Radon problems have been identified in every state, and millions of homes throughout the country have elevated radon levels. Radon in high concentrations has been determined to cause lung cancer in humans.

Smoking can be categorized as voluntary pollution. The smokers not only create a health hazard for themselves but also for the nonsmokers in their company. Cigarette smoke causes lung cancer, and in pregnant women it may cause premature birth and low birthweight in newborns.

Asbestos is a mineral fiber that has been used commonly in a variety of building construction materials for insulation as a fire retardant. The EPA and other organizations have banned several asbestos products. Manufacturers have also voluntarily limited the use of asbestos. Today asbestos is most commonly found in older homes in pipe and furnace insulation materials, asbestos shingles, millboard, textured paints, and floor tiles. The most dangerous asbestos fibers are too small to see. After the fibers are inhaled, they can remain and accumulate in the lungs. Asbestos can cause lung cancer, cancer of the chest and abdominal linings, and asbestosis (irreversible lung scarring that can be fatal). Symptoms of these diseases do not show up until many years after exposure. Most people with asbestos-related disease were exposed to elevated concentrations on the job, and some developed disease from clothing and equipment brought home from job sites.

Noise pollution is not usually placed among the top environmental problems facing the nation; however, it is one of the more frequently encountered sources of pollution in everyday life. Recent scientific evidence shows that relatively continuous exposures to sound exceeding 70 dB can be harmful to hearing. Noise can also cause stress reactions that include: (1) increases in heart rate, blood pressure, and blood cholesterol levels, and (2) negative effects on the digestive and respiratory systems. With persistent, unrelenting noise exposure, it is possible that these reactions will become chronic stress diseases such as high blood pressure or ulcers.

Plants Pollutants, especially in the air, cover a wide spectrum of particulate and gaseous matter, damaging and effecting the growth of many types of vegetation.[20] Whether particulate matter is harmful to vegetation depends upon the type of particulate matter predominating, upon the concentration of particulate matter versus time, the type of vegetation under consideration, climatic conditions, the duration of exposure, and similar factors.[21]

Different types of plants are affected differently by pollutants. The three major types of plants are trees, vegetative plants (crops), and flowers. Only a few kinds of trees can live in the polluted air of a big city. Sycamores and Norway maples seem to resist air pollution best. That is why those trees are planted among most city streets. However, air pollution can kill even sycamores and Norway maples. The danger to the trees is greatest at street corners. That is where cars and buses may have to stop and wait for traffic lights to change. While they are waiting, exhaust pours out of their tailpipes, resulting in tree kills. Pine trees do not resist air pollution as well as sycamores and Norway maples. Air pollutants, even in small amounts, are very harmful to pine trees. For example, the San Bernadino forest was a beautiful forest about 60 miles east of Los Angeles. Most of the trees in the forest were pines. Winds usually blow from west to east. The winds carried polluted air from the streets of L.A. to the San Bernadino forest and harmed the pine trees.[24] Crops and flowers cannot be planted within many miles of industry because they will not grow due to the pollution emitted from the factories. The major contributors to plant pollution are sulfur dioxide, ethylene, acid deposition, smog, ozone, and fluoride.

Metallurgical smelting processes emit substantial quantities of *sulfur dioxide*, and they are in, general associated with a good degree of defoliation. Serious damage from sulfur dioxide is usually characterized by loss of chlorophyll and suppression of growth. Leaf and needle tissues are damaged, and die as the time of exposure increases. The attack starts at the edges, moving progressively toward the main body of the leaf or needle. A concentration as low as 2 pphm could suppress growth. Cereal crops, especially barley, are readily damaged at concentrations less than 50 pphm. The presence of soot particles in the air can increase the damage because sulfur dioxide and sulfuric acid mist are enriched at the surface of particles. It has been determined that pine trees cannot survive the damage when the mean annual concentrations of sulfur dioxide exceed 0.07 to 0.08 ppm.[23]

Ethylene in the air causes injury to many flowers, whether they are orchids, lilacs, tulips, or roses. The first symptom of ethylene damage is the drying of the sepals, which are leaflike formations located at the bottom of the flower bloom. This attack destroys the beauty of the flowers and contributes to extensive economic losses to growers. In addition, accidental escape of ethylene from a polyethylene plant caused 100 percent damage to cotton fields a mile away.[23]

The process of *acid deposition* begins with emissions of SO_2 and NO_X. These pollutants interact with sunlight and water vapor in the upper atmosphere to form acidic compounds. When it rains (or snows), these compounds fall to the Earth. Forests and agriculture may be vulnerable because acid deposition can leach nutrients from the ground, killing nitrogen-fixing microorganisms that nourish plants and release toxic metals.

Smog damage to vegetation is serious, especially in locations such as Los Angeles; the lower leaf surfaces of petunias and spinach become silvery or bronze in color. The most toxic substance of the Los Angeles air has been identified as peroxyacetyl nitrate (PAN), formed by photochemical reactions of hydrocarbons and nitrogen oxides emanating mostly from automobile exhausts.[23]

Ozone is a major component of the Los Angeles smog; it is phytotoxic at concentrations of 0.2 ppm, even when exposure time is only a few hours. Its effect on spinach is strong and destructive, causing whitening or bleaching of the leaves. Certain tobaccos are damaged by concentrations as small as 5 to 6 ppm. Ozone hinders plant growth even if bleaching or other distinctive marks are not found.

Fluorides are given off by factories that make aluminum, iron, and fertilizer. Due to these factories, growers have complained about the damage to fruits and leaves of peach, plum, apple, fig, and apricot trees. Fluorides also damage grapes, cherries, and citrus. It has been observed that the average yield of fruit per tree decreases 27 percent for every increase of 50 ppm of fluoride in the leaves.[23]

Animals Animals are also affected by pollutants in the air. There are many similarities between the effects on humans and the effects on animals. For example, animals in zoos suffer the same effects of air pollution as humans. They also are beset with lung disease, cancer, and heart disease. Their babies have more birth defects than those of wild animals.

Air that is polluted with *fluorides* can be deadly for sheep, cows, and some other animals. However, inhaling the polluted air is not what causes the damage. Some plants that are eaten by the animals store up the fluoride that they have taken from the air, and after a while contain dangerous amounts of fluoride. Animals become ill and even die after eating these plants.[23]

The bald eagle is the U.S. national bird, but it is being killed mainly with *insecticides.* The eagles are not killed by breathing the polluted air but are dying because they cannot reproduce. When an insecticide is sprayed on plants, some of it misses the plants and gets into the air as a pollutant. Certain kinds of insecticides do not change into harmless substances; they are referred to as "persistent" insecticides because they remain harmful for years. Rain washes these insecticides out of the air and into the water. Small animals bioaccumulate the insecticides, and these animals are often eaten by larger animals, who also have absorbed the insecticide, thereby doubling their insecticide intake. Bald eagles eat large animals (fish), and they may store enough insecticide to kill them. Even if they do not die, the insecticide prevents the bird from reproducing. The eggs that the females lay either have very thin shells or no shells at all, causing the inability of baby eagles to hatch.[24]

Materials of Construction Air pollution has long been a significant source of economic loss in urban areas. Damage to nonliving materials may be exhibited in many ways, such as corrosion of metal, rubber cracking, soiling and eroding of building surfaces, deterioration of works of art, and fading of dyed materials and paints.

An example of the deterioration of works of art is Cleopatra's Needle standing in New York City's Central Park. It has deteriorated more in 80 years in the park than in 3000 years in Egypt. Another example is the Statue of Liberty located on Liberty Island in New York Harbor. When the statue arrived from France in 1884 it was copper, and 100 years later it has turned a greenish color. It was so deteriorated that the internal and external structures had to be renovated. The steady deterioration of the Acropolis in Athens, Greece, is yet another example.

Water Pollution

Pollution in waterways impairs or destroys aquatic life, threatens human health, and simply fouls the water such that recreational and aesthetic potential are lost. There are several different types of water pollution and there are several different ways in which water can be polluted. This section will focus on:

1. Drinking water and its sources (groundwater and tap water)
2. Critical aquatic habitats (wetlands, near coastal waters, the Great Lakes, and oceans)
3. Surface water (municipal wastes, industrial discharge, and nonpoint sources)

Drinking Water Half of all Americans and 95 percent of rural Americans use groundwater for drinking water. Through testing water in different areas and at different times, pollutants were found in the drinking water. Several public water supplies using groundwater exceeded EPA's drinking water standards for inorganic substances (fluorides and nitrates). Major problems were reported from toxic organics in some wells in almost all states east of the Mississippi River. Trichloroethylene, a suspected carcinogen, was the most frequent contaminant found. The EPA's Ground Water Supply Survey showed that 20 percent of all public water supply wells and 29 percent in urban areas had detectable levels of at least one VOC. At least 13 organic chemicals that are confirmed animal or human carcinogens have been detected in drinking water wells.

The most severe and acute public health effects from contaminated drinking water from the tap, such as cholera and typhoid, have been eliminated in America. However, some less acute and immediate hazards still remain in the nation's tap water. Contaminants of special concern to the EPA are lead, radionuclides, microbiological contaminants, and disinfection by-products. Each of these is discussed below.

Lead in drinking water is due primarily to the corrosion of plumbing materials. The health effects related to the ingestion of too much lead are very serious and can lead to impaired blood formation, brain damage, increased blood pressure, premature birth, low birth weight, and nervous system disorders. Young children are especially at high risk.

Radionuclides are radioactive isotopes that emit radiation as they decay. The most significant radionuclides in drinking water are radium, uranium, and radon, all of which occur in nature. Ingestion of uranium and radium in drinking water can cause cancer of the bone and kidney. Radon can be ingested and inhaled. The main health risk due to inhalation is lung cancer.

Microbiological contaminants such as bacteria, viruses, and protozoa may be found in water. Although some organisms are harmless, others may cause disease. Microbiological contamination continues to be a national concern because contaminated drinking water systems can rapidly spread disease.

Disinfection by-products are produced during water treatment by chemical reactions of disinfectants with naturally occurring or synthetic materials. These by-products may pose health risks, and these risks are related to long-term exposure to low levels of contaminants.

Critical Aquatic Habitats *Wetlands* are the most productive of all ecosystems, but the United States is slowly losing them. There are many positive effects of wetlands: converts sunlight into plant material or biomass that serve as food for aquatic animals that form the base of the food chain, habitats for fish and wildlife, and spawning grounds; maintains and improves water quality in adjacent water bodies; removes nutrients to prevent eutrophication; filters harmful chemicals; traps suspended sediments; controls floods; prevents shoreline erosion with vegetation; and contributes $20 to 40 billion annually to the economy.

Coastal waters are home to many ecologically and commercially valuable species of fish, birds, and other wildlife. Coastal waters are susceptible to contamination because they act as sinks for the large quantities of pollution discharged from industry. The effects include toxic contamination, eutrophication, pathogen contamination, habitat loss and alteration, and changes in living resources. Coastal fisheries, wildlife, and bird populations have been declining, with fewer species being represented.

The Great Lakes are all being affected by toxics that are contaminating fish and the water. Lake Ontario and Lake Erie are also being affected by eutrophication.

Oceans are being polluted with sediments dredged from industrialized urban harbors that are often highly contaminated with heavy metals and toxic synthetic organic chemicals. The contaminants can be taken up by marine organisms. In addition, persistent disposal of plastics from land and sea have become serious problems. The most severe effect of the debris floating in the ocean is injury and death of fish, marine animals, and birds. Debris on beaches can affect the public safety, the beauty of the beach, and the economy.

Surface Waters *Municipal wastewater and industrial discharges* produce nutrients in sewage that foster excessive growth of algae and other aquatic plants. Plants then die and decay, depleting the dissolved oxygen needed by fish. Wastewater that is poorly treated may contain chemicals harmful to human and aquatic life.

Non-point-source pollution consists of sediment, nutrients, pesticides, and herbicides. Sediment causes decreased light transmission through water resulting in decreased plant reproduction, interference with feeding and mating patterns, decreased viability of aquatic life, decreased recreational and commercial values, and increased drinking water costs. Nutrients promote the premature aging of lakes and estuaries. Pesticides and herbicides hinder photosynthesis in aquatic plants, affect aquatic reproduction, increase organism susceptibility to environmental stress, accumulate in fish tissues, and present a human health hazard through fish and water consumption.

Humans Humans are not affected similarly by the presence of water pollution as they may be by the presence of polluted air. Humans are affected by water pollution through consuming contaminated water or animals (fish). Due to contaminated drinking water, lakes, and oceans, humans are inflicted with diseases, impaired blood formation, brain damage, increased blood pressure, premature birth, low birth weight, nervous system disorders, and cancer (bone, kidney, and lung).

Plants Plants are affected by wastewater, sewage, sediments, pesticides, and herbicides found mainly in surface water. Effects on plants in these areas are:

1. Decreased plant reproduction
2. Hinderance of photosynthesis in aquatic plants
3. Excessive growth of algae and other aquatic plants
4. Ultimate death of plants

Animals Animals, especially those that live in or near the water, are directly affected by water pollution. Chemical and solid waste disposal in water can affect animals in many ways, varying from waste/pollutant accumulation effects to death. Animals such as fish, marine mammals, and birds can be injured or killed due to floating debris in the ocean. Contaminants can be taken up by marine organisms and accumulate there. The accumulations increase as the larger fish consume contaminated smaller fish. This cycle interferes with animals feeding and mating patterns, affects aquatic reproduction, and decreases the viability of aquatic life.

International Effects In Japan, contamination of seawater with organic mercury became concentrated in fish and produced a severe human neurologic disorder called Minamata disease. The epidemic occurred in the mid-1950s. Almost 10 years passed before it was realized that there was an accompanying epidemic of congenital cerebral palsy due to a transplacental effect; e.g., pregnant women who ate contaminated fish gave birth to infants who were severely impaired neurologically.[25]

Land Pollution

Land has been used as dumping grounds for wastes. Improper handling, storage, and disposal of chemicals can cause serious problems. Several types of wastes that are placed in the land are:

1. Industrial hazardous wastes
2. Municipal wastes
3. Mining wastes
4. Radioactive wastes
5. Leakage from underground storage tanks

Humans Potential health effects in humans range from headaches, nausea, and rashes to acid burns, serious impairment of kidney and liver functions, cancer, and genetic damage. Underground storage tank leaks may contaminate local drinking water systems or may lead to explosions and fires causing harm and injury to the people in the vicinity.

Plants Trees are usually not planted around landfills, and if they were they would have difficulty growing due to the contaminated soil in the vicinity of the landfill. Vegetative plants also have difficulty growing around landfills. This is due to the fact that the hazardous wastes from industry are usually dumped in the landfills. Flowers also do not normally grow near landfills for similar reasons.

Animals Animals are essentially affected in the same ways as humans. They may experience the effects of drinking contaminated water and suffer from acid burns, kidney, liver, and genetic damage, and cancer.

1.9 TEXT CONTENTS

This project was a unique undertaking. Rather than prepare a textbook on nanotechnology, the authors considered writing a book that was concerned with the environmental implications of nanotechnology. Because of the dynamic nature of this emerging field, it was also decided to write an overview of this subject rather than to provide a comprehensive treatise. One of the key features of this book is that it could serve both academia (students) and industry. As such, it can be used as a text in either a general engineering or environmental engineering/science course or (perhaps primarily) as a training tool for industry.

The book contains 10 chapters. This first chapter provides an introduction to background issues surrounding nanotechnology and the environmental implications associated with the new technology. Chapter 2 covers nanotechnology. Chapters 3, 4, and 5 address air, water, and land (solid waste) issues, respectively, particularly as they relate to control and monitoring. The general subject of multimedia approaches is reviewed in Chapter 6. Chapters 7 and 8 address risk concerns—health in the former and hazard in the later chapter. A brief introduction to ethics can be found in Chapter 9, and the text concludes with a short chapter (10) on future trends.

1.10 SUMMARY

1. Nanotechnology is concerned with the world of invisible miniscule particles that are dominated by forces of physics and chemistry that cannot be applied at the microscopic or human scale level.

2. Two very recent nanotechnology applications include the development of a nanoscale palladium that can efficiently and economically clean groundwater contaminated with trichloroethylene and the synthesis (assembled molecule by molecule) of a novel metal rubber material that has the qualities of both metal and rubber.

3. The most pertinent of intellectual property rights for nanotechnology inventions are patents. It is incumbent upon those engaged in any area of technological development to acquire a basic understanding of patent law.

4. Nanotechnology patents have increased by over 600 percent in the 1997 to 2002 periods. Most of these applications are filed by large private corporations.

5. There are both positive and negative implications associated with nanotechnology. The primary negative impacts are the potentially unknown and unforeseen environmental effects associated with this technology.

6. Environmental regulations are an organized system of statutes, regulations, and guidelines that minimize, prevent, and punish the consequences of damage to the environment. The recent popularity of environmental issues has brought about changes in legislation and subsequent advances in technology.

7. All of the criteria pollutants (ozone, carbon monoxide, airborne particulates, sulfur dioxide, lead, nitrogen oxide) except lead and nitrogen oxide are currently

a major concern in a number of areas in the country. Indoor air pollutants of special concern include radon, environmental tobacco smoke, asbestos, formaldehyde and other VOCs, and pesticides. The U.S. EPA focuses its water pollution control efforts on three themes: maintaining drinking water quality, preventing further degradation and destruction of critical aquatic habitats (wetlands, nearshore coastal waters, oceans, and lakes), and reducing pollution of free-flowing surface waters and protecting their uses. Land pollutants arise because of industrial hazardous wastes, municipal wastes, mining wastes, radioactive wastes, and leaking underground storage tank pollutants.

8. Humans and animals are affected by air pollution. Some sources of pollution affecting them are sulfur dioxide, carbon monoxide, nitrogen oxides, ozone, carcinogens, fluorides, aeroallergens, radon, cigarette smoke, asbestos, and noise. Those affecting only animals are insecticides. Plants are also affected by air pollutants such as sulfur dioxide, ethylene, acid deposition, smog, ozone, and fluoride. Pollution in waterways impairs or destroys aquatic life, threatens human health, and fouls the water such that recreational and aesthetic potential are lost. Land has been used as dumping grounds for wastes. Improper handling, storage, and disposal of chemicals can cause serious problems.

9. This book contains 11 chapters. Hopefully, it offers material not only to individuals with limited technical background, but also to those with extensive industrial experience.

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