INTRODUCTION

Children of Invention Revisited

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IF NECESSITY IS THE MOTHER of invention, who is the father, and who, or what, are invention's children? Necessity, of course, is a matter of degree: We actually only *need* air, water, and food to survive. Shelter, clothing, and a few material possessions are also nice, as are companionship, affection, security, and several other psychological goods that we crave as social animals. But we humans learned how to satisfy these basic biological needs millions of years ago. Why then did we embark on the long journey that transformed us from cavemen into cosmonauts? What was it that made possible the ascent from the Stone Age to our present global technological civilization?

Clearly, the leading answer to these questions is superior intelligence. But in what specific respects is human intelligence superior to that found in other species? Is it our capacity to learn from observation and experience and to transmit what we learn to others? Is it our ability to create and use language? Or might it be these two general cognitive capacities for culture and language, together with our unique ability to discover new solutions to old problems, better ways of making and doing things? In short, is it our unique capacity as a species to form science and technology? Coupled with our needs and desires, which provide the motives that propel us to discover and invent, our scientific and technological creativity has guided the development of civilization through the development of theories, tools, inventions, and technologies that have transformed the ways that we live and work.[1]

For most of us, a world without technology is inconceivable. The inventions that it has given us are all around us. In fact, most of us spend most of our lives in completely artificial environments, wrapped in a technological cocoon that provides us with much more than merely food and protection from the elements. We are so wrapped up in our technological culture, in fact, that it takes an effort to distance ourselves from it in order to understand how technology has transformed human existence from its natural state. Such a historical perspective also helps us see how contemporary technologies, such as genetic engineering and the Internet, are now changing us in even more dramatic ways, creating new opportunities for humans to flourish, new ways of life, and also, in some cases, new social and ethical problems. These social and ethical issues arising from technological innovation are the "children of invention" that this book is about. To understand these issues, however, it is first necessary to get a clear view of their source—*technology*.

THE SCOPE OF TECHNOLOGY

The word *technology* is itself of fairly recent coinage; Johann Beckman of Gottingen first used it in 1789. Its root, *techne,* is the ancient Greek word for "art," "craft," or "skill," which itself is derived from an earlier Indo-European root, *teks,* which means "to weave" or "to fabricate" (*teks* is also the root of the word *textile*). Recent archeological evidence suggests that the weaving of cloth predates the birth of agriculture and the dawn of civilization, going back to about 35,000 BCE, making it one of the first technologies. As the etymology suggests, a *techne* is a method, craft, or skill used in making things, not the things themselves, which are called *artifacts.* For instance, a woven object made from animal hairs that have been twisted together into long strands, dyed with vegetable colors, and interlaced by a weaver is an artifact. Let's say that this object functions primarily as a blanket; a person wraps her- or himself in it to stay warm. A typical use, or function, of an artifact is called its purpose or end, and the knowledge of how to gather the fibers, twist them, dye them, and weave them are the individual *techniques* that comprise this particular technology. Thus, the core meaning of the word *technology* refers to the ensembles of techniques by which humans make artifacts that serve certain useful ends. However, this original meaning is too restrictive for the contemporary context in which we think about the relationship between technology and modern society.

As Rosalind Williams (Selection 1.1.4) notes, in recent years there has been an unfortunate tendency to narrow the definition of technology to contemporary information-communications technologies (ICTs) such as personal computers, the Internet, and the digital gadgets advertised in *Wired*. This way of thinking about technology is clearly too restrictive; it ignores other areas of contemporary technological innovation, such as biotechnology and nanotechnology, as well as the technologies of earlier periods, such as the automobile, the steam engine, or the water wheel. When one ordinarily thinks of technology, what most likely comes to mind are technological *artifacts*—the objects, machines, structures, and devices that are the useful end products of technological design. Then, perhaps, one thinks of the less familiar but potentially more impressive machines and industrial processes tucked away in the factories that manufacture the various gadgets and widgets that we use. Finally, one might visualize the scientists, engineers, and technicians in white laboratory coats, hard at work in the laboratories of the Research and Development Division, designing the next generation of technological devices and processes.

Although it is true that each context through which artifacts come into being—design, manufacturing, and end use—is a technological context, it is still too narrow a view to identify technology with only the material culture of designed or manufactured physical objects. We take an even broader view: Technology consists of not only useful artifacts and the tools and processes needed to produce them but also the entire social organization of people and materials that permits the acquisition of the knowledge and skills needed to design, manufacture, distribute, use, repair, and eventually dispose of these artifacts. Technology is not a collection of things but is a systematic and rational way of doing things; it is, in general, *the organization of knowledge, people, and things to accomplish specific practical goals.*[2]

Technology includes not only the obvious candidates—the mechanical, structural, and electronic know-how that directs the purposeful organization of materials—but also the less obvious *invisible technologies* that control the purposeful organization of people and their labor. The mechanical clocks described by David Landes (Selection 1.1.1), for instance, enabled people to coordinate their activities and thus made possible a more productive use of human labor. But clocks and calendars are useful as ways of measuring units of time—the minutes, days, weeks, months, and the like—that comprise the invisible technology of time. The monetary system, the banks, and the stock and commodity markets are technologies for the distribution of economic value that was once associated with gold coins, then with pieces of paper, currency notes, or stock certificates, and is nowadays represented by encrypted bits of digital data. The ideologies of free-market capitalism and centralized planned economies are competing economic theories about how best to organize social production. Even governmental systems, ranging from varieties of representative democracy to theocracy and dictatorship, are competing political technologies for managing concerted societal action and resolving political conflicts. People ask, "Is there a better way to run the government?" no less frequently than "Is there a better way to design a mousetrap?" Both questions are requests to find a better technology—that is, to acquire knowledge that enables one to solve a practical problem.

Contemporary writers often speak of technology as consisting of systems; for instance, Ruth Schwartz Cowan (Selection 1.1.2) describes the telegraph and telephone, the railroad, the petroleum, and the electrical systems that came about in the later half of the nineteenth century. Large-scale technological systems are linked with one another, often in relationships of mutual interdependence; for instance, telegraph wires were strung along railroad rights of way, and railroads came to depend on the telegraph for scheduling and signaling. Similarly, contemporary ICT systems, such as the Internet, depend on a great many other technological systems for their creation and use but then are used by them, creating a matrix of complex interdependencies. One might think of the entire *technosphere*—that is, the sum total of all human-created artifacts together with the enabling knowledge that created it and sustains it—as constituting one giant technological system. However, this definition of the scope of technology is too broad to be of much practical use. Instead, we will think of technologies as consisting of several distinguishable but interacting aspects: (1) skills, techniques, human activity-forms, or sociotechnical practices; (2) resources, tools, and materials; (3) technological products, or artifacts; (4) ends, intentions, or functions; (5) background knowledge; and (6) the social contexts in which the technology is designed, developed, used, and disposed of. These six aspects are present in every technology.

The first aspect of technology is the *human activity-form*—that is, the particular skills, techniques, methods, practices, or ways of doing things. We know that animals other than humans can make and use tools; for instance, chimpanzees strip branches off tree limbs to make sticks that can be used for gathering insects. For the purposes of our characterization of the technological system, we restrict activity-forms or techniques to those employed by human beings. Some human activity-forms employ natural objects rather than tools to achieve ends; for instance, if one throws a spear in order to try to kill an animal for food, one is employing a particular technique. But throwing spears is a primitive and not very useful hunting technique; our technologies for providing our food have improved considerably. Today, there are complex ensembles of techniques for doing just about everything from planting and harvesting crops to figuring out the orbit of a moon of Jupiter, from designing a house to conducting a leveraged hostile takeover, from cooking lasagna to programming a computer to sort sales data. Such complex techniques represent what is called *procedural knowledge,* or more commonly "know-how," and is contrasted with *propositional knowledge,* or "know-that." Both of these types of knowledge are necessary aspects of technological systems, but techniques are its essence. Procedural knowledge forms the basis of technology because it provides the patterns for the sociotechnical practices or human activity-forms that we use to create artifacts of all kinds and to build and maintain our complex technological systems.

One of the main consequences of technology is to increase our capacity to do things. Technologies, techniques, and tools extend, enhance, and sometimes even replace our natural powers such as sight, hearing, muscle, and even memory and thought. By using tools, we can accomplish things that we could not otherwise achieve and to do things that we could not otherwise do, thus increasing our repertoire of human activity-forms. Tools are artifacts at our disposal that can be used to make other artifacts, but tools, even the dawn stones used by our distant ancestors, are themselves artifacts that have been transformed from their natural states in some way by means of human action.

Earth itself is of course not an artifact but has for many centuries been viewed as a *resource well* into which we can dip at will in order to satisfy our needs and desires. Technology requires resources of various kinds as inputs to technological processes, and by employing specific techniques or human activity-forms, we act on and transform these resources from their original or natural states. Once a *built environment* has been created, however, everything in it can serve as a resource to further technological development. The term *infrastructure* describes elements of the built environment that are available to be used to create or apply new technologies. We live on an increasingly anthropogenic planet, one in which the evidence of the built environment can be seen from outer space in the form of clusters of light emanating from our major cities. In fact, if we include the unintended effects on Earth's atmosphere and climate caused by anthropogenic global warming, there are very few things on Earth that are unaffected by human activity.

By acting on either natural or artificial resources, through techniques, we alter them in various ways and thus create *artifacts,* which form the third aspect of technologies. A clay pot is an example of a material artifact, which, although transformed by human activity, is not all that far removed from its natural state. A plastic cup, a contact lens, and a computer chip, on the other hand, are examples of artifacts that are far removed from the original states of the natural resources needed to create them. Artifacts can serve as resources in other technological processes. This is one of the important interaction effects within the technological system: Each new technology increases the stock of available tools and resources that can be employed by other technologies to produce new artifacts, forming what Deborah Johnson and Thomas Powers (Selection 1.3.4) call the *artifactual platform.*

The fourth aspect concerns the ends or functions of an artifact or technique. Most artifacts have typical or intended uses, but artifacts can in fact be embedded in multiple contexts of use or can serve multiple ends, a property that Richard Sclove (Selection 1.2.1) calls *polypotency.* However, most artifacts have an intended use, or *focal function;* a toaster, for instance, is designed to lightly burn slices of bread, but it is also polypotent and can be used as hand warmer or as a murder weapon. There is a double ambiguity in the relations between artifacts and practices and between ends and practices; the same artifacts can be used to achieve different ends, and different practices and their associated artifacts can be used to accomplish the same ends. For instance, I could have written this sentence with a quill pen, a pencil, a ballpoint pen, a typewriter, or a personal computer (PC) running text-editing software (although I used the last). And I could have used my PC to play an adventure game or calculate my income tax instead of writing this sentence. Because artifacts are designed and created to serve certain functions, it is possible to talk about the ends of these objects—that is, their intended purposes or focal functions even though the objects themselves may often also be used in ways that were not intended. The term *valence* is sometimes used to refer to the typical or conventional uses of artifacts, which may or may not match their intended purposes.[3]

The fifth aspect of technological systems is *knowledge-that,* or factual knowledge about what the universe consists of and how it operates. To employ our technologies, we need background knowledge of various kinds: what resources to use and where to find them, what techniques to employ to fabricate various artifacts, the ends and purposes that are typically served by various techniques and objects, and how all these elements fit together in a systematic way. Both knowledge-how and knowledge-that have always been an important aspect of technologies. However, since the scientific revolution of the seventeenth century, scientific knowledge—that is, both factual and theoretical knowledge about the universe and the way it works—has come to play an increasingly important role in technological development.

The sixth aspect of technology is the *social context or* organization in which technologies are developed, distributed, and employed. A division of labor in which different individuals perform different tasks or occupy different roles to accomplish common or coordinated ends characterizes technological societies. The schemes that we use for organizing human labor represent a kind of technology that can be applied to the most important resource of all—ourselves. Complex schemes for organizing human activities that have become more or less institutionalized can be called *social artifacts.* Examples of social artifacts include the stock market, battalions or divisions in an army, baseball teams, hospitals, schools, and corporations. In each case, human resources are organized in a particular way according to a plan or technique involving a division of labor in which different persons occupy different roles, and their labor is coordinated to accomplish specific sorts of goals. It is important to understand that technology encompasses not only material artifacts but also social and organizational forms and even the cognitive techniques that produce the material and social infrastructure of human civilization. These *invisible technologies* frequently consist of formal, mathematical, or analytical techniques—for instance, the scientific method, statistical analysis, or procedures for creating a balance sheet—and many other specific, high-order thinking skills, which are the content of higher education. Becoming a scientifically or technologically educated person consists mainly in the acquisition of a fairly extensive repertoire of such cognitive techniques.

The social and psychological aspects of technological systems are the least obvious but also the most important. Technology is a human social construction. This is true in an obvious and straightforward sense when we speak of large technological structures—such as bridges, buildings, or dams, which obviously came into existence only by the coordination of the activities of numerous individuals—but it is equally true in the case of the lonely amateur inventor toiling in the attic. Inventions today are rarely the result of such solitary creativity, but even when they are, the resources and techniques employed and the knowledge by which they are put to use by the inventor are themselves the products of prior social processes. Even the inventor's own knowledge and abilities have been shaped by her education and by the repertoire of cognitive techniques that she has acquired through education. So, there is really very little, only the raw materials and the laws of nature, that has not in some way resulted from a process of social production. Even when an inventor succeeds in inventing something new, it is still unlikely to be brought into production and placed on the market unless it has some social value or is of use to other people. So, all technologies must be seen as embedded in social contexts of development, deployment, and use.

To summarize this discussion, we can define technological systems as the *complex of techniques, knowledge, and resources that are employed by human beings in the creation of material and social artifacts that typically serve certain functions perceived as useful or desirable in relation to human interests in various social contexts.*

TECHNOLOGICAL REVOLUTIONS

The use of technologies to satisfy our needs is a fundamental feature of human nature. All human societies we know of, both those presently existing and those that existed hundreds of thousands of years before the dawn of civilization, were technological to some degree. For almost all of our species' evolution, we lived in small, nomadic bands whose main means of livelihood were hunting, gathering, and scavenging. But we were also toolmakers and tool-users during this long period of human evolution, and tools were the principal means by which we satisfied our physiological needs for food, warmth, and shelter. Our hominid ancestors first began chipping stones to make simple hand tools about 2.5 million years ago. Fire was used as early as 1.5 million years ago. If *Homo sapiens* (literally, "man the wise") is now the dominant species on the planet, it is in large part because he is also *Homo faber* ("man the maker").

Early human societies were organized as hunter-gatherer groups, gathering edible plants in season and supplementing their diet with the meat or marrow of hunted animals. Quite likely, these bands of hunter-gatherers were nomadic, following animal migrations and seasonal food-plant distributions. As with present-day hunter-gatherers, ancient nomadic societies were severely limited to only those objects that they could take with them; thus, they tended to develop simple portable technologies for hunting, gathering, cooking, transportation, and defense. Perhaps surprisingly, life does not seem to have been especially hard for hunter-gatherers. The secrets of their success seem to have been populations that did not exceed the food supply, simple and limited material needs, and the ability to move to another area when the local food supply ran out. Nomadic hunter-gatherer societies have persisted into the twentieth century in such diverse environments as the African desert, the tropical rain forest, and the Arctic tundra. Remoteness might be the key to avoiding conversion to more technologically intensive ways of life. For the rest of us, our lives now deeply depend on far-flung and complex technological systems.

About 10,000 years ago, the first great technological revolution occurred in several fertile river valleys of Asia Minor and North Africa. During the *agricultural revolution,* humans learned how to domesticate animals and to plant, grow, and harvest crops to sustain their existence. This enabled humans to give up the nomadic lifestyle and to build permanent cities. *Civilization,* which means the building of cities, originates at this time, as do morality, law, religion, record keeping, mathematics, astronomy, class structures, patriarchy, and other social institutions that have since come to characterize the human condition. With the adoption of settled agriculture in the fertile river valleys, the history of humankind begins. Permanent houses could be built, tools and objects could be accumulated from year to year, and so humanity began the long climb toward the collections of miscellany and junk that now clutter people's closets, attics, and garages.

Settled agriculture had many advantages and a few disadvantages. The quantity of food that could be produced per acre was much higher, so population densities could also be much greater. With permanent dwellings, creature comforts could be made that did not have to be portable. With larger numbers of people living together, specialization of activities could take place, and specialists were more likely to find better ways to do things. Larger concentrations of people could better share and perpetuate knowledge and band together to cooperate on projects that smaller groups could not attempt. Thus, we see that even at this early stage of technological development, the organization of people, information, and accumulated resources were essential aspects of emerging technological societies.

In regions with insufficient rainfall to sustain many crops, it was necessary to design, construct, and maintain either irrigation canals or aqueducts. There is evidence of canal irrigation in both Mesopotamia and Egypt as early as the sixth millennium BCE, and in areas where the topography posed challenges various devices were developed to raise water above its natural level. Some of these devices, such as the noria used with flowing water, were sophisticated; others, such as the chain-pump used with still water, were simple, being powered either by animals or humans. Devices of the latter type are still being used today in some parts of the world. Even with the Nile River's normally adequate supply of water for irrigation in Egypt, it was usually necessary to employ technology to direct and control its distribution, making agriculture a more complex undertaking than originally might be thought.

The disadvantages of settled agriculture sprang from the fact that society had "put all its eggs in one basket" and had committed itself to living in one place. A settled society is prey to flood, drought, and insects. Persistent weeds must be removed from fields before they displace crops. Houses and farm implements must be maintained. Crop seeds must be gathered and sown. The final product, food, must be harvested, stored, and distributed. In short, the settled farmer has more but must work harder to maintain his or her improved standard of living. Irrigated agriculture is even more technologically intensive and requires more complex social organization. Large irrigation projects demand larger groups to support them and must be maintained throughout the year, not just during the growing season. Irrigated farms produce more food per acre, more reliably than dry farms that rely on uncertain rainfall, but they also require more work per person fed. At the extreme are rice paddies in the river deltas of southeast China where three crops are grown each year. They are the most productive farmlands but also the most labor intensive. Today, most agricultural production in industrialized countries occurs on large farms where energy-intensive farm machinery substitutes for human labor and chemical fertilizers maintain soil fertility.

The second great technological revolution took place many centuries later, during the eighteenth century in Europe about 250 years ago. The *Industrial Revolution* replaced the muscle power of animals with coal-fired steam energy and then later, about 100 years ago, with gasoline-driven internal combustion engines. The first steam engines, patented in 1698, were designed to pump water from coal mines in England, but before long they were improved and used to power looms and other machines in factories. The machine age caused profound changes in economic and social relations. The number of people needed to produce food declined as the number of people engaged in factory work increased. People migrated from rural areas to cities in search of higher-paying factory jobs, and new inventions such as the cotton gin, the locomotive, and the telegraph laid the groundwork for the emergence of the complex technological society that we live in today.

The methods that a society uses to produce goods have a profound effect on what life is like in that society, for both producers and consumers of goods. Prior to the industrial age, production was organized by crafts. Individual artisans both designed and produced each individual product, usually guided by traditional techniques that were occasionally modified by creative innovations. The relative value of the product was largely determined by the artisan's skill. As a result, artisans were relatively autonomous, and production units often consisted of a single artisan and several apprentices in cottage industries.

When the invention of the steam engine made power available on a scale never previously possible, it became feasible to concentrate larger numbers of workers in one place, and to have each worker perform only a small part of the production process. This resulted in a much more specialized division of labor, and the factory system was born. The factory system required far greater concentrations of power, labor, and raw materials than either agriculture or cottage industries. It also required the development of infrastructure for transportation of raw materials to the factory site and finished products from the site. Railroads and canals were thus as essential a part of the Industrial Revolution as the factories themselves. The industrial system also required a large labor force near the factory, so society's living patterns were reorganized to include factory towns where workers lived and the means to supply them with food and other necessities. Factories were often located near sources of power or raw materials, resulting in net population shifts away from agricultural lands.

In the early twentieth century, technological experts working under the banner of "scientific management," developed by F. W. Taylor in 1911, studied the production process and learned what each worker knew about making the product. They then ordained the perfect way to produce a given product using standardized parts, the division of labor, and mass-production techniques, what each worker would do, and at what pace he or she would do it. Each worker needed fewer skills and could be paid less per item. Cheaper workers making larger numbers of products using specialized machinery resulted in less expensive goods. Lower prices resulted in increased standard of living for consumers. Factory work may have become onerous, but a salary could buy more than it could previously. In recent decades, much of the world's production has moved to low-wage countries such as China and India where workers are paid far less for their work than workers in developed countries would be paid for comparable labor; workers in these countries usually do not have the right to form unions and bargain collectively with their employers. But jobs with low wages and limited rights, many claim, are often better than no jobs at all or trying to scrape out a subsistence living on small farms.

In the search for increased productivity, working conditions in early factories were often harsh and dangerous. In response to the many abuses that existed, employees often battled tyrannical bosses for the right to form unions and bargain collectively, many times suffering injuries or even death for their actions. The sacrifices made by such organizing drives secured improved working conditions and raised the standard of living of millions of workers and their families. A similar process of humanizing conditions of factory workers is now taking place in the developing countries where most current production is located. Despite the dominance of the factory system, crafts did not vanish entirely. They survived in niches where no one could think of an economical way of applying mass-production techniques or as a way to produce distinctive, high-quality goods. In some cases, they survived because traditional cultural values prevailed over the lure of newer technologies. As David Edgerton (Selection 1.1.3) notes, in many countries sewing machines continued to be used in homes to make clothes for the family, and in India, Mohandas Gandhi revived the spinning wheel as an alternative to mass-produced thread. But the dominant trend throughout the latter half of twentieth century was toward mass-produced, globally distributed consumer goods produced by workers in low-wage countries.

The technologies of power production were driving forces of the industrial system, and each new source of power required industrialized society to provide an accompanying infrastructure to make the system work. Water power, an ancient technology, was limited in availability and location prior to the building of aqueducts and required relatively little additional infrastructure beyond that already available in an agricultural and craft society. Coal could be more widely distributed, but coal-powered factories were large because efficient steam engines were large. Railroads and canals began to crisscross the countryside from mine to factory to market. Monetary supply and financial services had to expand to serve a system with increasing separation between producer and consumer. Electricity is a more flexible source of power, capable of efficiently driving both large and small machines. As Ruth Schwartz Cowan (Selection 1.1.2) observes, electricity permitted greater decentralization of industry supported by a network of power grids that eventually reached nearly every house and factory in the country. Oil and gasoline revolutionized transportation and distribution of goods. Internal combustion engines fueled by gasoline and diesel oil made it possible to have smaller vehicles, and smaller vehicles continued the trend toward decentralization. However, gas- and oil-powered vehicles required more and better roads. The U.S. interstate highway system, built in the 1960s–1980s (and similar systems in other industrialized countries) are society's most recent contributions to an industrial technology system based on oil, a system that may now be reaching its final phrase, perhaps to be replaced during the twenty-first century by a "greener" energy system that uses renewable forms of energy.

Many people believe that since the mid-1970s we have been going through a third great technological transformation—from the machine age to the *information age* (also called the "third wave" and the "knowledge revolution"). Computers, communications satellites, fiber-optic cable, and other developments—which make possible global, high-capacity, high-speed communications technologies such as the Internet—are already profoundly changing the way that we live, work, and play.

Revolutionary developments in computing and communications technology have transformed the workplace, faster than some would like but slower than its visionaries had hoped for. The earliest successes of computers in industry were in payroll, inventory, and similar routine and repetitive kinds of record keeping. The automated processes were well understood, straightforward, and implemented exactly as they had been done before the advent of computers. In some cases, they didn't even save time or work, but they were the wave of the future.

The next stage gave decision makers more and better information to enhance efficiency, competitiveness, and other factors reflected in the bottom line. Computers made it possible to gather and organize data on an unprecedented scale. Also successful were the attempts to use computers to improve scheduling and reduce inventory in the production process. Goods stored in inventory cost money to store and contribute nothing to profit until they are used or sold. Predicting exactly how much of which raw materials and parts are needed at which steps of the manufacturing process and scheduling their arrival in the factory at precisely the right place at precisely the right time was the just-in-time manufacturing technique developed in Japan that led to real gains in productivity that drove the global economy in the 1990s.

As computers and computer programmers got better, computers became capable of doing jobs that were formerly thought to require human intelligence. Typically, computers proved capable of doing far more than most people would have predicted in advance and far less than their most vocal proponents claimed was possible. Although the conceptually most impressive achievements were in areas like expert systems for medical diagnosis, the biggest successes of computer technology were in the simpler applications now so common that we take them for granted: automatic pilot, antilocking brakes, electronic fuel injection, and most important, in more flexible, general-purpose tools and machines for making other products.

With flexible, modifiable, reprogrammable tools, it was no longer necessary to have long production runs to amortize the setup time of the machinery. Computer-controlled machinery could switch quickly from one task to another, and customized production runs became in some cases economically viable. Supply could now more accurately follow demand, and both idle machinery and unproductive inventory were virtually eliminated in those industries adopting the new technology.

The synergies created by computers, user-friendly software applications, satellite-mediated communications, the Internet, containerization, and rapid and relatively inexpensive air freight made possible the kind of geographically distributed production systems that are characteristic of the contemporary era *of globalization*. One can now order a computer to one's precise specifications on the Internet, have it custom built in a Chinese factory, and delivered by an air freight carrier to your door in a matter of days. In fact, without computers and rapid worldwide communications, our present-day global marketplace would not be possible. Some authors, such as Thomas Friedman (Selection 2.1.1) believe that around the year 2000 we entered a new phase of this information-revolution form of globalization, what he calls "Globalization 3.0." This new phase springs from a Web-based global platform that enables multiple forms of knowledge sharing and collaboration irrespective of distance; this in turn creates a "flatter" world in which the economic playing field is getting more level between people in the developed and the developing countries. Cass Sunstein (Selection 2.2.1) explores how Web-enabled collaboration using wikis, open-source software, and blogs is changing the way in which knowledge is assembled, transformed, and disseminated in the information age. But ICT is not only changing commerce and industry but also transforming the power of government and big corporations to collect and assemble data on individuals, as described by Jay Stanley and Barry Steinhardt (Selection 2.2.3). It is also altering the way in which soldiers operate on the battlefield, as described by Max Boot (Selection 2.2.2). Futurists such as Rodney Brooks (Selection 2.3.1) and Ray Kurzweil (Selection 2.3.4) predict that by the middle of the twenty-first century synergies created by the convergence of ICTs, artificial intelligence, robotics, biotechnology, and nanotechnology will create another technoscientific revolution, what Kurzweil calls a "singularity," in which the intellectual capabilities of our machines will exceed that of human intelligence. While some, like Kurzweil, welcome such developments, others, such as Bill Joy (Selection 2.3.3), fear that we may not be able to control the technological genies once they are out of the bottle. Still other authors, such as William Clocksin (Selection 2.3.2), doubt that artificially intelligent machines will ever be able to master the complexities of human narrative communication. Whichever of these future projections turn out to be correct, it is certain that we will have to grapple with the social impacts and ethical challenges of twenty-first-century technologies.

SCIENCE, TECHNOLOGY, AND SOCIETY

In the modern world, technology and science often go together, with science supporting technology and technology supporting science. Although they now share a great deal in common, their goals have been historically different. In the ancient world, science, then known as natural philosophy, was viewed as an elevated activity involving pure contemplation and the value-free pursuit of knowledge, whereas technology was associated with more practical concerns and with the arts. It was not until the beginning of the modern period in the seventeenth century that there was a decisive shift to the view that scientific knowledge was valuable because it was useful to us in gaining mastery over nature. This shift was largely due to the writings of several influential philosophers such as Rene Descartes and Francis Bacon. Bacon's works, particularly *Novum Organon* (1620) and *New Atlantis* (1624), are notable for their contempt of traditional speculative philosophy and their emphasis on the importance of empirical methods of investigation through which the secrets of nature could be revealed by means of judicious experiments. In 1637 Descartes wrote the *Discourse on Method* in which he proclaimed that

> It is possible to attain knowledge which is very useful in life; and that, instead of speculative philosophy which is taught in the Schools, we may find a practical philosophy by means of which, knowing the force and the action of fire, water, air, stars, the heavens, and all other bodies that environ us, as distinctly as we know the different crafts of our artisans, we can in the same way employ them in all those uses to which they are adapted, and thus render ourselves masters and possessors of nature.[4]

This change in the dominant view of the nature and bases of human knowledge set the stage for the modern belief in progress, which was expressed by Bacon as the belief that "the improvement of man's mind and the improvement of his lot are one and the same thing."[5]

Despite the marriage of science and technology in the modern period, some significant differences remain between the two enterprises. Technologists primarily seek to answer the question "How?" ("How can we keep warm in the winter?" or "How can we see distant objects that are invisible to the naked eye?") Engineers seek to design and produce useful material objects and systems that will function under all expected circumstances for the planned lifetime of the product. Science, on the other hand, may be considered as a form of systematic empirical inquiry, which seeks to describe the underlying laws governing the behavior of natural objects. Scientists primarily try to answer the questions "What?" and "Why?" ("What kind of thing is this?"

and "Why does it behave the way it does?"). In the early stages of science when little was known, the immediate goal of the science was to describe and classify the phenomena of the natural world. As more things became known, the sciences began asking, "How do these things change over time and interact with each other?" Scientists sought laws and principles that would enable them to predict and explain why things in nature behave as they do. This search produced the scientific revolution in the seventeenth and eighteenth centuries, culminating in the work of Sir Issac Newton. But Newton's universe has been superceded by Einstein's, and his by quantum mechanics and string theory. Despite the abstract nature of contemporary physical theory, natural science continues to provide the intellectual basis for technology.

Technology needs science to predict how its objects and systems will function so that it can tell if they will work, and science supplies the predictive laws that apply to these objects and systems. However, although the laws of science are often simple to state, applying them to the complex objects of technology is often anything but simple. Sometimes the engineer must experiment with the complex objects that are the building blocks of a technology to find out what will happen. At the same time, technology makes direct and obvious contributions to the progress of science. The laboratory equipment that the scientist uses is the product of technology. The biologist would discover little without a microscope and the particle physicist even less without an accelerator. In recent years, the lines between the role of the scientist and that of the engineer or technologist have become increasingly blurred. Much of the current research agenda is dictated by the possible practical applications of new scientific knowledge, and most research is carried out by multidisciplinary teams. This merging of science and technology has led some writers, such as Bruno Latour, to speak of contemporary research as *technoscience,* a term used to draw attention to the interdisciplinary character of most contemporary research as well as the social and historical contexts in which innovation takes place.[6]

The conventional linear understanding of the relationship between science and technology holds that science discovers natural laws, technology applies scientific knowledge to practical problems, and the market selects which technologies are destined for widespread diffusion and use by society. However, this simplistic model has been replaced in recent years by a more sophisticated understanding known as the social construction of technology (SCOT) model. According to SCOT, science and technology have a symbiotic relationship, each one helping the other, while social values shape the precise forms that technological artifacts take. As Judy Wajcman (Selection 1.2.3) points out, the new sociology of technology supports the view that "technological artifacts are socially shaped, not just in their usage, but especially with respect to their design and technical content."

Social values play a crucial role in shaping technologies and in determining which of several technological options gain widespread acceptance in society. The use context of technology ultimately determines the meaning and deployment of technological innovations. Consider the Amish religious sect of central Pennsylvania and Ohio who shun the use of many modern conveniences such as the radio, televisions, video recorders, and telephones in the home because they fear that their use would destroy the rhythm of family life and cause separation to develop among members of the community. However, the Amish make compromises with modern technology, allowing flashlights, hearing aids, and electric welders for what they collectively decide to be legitimate reasons.[7] But if society's values and attitudes toward technology play a central role in determining the course that technological change takes, what attitudes should we have toward technology? What kinds of moral values should guide the future development of technology in the twenty-first century?

TECHNO-OPTIMISM VERSUS TECHNO-PESSIMISM

Our attitudes toward technology are complex and often ambivalent. We cannot but acknowledge and credit science and technology with delivering many wonders that have improved and extended our lives, and many people believe that improved technologies hold the solution to our problems in the twenty-first century. But many people are also disturbed by what they view as technology being out of control and see technology as a threat to our traditional ways of life, to our environment, and even to our survival as a species. These contrasting attitudes toward technology are often referred to as *techno-optimism* and *techno-pessimism*.

Techno-optimists tend to emphasize technology's benefits; they believe that science and technology are not the cause of society's current ills; they do not believe that technology needs to be controlled or regulated; and they have faith in "technological fixes" that will solve outstanding social problems. Techno-pessimists, by contrast, tend to emphasize the risks and costs of technological changes; believe that many social ills are attributable to technology; and think that technology needs to be controlled or is incapable of being controlled. They do not have faith in "technological fixes" to solve social problems, instead emphasizing moral or political solutions.[8]

While there are some extreme Luddites (those who are opposed to technological changes) and antitechnologists, the dominant view of contemporary society still seems to be a cautious form of techno-optimism. The modern idea of scientific and technological progress continues to hold sway not only for people in the developed countries but also increasingly for those in the less developed nations of the world who tend to see development largely in terms of access to more sophisticated forms of technology. However, although technological development can raise the standard of living, rapid technological and social change also brings with it social dislocation, identity confusion, and a sense of disappointment and social alienation. Part of the problem is that technology has been allowed to assume a greater and greater role in human affairs without anyone in particular being responsible for this change. Some writers see this as a problem, and others see free technological innovation as the source of prosperity and human progress.

Among the ideas that critics of technology question is the concept of progress. Throughout most of history, most societies believed strongly in tradition, and changes were presumed to be unwelcome and probably harmful. Kings sat comfortably (or uncomfortably) on their thrones, and when they were replaced through succession or conquest by other kings, quality of life changed little for the general populace. As late as 1800, life was relatively little different than what it had been in prehistoric times—most people lived in extreme poverty. Then came the steam engine, the railroad, and the automobile.

Productivity exploded in the factory and on the farm as new crop varieties and chemical fertilizers enabled fewer farmers to produce more food than ever before. As gains in productivity outstripped population growth, the industrial societies of England, Germany, and the United States grew wealthier faster than any societies in history. Telephones and railroads shrank time and space, and the factory system mass-produced goods that offered unimagined comfort and convenience to the bulk of society. Improvements in agriculture, medical advances, and improvements in public health and hygiene increased life span. In the industrialized world, progress was more than an idea; it was an everyday fact of life, and the cornerstone of progress was seen to be scientific discovery and technological innovation.

In the industrialized world, however, over a century of unchallenged belief in progress was disturbed by several rude surprises. World Wars I and II demonstrated that human cruelty and brutality were still with us, only magnified by weapons capable of producing mass death. Although science and technology could put a man on the moon, the Cuban missile crisis in 1962 reminded the world that we were only a button's push away from a global nuclear war that could destroy humankind. That same year, Rachel Carson published *Silent Spring* in which she warned that pesticides such as DDT were accumulating in ever-larger amounts in species that progressed up the food chain until eagles and peregrine falcons could no longer reproduce. DDT was making their eggshells too thin to keep from cracking. It did not take a genius to realize that humans are also high on the food chain, and DDT was eventually banned. But more bad news was to follow. Mountain lakes in the northeastern United States and Europe were found to be too acidic to support fish, and the problem was traced back to acid rain, automobile emissions, and the exhaust of coal-burning electric power plants. Asbestos, our modern weapon against the age-old danger of fire, turned out to cause the lung disease mesothelioma in asbestos workers and in people living and working in asbestos-lined buildings. Radioactive by-products of nuclear power plants piled up, and no one could think of a foolproof way to keep them isolated and sealed for the thousands of years that they would be a hazard. In 1986 the Chernobyl nuclear disaster spread radioactive contamination as far away as Sweden, and the world became even more worried about the dangers of nuclear power.

Once the myth of technology as unmitigated blessing was destroyed, some people began looking for hazards posed by technology with as much fervor as had previously accompanied the search for benefits. They were not disappointed; there were heavy metals in the rivers and fish, farmland soil erosion and salinization, lead paint in pipes, houses built on industrial waste dumps, health problems of people processing radioactive materials, smog, ozone holes, radon, and global climate warming. Technology helped in the search for its own defects by supplying satellite photographs and instruments that could detect trace chemicals in parts per billion.

Many potential threats to human well-being have been identified, and others no doubt soon will be. Some may be false alarms that are best ignored; some may be early warnings for which action will someday have to be taken; and some may be urgent last calls for which the optimum time to respond has already passed. If technology is responsible for many of our present problems, it will likely be technology that will enable us to overcome them, sometimes in the narrow sense of finding a technological fix but more often in the wider sense that the processes of democratic decision making and economic restructuring are social technologies that we use to address and resolve social problems. As Sheila Jasanoff (Selection 1.2.4) urges, the issue is "no longer whether the public should have a say in technical decisions, but how to promote more meaningful interaction among policy-makers, scientific experts, corporate producers, and the informed public." Taking part in these decisions in a democratic society, however, depends on informed "technological citizens" who have attained a degree of scientific and technological literacy.

Technological citizenship is a modern moral virtue. Being a good technological citizen implies an understanding of mutual rights and responsibilities between oneself and other citizens and between citizens and the government. Among our rights as citizens are the right to receive knowledge and information about technologies and how they might affect our lives, the right to express views and opinions about the development and use of technologies, and the right to participate in decisions concerning the development and deployment of technologies that are potentially harmful to us. To exercise any of these rights, however, citizens must first accept the responsibility to educate and inform themselves about the nature of the technologies that are changing their lives and to understand the ethical and public policy dimensions of the decisions in which they claim the right to participate.

As Langdon Winner (Selection 1.2.2) emphasizes, technologies are not value neutral. In each case, there are human ends and values that stand behind and direct the technological processes. Technology itself is perceived by most people as of positive value because they understand that through technology we can increase our powers and capabilities and are therefore better able to satisfy our needs and desires. But most people also realize that technological innovations are seldom all for the good, and almost inevitably trade-offs need to be considered. A new drug may help cure a disease but may also produce undesirable side effects in some patients and may in the long run promote the spread of new and more drug-resistant forms of the disease. Car ownership may enable one to move about freely and comfortably, but it also entails loan payments, insurance payments, repairs, gasoline, smog, car accidents, global warming, and other downside effects.

Predicting how inventions and technological innovations will be used and how they will ultimately affect society is often very difficult. The history of technology is full of stories of inventors and innovators who had no idea of how their inventions and innovations would ultimately be used or the far-reaching effects that they would have on society. Johannes Gutenberg, inventor of the printing press and movable metal type, was a devout Catholic who would have been horrified to know that his invention enabled the Bible to be widely printed and so helped stimulate the Protestant Reformation. Thomas Edison apparently believed that the phonograph would be mainly used for recording people's last wills and testaments and would undoubtedly be amazed by today's tapes, CDs, and MP3 players, all of which are descended from his invention for recording sound. And who, until recently, would have thought that chlorofluorocarbons, which have been used for decades as refrigerants, would be eating away the ozone layer in the upper atmosphere? Given enough experiences of this kind, one gets the idea that every new technology has not only known and expected benefits and costs but also unknown and unforeseen benefits and costs. New technologies sometime even produce consequences exactly the opposite of what they were intended to produce, what the author Edward Tenner calls "revenge effects."[9] Powerful new technologies alter the social context in which they arise; they change the structure of our interests and values; they change the ways in which we think and work, and they may even change the nature of the communities in which we live.

Another feature of technological change is the way in which it produces winners and losers in society. If technology is a source of power over nature, it is also a means by which some people gain advantage over others. Every technological revolution has witnessed the competition among technologies and the eventual replacement of one technology or technological system by another. Think of what happened to blacksmiths when the automobile came along, or what happened to watchmakers when the quartz-electric digital watch came along, or what is today happening to bank tellers with the introduction of ATMs. In such processes of technological change, groups and individuals whose interests and livelihoods are connected to the older technology are usually the losers, and those whose interests are connected to the "next wave" of technological innovation are the winners. However, because the directions and effects of technological change are often unpredictable, it's difficult to tell in all cases whether any particular individual or group will come out as a winner or a loser.

Similar social phenomena are occurring today in the midst of the information and biotechnology revolutions and the economic phenomenon known as *globalization*. By and large, the wealthier and better-educated people in society remain largely favorably disposed toward new technologies such as computers, the Internet, gene splicing, and robots and toward the globalization of production and distribution that these technologies have made possible. Many others, however, see these developments as threatening their jobs and livelihoods, their religious beliefs, and their traditional ways of life. New technological elites are being created in each of these fields while other people are becoming newly unemployed. Such social effects of technological change bring into sharp relief the need to consider the ethical and moral dimensions of technology.

TECHNOLOGY AND ETHICS

In considering the ethical issues arising from technology, it is important to distinguish clearly between the specific products of technological development, artifacts (for example, clocks, internal combustion engines, digital computers, respirators, and nuclear bombs), and the typical uses to which people put them, or what might be termed their associated *sociotechnological practices*. The fact that a particular device or technology is available for human use does not by itself imply that we ought to adopt and use that technology, nor does it tell us how the technology should or should not be used. A gun, for instance, can be used in many ways: as a paperweight, for recreational target practice, for hunting, for personal protection, or for the commission of a crime. Although a gun has many uses, its valence lies in the social practices of use typically associated with it, which may or may not match its intended purpose. We can and do make moral judgments concerning the various sociotechnological practices associated with different products of technology. We accept some uses as morally legitimate, find others to be morally questionable or problematic, and take steps to restrict or outlaw certain other uses to which these devices may be put. In some cases, such as chemical or biological weapons whose only purpose is to produce mass death and destruction, we attempt to outlaw them entirely rather than to regulate their use. The war in Iraq that began with the U.S. invasion in March 2003 was premised on the notion that such weapons of mass destruction were present in Iraq and that, if not found and destroyed or allowed to fall into the wrong hands, could produce catastrophic results.

When we consider these sorts of questions about how the products of technology ought to be used, we are really asking questions about how people ought to behave or act. Questions about whether to use products of technology or how such products should be used are ethical questions; that is, they are questions concerning what we *ought* to do rather than about what we *can* do. Ethical questions related to technology are basically no different from other ethical questions that we ask about human conduct: In each case, we must attempt to determine which action or policy, from a range of alternative possible actions or policies that we might follow, is the one that we morally or ethically ought to choose. Viewed from the standpoint of technology, broadly defined, morality, ethics, and their cousin, law, are social techniques for regulating human behavior in society. They arose in human history at about the same time when most humans gave up the nomadic lifestyle and began building the permanent settlements that we call cities. Cities require the maintenance of high levels of social cooperation based on reliable expectations that others will act as they are required to do. For instance, a simple commercial transaction in which one person buys something from someone else at a mutually agreed-on price presupposes that the buyer and seller cooperate in settling on a price and, once a price has been agreed on, in actually exchanging the goods and money that the deal requires. Such economic exchanges are regulated by social custom and, in modern societies, by a complex system of laws permitting the drawing up of contracts that legally bind individuals to the performance of the agreement terms. Other laws, such as those that prohibit theft of private property or forbid others from assault, rape, and murder, are part of a social contract that we make with one another that allows us to live together in mass societies with a reasonable degree of freedom and security.

Many people are skeptical about whether there is single, universal correct moral viewpoint. However, almost everyone believes that there is a difference between right and wrong and that most people understand that difference and can use that understanding to guide their behavior. Ethical decision making, like most other things in the modern age, is something that can be rationalized and practiced in accordance with a technique. The technique of ethical decision making consists in a conscious attempt to get a clear view of the issues, options, and arguments that present themselves in any situation that calls for ethical judgment or decision. The technique is basically this:

1. Identify all *stakeholders*—that is, all individuals whose interests might be affected by a decision.
2. Identify all possible courses of action that one might follow.
3. Review all arguments for each option, developing pros and cons in terms of their potential risks and rewards for all stakeholders.
4. Then, after having carefully worked through such deliberations, make a rational choice about which of the available options has the strongest set of moral reasons behind it.[10]

Moral reasons are those that involve ethical principles governing such notions as fairness, justice, equality, duty, obligation, responsibility, and various kinds of rights. In most ethical decisions, such reasons contend with other, nonmoral reasons for actions based on prudence or self-interest, efficiency, and economy. From the moral point of view, ethical reasons ought always override nonmoral reasons for action when the two kinds of reasons conflict, although people do not always do what they ought to. Ethical decisions concerning the use of technologies involving judgments of value and obligation, responsibility and liability, and assessments of risk and benefit can arise at various levels: the personal level of individual behavior, the level of institutional or organizational policy, and the social level of public policy. As individuals, we are the consumers and users of the products of technology in our everyday lives; as workers or students, we belong to and participate in institutions or organizations whose policies and practices can affect our health and well-being; and as citizens, we all must be concerned about the ethical issues that we face because of modern technology.

Ethical concerns arising from technology can be divided into four kinds. The first and most basic address questions about whether and how traditional ethical values and norms apply in new technological contexts. Technological innovations enlarge the scope of possible human action by allowing us to do some things that we could not do before (for example, liver transplants) and to do things we could do before in different ways (for example, reheat food in microwave ovens). Each new technology thus raises the implicit ethical questions: "Should we employ this new technique/technology?" and if so, "How should we employ this new technique/technology?" In many cases, such questions are answered easily. However, in many other cases, decisions about whether, how, and when to use particular technologies can raise difficult and troubling ethical issues about how our traditional ethical values and rules apply in new technological contexts.

To illustrate this kind of issue, consider how our traditional notion of privacy is being altered by modern computer and communications technologies that make it much easier to collect and analyze information about individuals. In this arena, people are asking how the traditional value that we place on privacy can be protected in the digital age. Jay Stanley and Barry Steinhardt (Selection 2.2.3) raise the alarm concerning the increasing use of electronic-surveillance technologies by the government and giant corporations, and James Stacey Taylor (Selection 2.2.4) argues that on balance the use of these types of technologies will make us more rather than less secure, assuming that their use is properly regulated and controlled. But as even Taylor admits, how the calculation of risks and benefits turns out will depend to a great extent on the social and political contexts in which these technologies are employed and by whom.

Traditional approaches to ethics are basically two kinds: *utilitarian* (consequentialist) and *deontological* (Kantian). Consequentialist reasoning in ethics involves evaluating the rightness or wrongness of actions or policies in terms of the goodness or badness of the consequences that they produce. Ian Barbour (Selection 1.3.1) points out that it is often impossible to apply utilitarian, or consequentialist, reasoning to ethical problems involving technologies because it is difficult to quantify and compare the expected benefits, harms, and risks that they may produce when placed in use. One main theme of this book is that when we evaluate which new technologies to develop, which to deploy, and how to deploy them, we need to consider carefully both the benefits and costs and the opportunities and risks that the technologies entail—to the extent that we are capable of making such judgments. Often doing this sort of *cost-benefit analysis* is very difficult or extremely inaccurate because (1) manifold aspects need to be considered, (2) costs and benefits often have no common measurement scale (if they can be measured at all), and (3) we are uncertain in predicting future or long-term consequences of introducing a new technology into society. A second problem with the consequentialist approach is that it does not take into account the way in which benefits and harms are distributed and thus may give rise to allocations of social costs and benefits that are unjust. Despite these problems, consequentialist reasoning remains the dominant approach in the moral evaluation of technology.

Deontological theories in ethics emphasize not only justice but also rights and duties, which in some cases will lead to ethical judgments that would require us to follow a moral rule, honor a right, or discharge a moral duty even if doing so does not produce the greatest good. The theory of John Rawls may provide a way of combining the best elements of each approach by suggesting a way in which we can balance freedom and equality that allows each person the maximal liberty to pursue his or her own self-interest, compatible with an equal liberty on the part of others, while also requiring that deviations from equality be arranged so that they benefit the least advantaged.[11] Under this sort of view, for instance, everyone would have an equal liberty to benefit from new pharmaceutical treatments for disease, but the poorest and sickest among us would be entitled to social support to ensure that they can access these lifesaving technologies. Generally speaking, deonotological considerations set limits on the possible uses of technologies and counsel us to employ our technologies only within the limits of what is ethically permissible. So, for instance, although supercomputers operated by the National Security Agency make it technologically possible for the government to monitor the billions of e-mail messages that fly around the planet each day, ethical considerations concerning civil liberties such as freedom of speech and privacy should determine what forms of electronic surveillance should be allowed.

A second kind of ethical problem arises concerning some sociotechnological practices that, although innocuous in themselves, when employed by individuals, raise serious concerns when their effects are aggregated across millions of users. There is, for instance, nothing intrinsically wrong with throwing empty bottles and cans into the trash to be carted off to the nearest landfill. But when millions of American households engage in this practice on a regular basis, we find that we are wasting recyclable resources and running rapidly out of space for new landfills. Similar sorts of *aggregation problems* arise with respect to air and water pollution, overfishing, suburban development, and many other cases in which the aggregate and cumulative effects of individual sociotechnological choices threaten the long-term well-being of all.

The current debate over global climate change due to the accumulation of greenhouse gases in Earth's atmosphere exemplifies this kind of ethical issue. The 2007 report of the Intergovernmental Panel on Climate Change (IPCC) documents the fact that "the atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have increased markedly as a result of human activities since 1750 and now far exceed pre-industrial values."[12] The changes are mainly due to the burning of fossil fuels and agriculture and are thus anthropogenic—that is, caused by human activity. We are already seeing the effects of this global warming in phenomena such as the shrinking of glaciers, the defrosting of the tundra, and the reduction in Arctic ice in the summer. The IPCC predicts that unless we do something to stabilize the atmosphere, Earth may reach a "tipping point" later in this century that will dramatically alter Earth's climate and produce a significant rise in the ocean levels that will inundate many coastal areas and cause other significant environmental damage. In his popular documentary film, *An Inconvenient Truth,* former vice president Al Gore states his view that global climate change "is not a political issue; it is a moral issue, one that affects the survival of human civilization."[13] (Gore and the IPCC were awarded the 2007 Nobel Peace Prize for their work on the issue of global climate change.)

Garrett Hardin (Selection 2.5.1) analyzed similar moral problems in his famous essay "The Tragedy of the Commons," using as his example herdsmen overgrazing common lands. In such cases, each herdsman treats the common pasture as an inexhaustible resource and seeks to maximize his own self-interest. But if every herdsman does this, the result is that the pastureland soon becomes overgrazed so that nobody can use it. Earth's atmosphere has been treated in this way by humankind throughout most all of our history, but especially since the beginning of the industrial age. We are rapidly reaching the limits of how much carbon the atmosphere can absorb without altering its geochemistry. Hardin argues that voluntary measures to limit this kind of overuse will not succeed and that the only solution available to us is greater responsibility. This responsibility is based not on individual acts of conscience but on "definite social arrangements" under which we mutually agree to coerce ourselves into reducing the emission of greenhouse gases into the atmosphere.

As Stephen Gardiner (Selection 2.5.2) points out, we use the term *responsibility* in both a backward-looking, or retrospective, and a forward-looking, or prospective, sense. In the retrospective sense, we think of responsibility primarily as liability for causing past harms, particularly in order to allocate blame and determine who should make amends. If we adopt this view of responsibility for global climate change, then clearly the older industrialized nations—such as England, Germany, and the United States—are responsible for the greater proportion of the greenhouse gases that have accumulated in the atmosphere and thus should bear the primary responsibility for cleaning up the mess. A second reason for allocating responsibility primarily to the older industrialized nations is that they are richer than other nations and can more easily bear the burden. On the other hand, from the prospective point of view, we still need to determine how to control future emissions of greenhouse gases, and in this case, various proposals have been made about how to allocate this responsibility for the present and future. One proposal that Gardiner discusses suggests that we determine the current acceptable level of anthropogenic greenhouse gas emissions necessary to safeguard the health of the planet and then allocate shares of that amount to each country based on its population. Under this scenario, however, the older industrialized countries would still bear the greatest burden of reduction. The United States with roughly 5 percent of the world's population is responsible for emitting roughly 25 percent of the greenhouse gases, while India and China, although they are both rapidly industrializing, still are below their per capita allocations. Under most all of these scenarios, it is becomingly increasingly clear that continued delay in addressing this global problem is not an acceptable option.

A third class of ethical problems associated with technology concerns questions of *distributive justice* and social equality. New technologies generally benefit or advantage certain groups or members of society over others—namely, those who have mastery over or access to the technology first. In many cases, we think that because such advantages are earned through hard work or special knowledge they are therefore deserved. However, in other cases, we may feel that such restricted access to some technologies gives certain individuals or groups unfair advantages over others, and we seek to extend access to everyone in the society. Public libraries, for instance, were built to ensure that everyone could obtain access to books and learning. Today, we are putting computers and Internet connections into public schools for the same reason. Questions of social justice and equality of opportunity thus can be occasioned by technological innovation. Freeman Dyson (Selection 1.3.3) discusses several historical examples of this phenomenon and goes on to propose some technologies of the future that may increase social justice.

Questions of social justice are also at the heart of the debate over the current wave of globalization. Some authors, such as Thomas Friedman (Selection 2.1.1) and Jagdish Bagwati (Selection 2.1.2), believe that globalization, as it has developed over the past several decades since the advent of the information age, is a net benefit to everyone on the planet and has the potential to alleviate poverty and create prosperity worldwide. Others, such as Joseph Stiglitz (Selection 2.1.3) and the International Forum on Globalization (IFG) (Selection 2.1.4), believe that the rules under which globalization has been conducted thus far are inherently unfair and are designed to allocate the benefits primarily to the already-rich countries and corporations at the expense of the poor and vulnerable. They argue that considerations of social justice demand that the global economic system be reformed to produce greater fairness and justice for all citizens of Earth. And in the spirit of Hans Jonas's notion of long-range responsibility (Selection 1.3.2), the IFG proposes that certain critical resources, such as freshwater, be placed off-limits to the market.

A fourth and final kind of ethical question raised by technology concerns the scope of modern technology's power to alter the world. In earlier and simpler times, we humans did not have the power to disturb very much the balance of nature or affect the life prospects of other species or future generations of human beings. But when we entered the *nuclear age,* all that changed. With nuclear weapons, we now have the power to destroy virtually all life on Earth. Nuclear waste material from our reactors will last 10,000 years, posing a potential threat to generations as yet unborn. Issues and concerns of this type raise what are perhaps the most profound ethical questions about humankind's relationship to nature through technology. Should we continue down the course set for us by Bacon and Descartes, who advised us to seek knowledge so that we could become the masters of nature, or should we change this course toward stewardship and long-term sustainability?

As Hans Jonas (Selection 1.3.2) argues, some contemporary technologies seem to open new and deeply troubling ethical issues, issues of a kind that humankind has never had to address before. The existence of nuclear weapons, for instance, forces us to "consider the global condition of human life, and the far-off future, even, the existence of the human race." The emerging technology of genetic engineering creates the prospect of our designing our own children and turning humanity itself into a kind of artifact. Some authors, such as Lee Silver (Selection 2.4.1), seem to welcome this prospect, but others, such as Leon Kass (Selection 2.4.2), believe that we are at a crossroads that requires that we relinquish the opportunity to acquire the knowledge that would enable us to create such a brave new world. Others, such as Michael Sandel (Selection 2.4.3), believe that we can place reasonable limits on how biotechnology and genetic engineering will be employed on human beings that will allow some uses but prohibit others. Genetic engineering of plants and some animal species is already in widespread use, as pointed out by Claire Hope Cummings (Selection 2.4.4), and it may already be impossible to put this particular genie back in the bottle. Jonas, for his part, believes that technologies such as these that give us the capability to alter nature in fundamental ways should be approached with a sense of "long-range responsibility" and, above all, a sense of humility.

ENERGY, ENVIRONMENT, AND A SUSTAINABLE FUTURE

Increasing evidence shows that our current technological society is rapidly transforming Earth's environment and probably not for the better. Hardly a day goes by that we do not hear of global environmental problems such as deforestation, species extinction, depletion of nonrenewable resources, desertification, acid rain, water pollution, ozone destruction, and atmospheric warming. In part, these problems represent the long-term and largely unforeseen effects of the Industrial Revolution, but they are also caused by the sheer weight of human population growth and the increasing demands that it places on Earth's ecosystem.

As Robert Kates (Selection 2.5.4) points out, there has been much discussion of the idea of a transition to systems of sustainable development, and many organizations and institutions now say they are committed to helping to bring about a more sustainable future. However, until recently the concept of sustainable development was ambiguous and ill defined, and discussions often tended to sidestep difficult questions about the real trade-offs between economic growth and environmental protection, and between the interests of the present and future generations. But a study group of the National Academy of Sciences in 1999 helped clarify the matter by defining a sustainability transition as one "that would meet the human needs for food, nurture, housing, education, and employment" for what is now predicted to be a maximum human population of about 10 billion people around the midpoint of the twenty-first century. Meeting this goal will require significantly reducing current levels of hunger and poverty while maintaining the essential life-support systems of the planet.

In 2000 the United Nations adopted the Millennium Development Goals (MDGs) in which the nations of the world committed themselves to the goals of eradicating extreme hunger and poverty; achieving universal primary education; promoting gender equality and empowering women; reducing child mortality; improving maternal health; combating HIV/AIDS, malaria, and other infectious diseases; and ensuring environmental sustainability.[14] According to the most recent MDG progress report, some progress has been made in some regions in meeting these goals by the target date of 2015, but much more still needs to be done. In particular, it is crucial that the richest countries honor their commitments to provide development assistance to the poor countries of the world. Particularly troubling is the continued increase of climate-warming carbon dioxide in Earth's atmosphere and the continuing migration of poor people from rural areas into already overcrowded cities. However, there are some hopeful signs even here as Janet Sawin and Kristen Hughes (Selection 2.5.3) report in their analysis of the ways in which improved building design, construction techniques, and energy-saving technologies can help us to create "greener" cities. The seeds of a future sustainable society are already present, but we need to nurture them so that they continue to grow.

The global threats of the twenty-first century require social solidarity and technological innovation for their solution. These threats are different in several important ways from the threats that we faced throughout most of our previous history. First, these threats arise not mainly from the consequences of individual acts or omissions or from forces beyond humankind's control but from our own collective action. Second, they do not involve direct harms, for the most part, but rather increased risks of harm that are distributed very broadly across individuals, often without their active participation or knowledge. Third, the threats affect not only the present but also the future—often the distant, incalculable future. Fourth, they threaten not only humans but also other animals, the natural environment, and life itself. Fifth, they are also to one degree or another the result of technology; they are problems that have arisen in part because of new powers given to us by technological progress, powers that we have not always learned to use wisely and responsibly. Sixth, they not only affect single communities or even single nations but also the whole of humankind.

Our previous ethics has not prepared us to cope with such global threats. Traditional ethics has focused primarily on the moral requirements concerning individual action, on the direct dealings between persons, rather than on the remote effects of our collective action. This problem is particularly important with respect to widely distributed technologies, such as the internal combustion engine, whereby the cumulative effects of individual decisions can have a major impact on air quality even though no single individual is responsible for the smog. By and large, traditional moral norms deal with the present and near-future effects of actions of individual human beings and do not prepare us to deal with cumulative effects and statistical deaths. Traditional ethics, above all, has been anthropocentric—the entire nonhuman world has been viewed as a thing devoid of moral standing or significance except insofar as it could be bent to satisfy human purposes. We have assumed that the natural world was our enemy and that it did not require our care (for what could we possibly do to harm it really?), and nature was not regarded as an object of human responsibility.

In the past, we have attempted to fashion our ethical theories in terms of these assumptions. The traditional maxims of ethics—for example, "Love thy neighbor as thyself," "Do unto others as you would have them do unto you," and "Never treat your fellow man as a means only but always also as an end in himself"—are in keeping with the individualistic, present-oriented, and anthropocentric assumptions of our ethical traditions. Even the Christian ethic of universal love does not transcend the barriers of time, community, and species. Even more modern ethical theories such as utilitarianism and Kantian ethics do not provide particularly good guidance when it comes to the sorts of ethical concerns raised by technology. In part this is because they were designed to be used to evaluate individual actions of particular moral agents. But the sociotechnological practices that comprise our collective action are not only made up of many individual choices—such as the choice to have a child, to eat a hamburger, or to invest in a mining stock—but also the aggregation of these individual choices, plus those of organized collectivities such as corporations and governments. In most cases, the individuals, business executives, or politicians who are making the choices that add up to our collective insecurity do not intend these threats to result, and neither they nor we consequently feel any sense of responsibility for them.

Although individuals view themselves as moral agents and consider themselves bearers of responsibility in all the roles in which they participate, the collectivities to which we belong do not. All the threats that we face are in part the result of this diffusion of responsibility. How then should we, the citizens of Earth, be responding to these environmental questions? Do people in richer countries have any responsibility to help those in poorer ones? Do we, in general, have any responsibilities to future generations concerning the long-term social and environmental effects of our present economic, lifestyle, and political choices? The notion of responsibility that we need to cultivate is not the backward-looking notion of responsibility as liability, which seeks to allocate blame for past harms, but the forward-looking sense of responsibility in which each of us and every organization and institution "takes responsibility" for doing our part to combat social injustice and to protect environmental quality for future generations of humans and the nonhuman species with whom we share this planet. This notion of social responsibility, although it is voluntary and discretionary, places real demands on us as individuals and members of communities and requires that we think carefully about the decisions and choices that we make.

All too often, decisions that involve complex political choices involving technologies are left to the discretion of elites (for example, scientists, engineers, policy "wonks," and corporate and government officials) even though the consequences of their decisions will usually affect the interests of others who are not elites. The other interested but often silent parties are sometime called *stakeholders*. We are all stakeholders in decisions concerning technology, but not infrequently the scientific, political, or corporate elites make decisions about these questions in ways that primarily benefit themselves at the expense of other stakeholders. It is often relatively easy for elites to "manufacture consent" for policies that they prefer by selectively sharing information about the possible risks and benefits of a particular technology policy with other stakeholders whose interests might be adversely affected by it.[15] For instance, in the 1950s U.S. soldiers were ordered to witness nuclear explosions and were told that there was no risk of harm due to radiation. In fact, there was a risk, and years later many of the soldiers who participated in these tests began developing lethal cancers. More recently, automobile companies, such as General Motors, conspired with giant oil companies and corrupt officials to "kill" a prototype electric car, the EV-1, despite consumer interest in an economical and nonpolluting alternative to petroleum-based personal transportation.[16]

To protect citizens against such unscrupulous practices, the government has established various special agencies, such as the Food and Drug Administration (FDA), the Environmental Protection Agency (EPA), and the Occupational Safety and Health Administration (OSHA), which are mandated to act as watchdogs and look out for the interests of the public and to prevent people from being exposed to unnecessary or unreasonable risks without their consent. However, the operations of these very governmental agencies have often become politicized, and key officials appointed to run these agencies sometimes represent corporate interests rather than the public interest.

Given the phenomena of regulatory capture by corporate interests, a more reliable line of defense is the hundreds of nongovernmental organizations (NGOs), such as Common Cause, Greenpeace, or the International Center for Technology Assessment, who conduct independent research, educate the public, and lobby decision makers to enforce and protect the stakeholder interests that they are supposed to represent. Such public-interest groups and the social movements that they represent play an important role in politics and provide a means, in addition to the ballot, by which ordinary citizens can participate in large-scale decisions that many affect their lives for good or for ill.

However, none of these advocacy groups can be effective without the support of an informed and attentive citizenry. In democratic societies, individuals and groups are given the right to inform themselves on the issues, associate with others having similar or common interests, and participate in the political discussions that will determine which laws and policies will be enacted. If we fail as individuals to exercise these rights—that is, if we shirk our responsibilities as technological citizens—it is likely that others will end up making these decisions for us, and when they do, they may not always have our best interests at heart or in mind. If we accept the responsibility to educate ourselves about the issues and to participate in the public conversations about them, then we will have some voice in how things will be decided and some control over the future directions that our technological society will take. In the last analysis, there is no way for us to escape this responsibility, living as we do at the cusp of the Third Millennium, for we are now all the children of invention.

Morton Winston
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NOTES

1. For a rather long but still incomplete list of some of humankind's most significant inventions, see the Time Line of Significant Technological Innovations on the inside front and back covers.
2. Compare this definition to that found in Rudi Volti, *Society and Technological Change*, 2nd ed. (New York: St. Martin's Press, 1992), in which technology is defined as "a system based on the application of knowledge, manifested in physical objects and organizational forms, for the attainment of specific goals" (p. 6).
3. The term *valence* is also used to describe the way in which tools and technological systems have "a tendency to interaction in similar situations in identifiable and predictable ways." The terms *end* and *focal function* refer to the purpose in the mind of the designer of the artifact. See Corlann Gee Bush, "Women and the Assessment of Technology: To Think, to Be; to Unthink, to Free," in *Machina ex Dea*, Joan Rothschild (Editor) (New York: Teachers College Press, 1983), 151.
4. Rene Descartes, "Discourse on the Method of Rightly Conducting the Reason and Seeking for Truth in the Sciences" (1637), *The Philosophical Works of Descartes*, Vol. I, trans. E. S. Haldane and G. R. T. Ross (Cambridge, England: Cambridge University Press, 1970), 119.
5. Francis Bacon, "Thoughts and Conclusions," in *The Philosophy of Francis Bacon*, ed. B. Famington (Chicago: University of Chicago Press, 1964), 93.
6. See Bruno Latour, *Science in Action* (Cambridge, MA: Harvard University Press, 1987).
7. See Donald B. Kraybill, *The Riddle of Amish Culture* (Baltimore: Johns Hopkins University Press, 1989), especially Chapter 7.
8. The terms *techno-optimism* and *techno-pessimism* were suggested by the discussion of pessimism and optimism about technology found in Mary Tiles and Hans Oberdiek, *Living in a Technological Culture: Human Tools and Human Values* (New York: Routledge, 1995), 14–31.
9. See Edward Tenner, *Why Things Bite Back: Technology and the Revenge of Unintended Consequences* (New York: Random House, 1996).
10. For more on ethical decision making, see C. E. Harris, Jr., *Applying Moral Theories*, 3rd ed. (Belmont CA: Wadsworth, 1997).
11. John Pauls, *A Theory of Justice* (Cambridge, MA: Harvard University Press, 1971).
12. Intergovernmental Panel on Climate Change, "Contribution of Working Group I to the Fourth Assessment Report," February 5, 2007; available online at http://www.ipcc.ch. Accessed July 7, 2007.
13. Davis Guggenhein, *An Inconvenient Truth*, Paramount Pictures, 2006.
14. United Nations, "Millennium Development Goals"; available online at http://www.un.org/millenniumgoals. Accessed July 9, 2007.
15. The idea of manufacturing consent is based on the work of Noam Chomsky, See especially, Noam Chomsky, "The Manufacture of Consent," in *The Chomsky Reader*, ed. J. Peck (New York: Pantheon Books, 1987), 121–136.
16. Chris Paine, *Who Killed the Electric Car?* Sony Pictures, 2006.

PART ONE

Perspectives on Technology

1.1 Historical Perspectives

1.2 Social/Political Perspectives

1.3 Ethical Perspectives