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The Center for Nanotechnology in Society
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Nanotechnology and Society

Nanotechnology and Society: Ideas for Education and Public Engagement

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Nanotechnology is poised to be one of the most significant scientific and industrial transformations of the 21st century. With nanotechnology, scientists are acquiring abilities to understand and manipulate materials at the scale of atoms and molecules. In the process, they are creating the potential for people to see the world, act in it, and change it, in fundamentally new ways. These abilities may even transform the foundations of society. While many of today's applications of nanotechnology are mundane, tomorrow's applications may seem miraculous. Just as they have with electricity, automobiles, and computers, people will use nanotechnology to change their lives, their work, their habits, their notions of fun and play, and so much more.

We believe it is essential, therefore, for society to deliberate about a nanotechnology-enabled society, especially now, as nanotechnology is being developed. Today, many are already making choices that will underpin our future, collective nanotechnological lives. What kind of society will we build, as a society, using nanotechnology? Whose ideas and choices will guide the design of nanotechnologies—consumers, corporations, regulators, or citizens—especially when those technologies impact the day-to-day lives of millions? Toward what ends will those ideas and choices be directed? To whose benefit, and whose detriment?

Such questions are not easy to answer. The answers are often complex, and just as often controversial. We see the exploration of these questions as an opportunity for people to think more clearly and deeply about how societies may change through their choices about nanotechnologies. The themes we discuss below are meant to stimulate further conversation about the ways that human lives and technological change are caught up in one another.

We hope that these ideas will help motivate people to take an active role in shaping the future of nanotechnology—and thus the future of society. The ideas contained here are meant as a starting point. We hope that they will help formal and informal science education projects to meaningfully address the societal dimensions and implications of nanotechnology. We welcome requests for further information, and we would welcome the opportunity to discuss these ideas further with anyone who is considering their use in an educational project or initiative.

1. **People make nanotechnologies**

> *Technology often seems to force changes on society and even, at times, to drive history itself. This impression is false. No technologies, including nanotechnologies, are independent of the choices that people make about how to design, create, buy, use, critique, regulate, or reject them. Individually and collectively, people shape technologies at all stages of innovation—whether they have technical training or not. Scientists and engineers are, of course, crucial to the process, but entrepreneurs, investors, consumers, lawyers, activists, and ordinary citizens are all part of the social forces that contribute to technological change. Thus, each of us has opportunities to make choices about technologies with greater care and forethought.*

It is obvious that people make nanotechnologies. Yet, we often talk about technologies as if people have little or no control over them. We say that a new technology brings about social change or that it "impacts" society. But attributing to technology the ability to force social change is mistaken. People are in control of all aspects of the production, distribution, operation, and use of new technologies (and, as we will see below, they have considerable choices about how to shape those technologies). Many people do change their lives when new technologies become available, as when people decided to buy cell phones and carry them with them everywhere, but these are still conscious or sometimes unconscious choices. Or, sometimes, people can be forced to change their lives when someone else decides to use a technology in a new way: for example, when day laborers were put out of their jobs because farmers decided to buy tractors to work their fields instead. So, when people say that technology causes social change, we should instead look behind the appearances for the choices people are making that are bringing about that change.

People make choices at all stages in technological development. A technology may be technically feasible, but unless someone makes a persuasive case for its development, it may never see the light of day. Even inventions that are technically and economically feasible—and socially desirable—may lose out in the competition to acquire scarce funding, laboratory space, and other resources necessary for research and development. Even if a particular idea captures the attention of researchers, funding agencies, or investors, it is rare that that idea represents the only possible technical approach. Rather, creative technological problem-solving is both enabled and constrained by social relationships, product timelines, technical imaginations, regulations, and markets—all of which are themselves the products of human activities.

In the case of nanotechnology, individuals such as Eric Drexler and Mihail Roco spent years promoting their visions of the field to politicians who ultimately agreed to provide financial support. But their respective visions for the future of nanotechnologies were very different from one another. At least for the time being, scientific and policy communities have selected Roco's vision over Drexler's as the one worthy of billions of dollars of government investment. As a result, nanotechnology research is taking one path toward the future, with few or no public resources committed to the other.

Other players have also contributed to what nanotechnology means today, its rate of development, and what types of nanotechnologies will become available in society. Business leaders have lobbied for nanotechnology and invested significantly in nanotechnologies of relevance to their forms. Non-governmental organizations (NGOs) like Greenpeace and the ETC group have also highlighted potential risks of nanotechnologies. Their efforts have helped persuade Congress to increase funding for research on the environmental and health implications of nanotechnology. A group of influential scientists, policy makers, business leaders, and NGOs called ICON has pushed for international standards for the safe handling of nanomaterials. The Meridian Institute, another NGO, has pushed for funding nanotechnology research that might help alleviate global poverty.

Government agencies in the US and elsewhere are making decisions about whether nanotechnologies will require new regulatory frameworks, or whether existing regulation will prove sufficient. As they make decisions, agencies like the Environmental Protection Agency and the Food and Drug Administration will help shape the kinds of nanotechnology-enabled products that reach the market. Similarly, American consumers have already begun to lend market resonance to nanotechnologies by quickly adopting such relatively mundane "nano-enabled" products as clothing, athletic equipment, electronics, and health care—as well as the *iPod nano*, a product that isn't really nanotechnology but helps brand "nano" as cool (to consumers) and profitable (for businesses).

Decisions about nanotechnologies matter immensely. These choices involve personal and professional values, social and institutional structures, policies and regulations, consumer needs and wants, and public hopes and fears. They also involve trade-offs among these values, institutions, and beliefs. These choices, however, will ultimately help determine what nanotechnology will mean, what applications it may yield, how people will use these applications, and how society will reshape itself around their use.

2. People live with, in, and through technologies

> *Technologies provide important influences on how people choose to live. They shape what people are able to see and do. They enable people to act in certain ways and foreclose other possibilities. They shape our relationships and facilitate communication and transportation. We modify behavior to take advantage of or avoid them or to ensure their continued operation. For example, we structure our foreign and military policies to help secure supplies of petroleum, which not only fuel the large technological systems of transportation and energy production that are the core of our economy, but also provide critical raw materials for products such as plastics and pharmaceuticals.*

Although it is certainly true that people make nanotechnologies, technologies are also key parts of the ways we live. Technologies do not force us to live in certain kinds of ways, but neither are they just tools. The availability of technologies makes some kinds of lifestyles easier and others much more difficult. Even as we remember that people choose to design, construct, use, or resist technologies, we also acknowledge that people make these choices because technologies can become important parts of their lives as status symbols and elements of day-to-day work and life. Often, our social values, behaviors, and interactions depend on or are focused on technologies.

A good example of living with, in, and through technologies is communication. An essential feature of all human relationships and institutions, communication is also fundamentally shaped by the technological systems that we have designed. Businesses – and many of the rest of us—place high value on face-to-face communication, which is partly why many people travel on airplanes. Telephones are an enormous technological system, but until very recently, they only allowed voice communication from one place to another. Today, we are inviting a range of different technologies that enable people to communicate in new and different ways, each with its own unique characteristics and possibilities. Cell phones, unlike their older cousins, are person-to-person and can be used in many more places—to the demise of many pay phones and even some people's land lines. An email is not a perfume-scented love letter. A blog is not a personal diary. Each is a novel form of communication that is facilitating new forms of social organization at times and in places that would not have been possible with earlier technologies.

Technologies also become part of the moral fabric of life as we shape our expectations around them. Cell phones are a good example. For example, many parents give their children cell phones in order to be able to reach them in an emergency. This capability has become so important that, when schools recently tried to ban cell phones, on the request of teachers whose classrooms were being disrupted by text messaging, parents objected. They feared for their children's safety in the event of violence or disaster, and they wanted their children to always have their cell phones with them.

There is also the question of where and when it is acceptable to use cell phones. Many states are discussing laws that would prohibit the use of cell phones when driving. Many restaurants and libraries have signs discouraging the use of cell phones, as do many businesses near their cashiers. All testify to growing moral questions about the inappropriate use of cell phones in a manner that disrupts others.

Along similar lines, the failure to answer the phone has also acquired greater social relevance with new cell phones. Parents whose children don't answer the phone experience greater concern that something might be wrong, while business employees may not be able to truly go on vacation, since their cell phone (or wireless computer) allows them to remain in contact with their employer. All in all, "being out of touch" has acquired new meaning as a result of new technologies.

Technologies can even become so important that people's lives become dependent on them. The residents of New Orleans built a city that depended on the continued functioning of technological systems that kept water out. When those technologies failed, a disaster occurred. On a smaller scale, we depend on working cell phones, cars, and alarm clocks every day. We rely so deeply on the functioning of a number of technological systems that we don't even notice—until they no longer work.

How will we incorporate nanotechnologies into our lives? This is probably the central question that is at stake in deliberations about nanotechnology-in-society. What is clear is that the choices we make, both collectively and individually, will have significant implications for our lives in the future.

3. Technological and social change are closely interconnected

> *When people make choices to build and buy new technologies, and then they subsequently alter their values, behavior, and relationships around those new technologies, the result is a close connection between changes in society and changes in technological systems. New technologies offer us new ways to see*

> *the world and new ways to act. In turn, these innovations prompt questions about the adequacy and appropriateness of existing values, behaviors, relationships, and institutions. In asking, wrestling with, and answering these questions, people change society in and around new technologies.*

One corollary of the fact that people live with and through technologies is that social and technological changes are closely coupled. Throughout history, changes in technologies have gone hand-in-hand with changes in the broad organization of society. Today, for example, workers in factories pursue lives and work that would have been unimaginable before the invention of the modern manufacturing technologies. Societies have also changed dramatically with the introduction of the automobile into widespread use, and again with the adoption of the personal computer and the Internet. In each case, as people have designed, tested, marketed, and bought new technologies, they have also made novel choices about how and where to live their lives, bringing widespread and sometimes dramatic social change. Today, for example, only 2% of the US population lives on farms, a tiny fraction of those who lived on farms only 100 years ago.

How does this kind of large-scale social change happen? Let's take an example. In the early 1980s, a new method of reproduction called in vitro fertilization was developed in which doctors extracted eggs and sperm and fertilized them in the laboratory instead of in the body. Perhaps this might simply have gone the way of other novelties, except that one group of people saw this as potentially very helpful: relatively wealthy couples who, biologically, were unable to have children now had a possible route to pregnancy.

This interest inspired entrepreneurial doctors to create clinics devoted to in vitro fertilization (IVF). Today, 50,000 or more couples in the United States choose to use IVF to have children each year. IVF doctors now make considerable incomes in the field and new opportunities for social and technological innovation have opened up, including markets for sperm, eggs, and surrogate mothers.

The changes have not simply been economic but social and ethical as well. Some IVF procedures, for example, raise questions about parental rights and responsibilities. What happens if a surrogate mother decides not to give up the genetically unrelated baby she has carried to term to the child's genetic parents? In this case, the courts have become the venue for deciding the legalities of parenthood when three persons rather than two are involved. Another aspect of parental rights is raised by new tests that allow for genetic assays of embryos. Do parents have the right and/or responsibility to conduct genetic tests on their unborn children? If they do, what decisions are they subsequently allowed to make on the basis of the information provided by those tests? Can they abort the embryo? Under what conditions: never; only if the test shows that the child will acquire a deadly childhood disease; if the test shows a disposition for cancer or other major disease; or if the genetics show that the child will show a socially undesirable trait?

These questions and others like them arise because a new technology has given us the ability to know and act in new ways. Answers to such questions are often controversial precisely because they represent departures from settled notions of morality and social behavior. Thus, answering these questions entails social deliberation through which individuals and communities decide for themselves and others what kind of a world the future will be with the new technology in it (including, potentially, the outright rejection of a new technology as incompatible with individual or community values, although this is rare). This is how social change happens around new technologies.

Nanotechnologies raise similar questions. Such questions may seem relatively mundane today. The choice to wear stain-resistant pants or to use nanotechnology enhanced golf balls, for example, probably doesn't raise many moral eyebrows. It is not an accident that most of the early applications—stain-resistant pants and improved golf balls—are technologies can enter our lives quickly. These technologies are simple modifications of existing technologies that do not call into question our existing values, behaviors, or interactions with others. Of course, people may still choose to act in new ways—golfers may brag even more than they usually do—but people do not yet appear to see important social consequences to such changes (although some have speculated whether wearing stain-resistant pants might increase people's propensity to eat in the car, which is known to increase the chance of accidents).

On the other hand, the question of whether the Food and Drug Adminstration should regulate the use of nanoscale versions of chemicals currently used in cosmetics and sunscreens is more complex and controversial. Regulators and consumers must make difficult decisions about whether to treat nanotechnology-enhanced versions of current products as equivalent in terms of public and personal risk to their non-nanotechnology predecessors. These decisions have considerably greater moral import. Over time, we can expect developers of nanotechnologies to use consumer and regulatory responses to these initial nanotechnologies to plan for future nanotechnologies. In turn, future innovations may raise deeper questions about existing values, behaviors, and relationships, prompting us to ask if our norms, our social arrangements, and our institutions are still up to the task of keeping society safe.

Now imagine a hypothetical nanotechnology product (but one that several scientific laboratories are working on): an inexpensive detector that can identify the influenza virus. Such a detector might initially be developed because of ready-made markets in health care and homeland security. But if it is inexpensive enough, people will probably also use it in other circumstances, such as schools or the workplace. And while we may anticipate early on how health care workers or security experts will use the detector—perhaps even because such users were involved in its planning and development—we may not so easily foresee how others would respond. Might parents insist that schools send other people's children home if they test positive for the virus? Will schools fear lawsuits if they do not test children every morning? We may find our values, our behaviors, and our relationships changing if we adopt this new technology.

The first-order impacts of cheaper and faster detection of influenza—faster access to health care and fewer illnesses and deaths—are often easier to imagine than these more subtle second-order impacts. The latter appear only as society reorganizes itself around new technological possibilities, as a result of thousands or millions of individuals and groups making technological choices. The results can be extraordinary, however. Since the introduction of the automobile, for example, many societies have radically transformed themselves, creating urban and, especially, suburban infrastructures that differ vastly from prior cities. Future nanotechnologies, too, may facilitate radical new ways of organizing society.

This perspective offers a valuable opportunity for nanotechnology. Can we learn to anticipate potential "second-order" impacts of nanotechnologies? Scenarios of the future to assist our imagination or early-warning systems that identify early changes in peoples' values and behaviors might help people to better deliberate and decide how to shape the development of alternative future nanotechnologies and societies.

4. There are many ways to design, implement, and use a given technology, and many technological solutions to any given problem

> *There is a common belief—a myth, really—that technologies exist the way they do because there is no better way—that equations, engineering practices, and the market allow for no other possibilities. But technologies are often highly flexible. There can be many different technical solutions to the same problem, many different notions of what the problem is in the first place, and many different possible ways that a given technology might be used to fix it.*

Technological systems and the societal arrangements that form around them are highly flexible. This results, in part, from choices available in the design and operation of technologies, as designers seek to meet a range of social, economic, and political criteria. Flexibility can also arise from the different meanings that different groups may give to the same technologies or from the different technologies used by different groups to solve the same problem. As a consequence of this technological flexibility, there is not one nanotechnology but rather many different nanotechnologies, driven by different agendas and choices, as well as by different ways they are interpreted and used.

Consider the problem of getting to work each day. Many people in the United States conclude that the best way to accomplish this is to drive a gasoline-powered vehicle. Automobiles seem the obvious choice to many because they are relatively fast and can take them wherever they want to go whenever they want to go. But while the automobile meets certain needs and values that are important in modern society, these are not the only needs people have and they do not embody all of the values that people have. And we should note that, the use of an automobile only seems easy because the driver can depend on others to build and repair it; find, mine, and refine oil into gasoline; deliver gasoline to businesses for sale; etc.

There are many solutions to the question of how to get from one place to another. The solution one develops is shaped by a wide range of criteria including economic, political, and social factors. Public transportation may be an option, if it is available, and if the person cannot afford a car or values environmental goals, the time to read, or even the ability to interact with others. A bike may be possible, if the distance is not too great, the weather amenable, or the person is concerned about getting exercise. With enough money, a person might choose to live close to work and walk each day, unless perhaps there are concerns about personal safety or the quality of schools or other services nearer to the workplace. Or perhaps the person identifies with the culture and lifestyle of skateboarding and he or she rides a board to work everyday – again assuming the terrain is friendly.

Another aspect to technological flexibility is that the same technology may mean very different things to different people. The same automobile that one person sees as a means of getting to work may be for others a source of identity, a hobby to enjoy in one's spare time, an icon of freedom, or a symbol of excessive consumption. A vivid cartoon in a South Asian newspaper shows an overweight gentleman with a cigar, leaning out of a Cadillac saying to a poor farmer in Latin America, "Yo amigo. We need that tree to prevent global warming." A person might buy a hybrid car because they think it will help the environment, because they like its futuristic looks, or because their favorite Hollywood star just bought one. A parent might buy a Japanese economy car because it is inexpensive and easy to maintain. Their son, on the other hand might add some accessories and decals, join a car club, and go drifting with it.

Nanotechnologies are also flexible, both in application and in interpretation. For instance, a handful of scientists are working to use nanotechnology to build interfaces between humans and machines that they believe will allow those who can afford the technology to live greatly extended lives. Other scientists and politicians contend that not only are such efforts technically impossible but also that the values motivating such efforts are misguided and dangerous. These latter groups are attempting to steer nanotechnologies to solve health problems that will benefit a much broader array of people. The discussions between these groups, and the influence that each can exert on engineers, corporations, politicians, consumers, and citizens will shape the technologies that we develop and the world we will eventually live in.

The directions we take in research and innovation are not preordained. There is thus no one best route to creating nanotechnologies. Nor is there necessarily one best nanotechnology for the job. We must recognize that we always have choices in how we design nanotechnologies and which nanotechnologies (if any) we use to solve problems. We must therefore decide what kinds of nanotechnologies we want – or are willing to tolerate.

5. **Technological systems are frequently highly complex, interdependent, and difficult if not impossible to predict**

> *Technologies are rarely stand-alone objects. They rarely work or have much impact unless they are part of complex systems. These systems connect individual technologies to far flung networks of people and machines. They can create unanticipated impacts and make it easier for technologies to break down or result in disasters.*

If your whole idea of technology is a simple electronic device like your MP3 player, a computer, or a pacemaker, then you are getting only a few notes of a very large score. A lot of work went into designing and building each of these objects. Engineers distilled corporate goals, technical requirements, and industry and regulatory standards into a design. Metals and plastics were fashioned into components that must work together seamlessly. A manufacturing facility was built to assemble these components. Market researchers analyzed people like you to see how best to sell you such items (which may also have fed into design choices). The manufacturer designed a way to package and distribute the devices. Retail shops and websites stocked the items and developed ways to get them to you. And marketing teams made you aware of the product and convinced you to buy it.

But these efforts describe only part of what makes the device possible. If you want it to do anything you have to cast your net still wider. The device may come with a battery (which, in turn, had to be made), but you'll want to plug into the electric power grid—which is of course linked to generating facilities that turn fossil fuels (or nuclear decay or falling water) into electricity.

And then, if it is the MP3 player we're talking about, there is the music. Musicians must record their work, and these recordings must then be transferred faithfully onto CDs or into digital music files for you to buy at the store or on the Internet. The intellectual property rules that protect their creative work must be in place. All of this interconnectedness is essential to making the MP3 player work. If any of the steps were missing or just a little bit different, what the device does and means might be very different.

The complexity of such systems also makes it difficult for the creators, regulators, and users of technologies to foresee the implications of their choices. Recently, for example, regulators in the United States required gasoline to contain a higher concentration of ethanol, which in the U.S. is most often made from corn. They hoped that such gasoline would help reduce both dependence on foreign oil and global warming. This seemingly simple change, however, rippled through a number of very different systems. Commodities traders decided that this policy change would make corn more valuable in the future, and so they began to buy it all over the world. Their rush to buy corn caused its price to shoot up, which increased not only the cost of ethanol, but also the cost of tortillas in Mexico. In Mexico City, thousands protested the impact of a more expensive staple food on their families. While such small changes do not always ripple into such big effects, the pervasive and integrated technological systems we have created are always open to the possibility that what may seem to be local decisions will have significant and broad reaching effects.

Because small disturbances can have large effects, technological systems can be very vulnerable to disruptions. The electricity grid is a good example. Over the past few years there have been a number of blackouts because small errors at a relay station or in computer software have given rise to widespread effects that shut down systems hundreds of miles away. Such blackouts may be inconvenient for some, but hazardous for others because we live with and through our technologies. Hospitals need to keep life support systems running, for example. And during a heat wave, or an average summer day in Phoenix, the absence of air conditioning can actually be deadly (and one common cause of blackouts is the demand on electricity grids from excess air conditioning used during heat waves). These vulnerabilities also make such systems potential targets for terrorists. A knowledgeable person with the intent to bring down a large technological system could have an even more disastrous effect.

Some scholars warn that the more complex and interconnected we make our systems—even those designed to increase our security—the more vulnerable we become to terrorism.

The complexity of technological systems is important to keep in mind in the analysis of new nanotechnologies. The interlocking systems that make our technologies possible also make it very difficult to forecast or control the outcomes of decisions. Whenever we develop new technologies, we must be very careful to think about the potential ramifications for a broad array of people. What we think are small discrete decisions may ultimately have broad effects in places we would not expect. Unanticipated consequences should be seen as the norm rather than the exception. And we must think about ways to monitor such effects and take steps to remedy them.

6. Social and technological change can be incremental—or disruptive—and it can be hard to forecast which

> *As technologies and societies change together, sometimes that change is incremental as a new technology provides a small improvement on an existing technology. Stain-resistant nano-pants are but one example. Other times, however, new technologies can be highly disruptive. In the 1990s, for example, many agricultural chemical and seed companies began to worry about the potential impact of new genetic engineering technologies on their own products. Pest resistant crops, for example, would eliminate the need for farmers to use – or buy – pesticides. A major reorganization of the two industries followed, as the chemical industry bought up the seed companies and invested in its own biotechnology products. Where once there were hundreds of small seed companies, today fewer than ten large companies control most of the US market share.*

The complexity of the interactions between technology and society makes forecasting social and technological changes difficult. In wrestling with questions about what new technologies mean for their lives, people imagine the changes that might occur around inventions.

Sometimes, people imagine huge changes that later turn out to be modest. In the 1950s, many politicians, scientists, and futurists claimed that nuclear power would make electricity "too cheap to meter." While nuclear power plants have had some impacts on our world, they have not produced the unlimited, costless electricity that was once predicted.

Sometimes the reverse happens as well. Looking back in history, we often see that major changes occurred unexpectedly and, at first, without notice. Thousands of years ago, women who saved seeds and put them into the soil instead of eating them contributed to the invention of agriculture, thus initiating profound changes in how food is produced, stored and processed, as well as how humans cooperate, build communities, trade with others, relate to the environment, etc. Perhaps motorized farm equipment appeared initially to farmers as merely labor-saving devices to improve agricultural efficiency. Now we know they contributed to the large-scale mechanization of agriculture in the United States and the subsequent urbanization of American life.

While there are some predictions that nanotechnology will contribute trillions of dollars to the global economy in the relatively near future, we still have very little idea what particular products will be involved. Equally unclear is how their production will be organized, e.g., in a few big firms, in many small ones, concentrated in a few industrialized nations, or spread across the globe. And we have little idea whether those products will provide only incremental modifications—e.g., longer-lasting tennis balls, stain resistant pants, or dirt-repellent windows—or whether radical and even disruptive products will be created.

At times it behoves those interested in promoting or opposing nanotechnology to emphasize that it will create vast social changes that will either make the world a better place or create enormous problems. Thus some claim that nanotechnology enabled power systems will fulfil the original ambitions of nuclear power to produce electricity that is "too cheap to meter." Others worry that nanotechnology may enable us to reprogram human biology to design and create "super soldiers". At other times it may be more expedient to downplay possible changes. At the same time that a corporation is telling its customers that a nanotechnology-enhanced product is revolutionary in its design, it may tell government regulators that the same product is nothing new and thus does not need to be regulated any differently from its non-nanotechnology counterparts.

Instead of attempting to predict the social changes that technologies may cause—in ways that would likely be both short-sighted and self-serving—we need to ask hard questions about both the beneficial and disruptive changes that might be possible, as well as their potential magnitude. For example, scientists are working with nanotechnology in an effort to create devices such as "labs-on-a-pill" that, while passing through a person's intestine, can detect and respond to illness. What would such a lab-on-a-pill mean for the practice of medicine? Others have suggested that nanotechnology may revolutionize energy production, perhaps by developing a nano-photoreceptor that can make any device powered by the sun. How would our lives—and global economic and political systems—change if we were no longer reliant on fossil fuels, or if we were no longer limited in how much energy we could use?

To battle security threats, nanotechnology-enabled surveillance devices might watch, identify and track the movement of people and goods—everywhere. What, in turn, would this mean for privacy, civil liberties, and the relationship between citizens and their government? Nanotechnologies may also bring about significant changes in national security and warfare possible by providing new devices to infiltrate foreign countries, observe and target certain groups or populations, equip soldiers, and expand arsenals. Might they also, like other military technologies, spark new arms races, as the know-how behind nano-weapons spreads?

Nanotechnologies might even become part of new human-machine combinations that will enhance the performance of physical, cognitive, emotional, or other functions. What would such developments mean for human identity, health, and therapy?

In all of these cases of potentially disruptive change, both individuals and societies need to find appropriate ways to reflect on and deliberate how to respond to scientific and technological change on the one hand, and on how science and technology might best serve to solve human needs and problems on the other. A key part of this effort is to recognize that new technologies may be more or less disruptive then the rhetoric surrounding them may at first make them appear.

7. New technologies are often controversial and may create new risks

> *As a consequence of the flexibility of technological design and use, as well as the different meanings attributed to them by different groups of people, new technologies are often controversial. The same kind of novelty that makes new technologies innovative and interesting to some groups and in some contexts may also make them risky or unpopular to other groups and in other contexts. Variations and inequalities in the distribution of risks and benefits can also foster controversy. Such controversies do not so much reveal anti-technology or "Luddite" tendencies as they indicate the existence of robust social debate over how to design the ways we will live with technologies in the future.*

Because new and emerging technologies are often complex—and occasionally disruptive—they are also often controversial. Consider cell phones. While many people in wealthy countries have cell phones (and many in poorer countries, too), their spread has not happened entirely without disruption. Responding to concerns about safety, some locales have outlawed the use of cell phones while driving vehicles. Libraries and commuter trains have instituted quiet zones, while theaters, restaurants, meetings, and classrooms remain vexed by ringing cell phones and their owners who tend to them—and by participants who are busy text messaging or reading email. Some athletic facilities have even banned their use because the cameras included on many cell phones have been used on unsuspecting guests in the showers.

Indeed, in many cases, the changes that occur around new technologies are even more significant and cause deeper conflict than cell phones have to date. Questions arise about how to adjust our moral, legal, and political sensibilities and understandings to new technologies and the new kinds of behavior they enable. At the same time, controversies emerge as a result of the complexities of technological systems. Different groups of people interact with complex systems in very different ways. Some may be consumers who want cheap products, while others are laborers who want to be well paid for their work.

A good example of the potential controversy associated with new nanotechnologies is the possibility discussed above that nanotechnology may enable the production of inexpensive, accurate detectors of an illness like influenza. Such detectors might be put to use, for example, to screen airplane, train, or subway passengers, raising questions about the conditions under which it is permissible for the government to prevent someone from traveling. Similar questions might be asked about whether commercial venues like malls, movie theaters, or sports stadiums might be legally obliged to install such detectors to protect the health of workers and customers.

In the United States, the courts have become central to managing conflicts over new technologies. Congress and state legislatures have generally been reluctant to set standards of design, behavior, and use for new technologies, and so people who believe they have been harmed by new technologies have little recourse besides the legal system. The result has been an explosion of technology-related lawsuits. Infertility treatments, for example, which have gone largely unregulated by states or the federal government, have led to dozens of court cases on the rights, responsibilities, risks, and benefits associated with in vitro fertilization techniques.

Controversies may also arise around new risks. One of the central claims about nanotechnology is that, as the size of materials change, so too do their properties. Many nano-sized materials have different electrical, magnetic, physical, and biological properties than larger particles of the same material. Gold, for example, is used in jewelry because at that scale it does not react with other substances in the environment (for example, tarnish). At the nano-scale, however, gold is very highly reactive. The special properties of nano-scale materials are one reason why people are so excited about the potential of nanotechnologies. At the same time, these novel properties also create the possibility that nanomaterials will interact in surprising new ways with complex biological systems, both in nature and in our bodies, creating new environmental and health risks.

At the moment, there are few if any processes in place to monitor either the presence of nanoparticles or their effects in most air, water, soil, ecosystems, or human bodies. Scientists are also unsure what the long term effects of nanotechnologies may be on human development or ecological health.

This uncertainty about the effects and dangers of nanotechnology is matched by uncertainty about how to manage such risks. Who is responsible for preventing nanotechnology risks? Who decides what an acceptable level of risk is? While regulations and safety standards exist for other chemicals, most of these regulations do not seem to apply to nanoscale materials. Indeed, nanotechnology crosses many different fields of use and thus may fall into gaps between existing regulations. Even where nanomaterials do fall under existing regulations, those regulations may not make sense. For example, titanium dioxide has long been used in sunscreen and is regulated by the Food and Drug Administration (FDA). But now sunscreen manufacturers are using titanium dioxide nanoparticles, which have different properties. Can they be treated the same for regulation, or do we need new regulations?

Controversies about new technologies should not be seen as simply roadblocks to new "advances." They are an important way in which we evaluate new technologies and debate about what values are most important. If we are to develop and accept technologies that promote our goals, we must actively discuss the pros and cons of new developments. Deliberations over how to best employ technology—and how to best organize our world around this technology—are a vital part of building better societies.

8. **Our technological imagination shapes our future**

> *Because of our inability to foresee all of the possible consequences of new and emerging technologies, our imagination becomes crucial in how we understand, interpret, and give meaning to technology in our lives. History, fiction, art, and even speculation are key elements in the stories we tell*

> *ourselves about why we should or should not support new technologies, why we should choose this design over that one, or how we envision a technology will impact our lives. Different ideas of progress and different experiences with technology shape our perspectives on whether a particular technology will be good or bad for society. Our ideas and expectations for the future also take on a life of their own, influencing the technologies we design, create, and choose.*

New technologies are often accompanied by elaborate promises of future benefits, and nanotechnologies are no different. The proponents of nanotechnology promise that it will alleviate human suffering by developing new diagnostics and pharmaceuticals and that it will end pollution through clean production and the development of new techniques to clean up old messes. On the other hand, some people fear the future of nanotechnology, suggesting that it will aggravate existing inequalities, allow surveillance of everyone and everything, and disturb what it means to be human by merging humans and machines in troubling ways.

These hopes and fears about whether new and emerging technologies will be good or bad for society are shaped by different notions of human progress. For some people, progress means healthier, more meaningful lives. For others, it means greater material wealth. For yet others, it means a life more attuned to nature and the environment. These ideas are crucial to how we understand and give meaning to technology.

The consideration of nanotechnology encourages the use of our imagination because so much of its potential is still to come. We use history, fiction, art, and speculation in the stories we tell ourselves to draw analogies, explore possibilities, or instill warnings about what might happen in the years to come. These imaginations can influence decisions about whether we should or should not fund new research, why we should choose this design over that one, or how to adjust our lives to the possibilities of new technologies.

In his early propaganda on behalf of nanotechnology, for example, Eric Drexler focused his imagination (and that of his readers) on billions of tiny machines working to solve many kinds of problems. Futurists like Bill Joy and science fiction writers like Michael Crichton picked these ideas up and gave them a more troubling twist, imagining a world of nano-machines run amok. In turn, Mihail Roco, who is in charge of nanotechnology research at the US National Science Foundation, explicitly rejected the idea of creating tiny machines and has, instead, imagined and funded a very different vision of where the field of nanotechnology research should go.

Science fiction writers often present worlds that are shaped by technology in an effort to show us where some of today's technological decisions may be headed. In a similar way, scientists often include visions of the future in their grant applications and solicitations for venture capital investment. They may justify their research with a picture of a world that could be made possible if only they had the funds to carry out the projects they have outlined.

This technological imagination is important because what we imagine informs what we create. Our visions about the future always contain an element of self-fulfilling prophecies—technologies come about a certain way because, at least in part, we expect or imagine them to do so. High School students who get excited about a particular vision presented in *Scientific American* or *Popular Science*—or a science fiction story—may decide to become an engineer in order to actively create such a future. One nanotechnology researcher, for example, was inspired by the movie *Gattaca* to try to create a portable device for rapidly sequencing samples of DNA. The way that we choose to design and invest in new technologies reflects a vision of the future. The futures that we imagine today thus help to shape the futures that we actually get tomorrow.

We should always keep in mind, however, that the future still has a tendency to surprise. There are always a great number of unknowns, and the technological imagination can deceive as well as inform. It is always important to ask which visions we are attributing to new technologies, why we are attributing them, and to whose ultimate benefit and cost? Whoever controls the visions of the future controls the decisions made today—even if those decisions do not necessarily result in the ultimate achievement of the visions that inspired them.

Being reflective about the future and exercising our technological imagination is particularly important in the context of nanotechnology. Nanotechnology remains relatively unformed as a technology, but the imagined possibilities of nanotechnology—good and bad—are already circulating. It is important that we subject those imagined futures to critical scrutiny and recognize that no one should have a monopoly on the construction of futures. It is important that a wider array of citizens become involved in imagining the nanotechnological future. Scientists and entrepreneurs may invent nanotechnologies, but we will all have to live in the future that those technologies imagine and create.

9. People already play an important role in governing new technologies, and they can play an even bigger role

> *People can and do play important roles in governing technological change, but they can also do so more actively. In many countries, citizens are being encouraged to become more active in debating new technologies through a range of activities that bring scientists and citizens into conversation (these sometimes go by the names of Science Cafés, consensus conferences, museum forums, and nanotechnology dialogues). These activities recognize the importance of citizens talking to scientists about the latters work, as well as citizens talking to one another about what the latest science means. In this way, people can learn about various possibilities for technology governance.*

People play an important role in governing new technologies in many ways. As parents, they imagine and plan futures for themselves and for their children. As consumers, they influence the market through their purchases, and they use new products in ways that their inventors anticipated and in others that they never imagined. As citizens, people help choose the political leaders who invest in the creation of new knowledge and technologies. As scientists and engineers they choose what knowledge gets pursued, elaborated, and reduced to practice. As activists they seek to assure that knowledge is pursued and applied in the public interest.

But while a large fraction of us plan for the future, buy new products, and even vote, only a very small fraction of us get to participate directly in the pursuit of new knowledge or in helping to ensure that its technological application is directed toward the public good. There are a number of ways to increase this fraction, ranging from opening science and engineering careers up to more diverse groups of people, to encouraging citizens to become more active in debating new technologies (for example, through Science Cafés, consensus conferences, museum forums, and nanotechnology dialogues), to finding ways for citizens to become involved in designing research priorities and technological development. These activities recognize the importance of ordinary people talking to scientists about their work and to one another about what scientific research means.

It is also important to understand that we have choices in how to guide or govern new technologies. Too often, it seems, that choice is portrayed as banning a new avenue of research or a new technology, or leaving it to an unfettered marketplace. This is a false choice. We have significant experience in varied and even nuanced approaches to managing technological change. We require laboratory researchers to follow a variety of rules regarding human and animal research subjects, occupational safety, and bio-hazards. We have regulatory agencies like the Food and Drug Administration, which oversees the testing of new pharmaceuticals for their safety and efficacy, and the Environmental Protection Agency, which performs a similar task for the toxicity of new chemicals and pesticides. We mandate safety and fuel efficiency standards for automobiles, "do-not-call" lists for telephones, and privacy requirements for medical records. We require licenses and operating standards, including age and competency requirements, for technologies like cars and guns that may be particularly dangerous in the wrong hands. We indemnify some technologies, like nuclear energy, against major accidents to protect their early adoption. We require that knowledgeable professionals prescribe, handle, and distribute new drugs.

These are only some of the many tools with which to govern scientific and technological change, and citizens have access to many of them either directly or through traditional political processes. In the case of nanotechnologies, we will need to figure out as a society precisely how we want to set up rules governing its use. This will not be easy, but it will be a crucial part of choosing our nanotechnological future.

10. We need to be more reflexive about how we assess nanotechnology

> *Each of the above points speaks to the need for many kinds of people, not just scientists, politicians, and CEOs, to reflect on and become more involved in decisions about new technologies. By "more reflexive," we mean many things: to better understand and use our ability to shape technology to achieve good societal outcomes; to recognize and better manage the uncertainties that come with complex technological systems; to watch carefully for unanticipated outcomes; to promote robust social debate about the kind of technological world we want to live in; and more. To help us do all these things, each of us needs new approaches for assessing social and technological changes in our own lives and more broadly in society.*

Each of these "big ideas" about nanotechnology-in-society can help us to become more reflexive about new technologies. That is, they assist us in thinking through the role of technologies in our lives and societies that we often take for granted. This kind of thinking is important because, in order to make better decisions about the future, we need to understand not only the role of science and technology in society but also our own role in shaping science and technology.

One way to improve this reflexive understanding involves asking just what it would be like to live without a particular technology, for example, email or a cell phone. How would you get along without it? How would you relate to people who continued to use it? You might even consider giving up the technology for a short period of time, the way some religiously observant people refrain from some activities during certain holidays, or the way campers go "back to nature" without some modern conveniences. The experience of being without a technology provides you with the opportunity to reflect on the technology itself, your relationship with it, and how it shapes your relationship with other people. Thinking through technology in this way can help us to realize the impact of our technological choices on the basic structures of our life and help us to evaluate such choices.

It's one thing to imagine putting down your cell phone for a day. It's another to try to think about such things for technologies that don't even exist yet. That's why this reflexive attitude toward science and technology needs to be distributed broadly through society—among ordinary people who have hopes and dreams for a better future; among the politicians and bureaucrats who are setting priorities for scientific research and development; among the scientists and engineers who are conducting the research itself; among the entrepreneurs, clinicians, and other professionals who help translate what is discovered in the laboratory into something that the rest of us can use; and among all of us who use technologies every day.

What does reflexivity mean? It means recognizing that social and technological systems are closely intertwined and that changes in one will likely be accompanied by changes in the other. It means recognizing that we have choices about which technologies to design and use and how to govern them. It means developing a deeper understanding of the complexity and interconnectedness of technological systems and the ways that they could fail. It means understanding how technologies are connected to people's hopes, dreams, and fears, and how those visions are connected to decisions to design, build, and use new and emerging technologies. It means, perhaps most of all, not taking the technological world that we live in for granted, recognizing what it takes to create and maintain that world, as well as what changes in it might mean for each of us, as individuals, and for all of us, collectively.