Nanotechnology:
The Technology of the Future

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Everything we use in our daily lives is made of trillions of atoms and molecules. Whether handcrafted or not, most of these objects were created without any thinking about their atoms. But, as the American physicist Richard P. Feynman asked, “What if we could arrange the atoms one by one the way we want them?”

Nanotechnology is a new technology being developed that could make this scenario possible. This science has been called “General Purpose Technology.” Perhaps you’ve heard related terms thrown about in science fiction: “nanites”, “nanobots”, “nanoprobes” ,etc. Or maybe this mysterious new technology has escaped your notice. Nevertheless, scientists have dreamed of it being used for everything from ending world hunger to destroying the entire planet. While these scenarios may seem outrageous, the truth is not far off. Nanotechnology could make products from even our wildest science fiction fantasies within our reach.

Nanotechnology is the science of matter at dimensions between approximately 1 and 100 nanometers (National Nanoscience Initiative). These dimensions have unique phenomena enable novel applications not feasible when working with atoms. A nanometer is one-billionth of a meter. For example, a sheet of paper is about 100,000 nanometers thick, and a single gold atom is about a third of a nanometer in diameter. Nanotechnology also includes the ability to see and control individual atoms and molecules (Board of Regents of the University of Wisconsin System 2008).

Researchers seeking to understand the fundamentals of properties at the nanoscale call their work nanoscience; those focused on effective use of the properties call their work nanoengineering (National Nanoscience Initiative). Encompassing nanoscale science, engineering, and technology, nanotechnology is also known as “the manufacturing technology of the 21st century,” and “general-purpose technology” (Encyclopedia Britannica).

The history of nanotechnology began about 3.8 billion years ago when the first living cells developed. Within these cells, nanoscale biological machines generated energy and assembled molecules into larger structures (World Book Science 2009). Nanoscale materials are not new. They have been used for over a millenium. Early examples of nano materials were based on craftsmen’s empirical understanding of materials. For example, the Lycurgus Cup in Rome is made of dichroic glass. The colloidal gold and silver in the glass allow it to look opaque green when lit from outside

but translucent red when light shines through the inside. High heat was used to make this material with novel properties. However, it took ten centuries to invent high-powered microscopes that gave humans the ability to see things at the nanoscale (National Nanotechnology Initiative).

The modern history of nanotechnology began about 53 years ago when the American physicist Richard P. Feynman delivered a lecture titled “There’s Plenty of Room at the Bottom.” In this lecture, he talked about the manipulation of objects on the atomic scale (Encyclopedia Britannica 2012) . He began with the question: “Why cannot we write the entire 24 volumes of Encyclopedia Britannica on the head of a pin?” He calculated the encyclopedia had to shrink by 25,000 times because the head of a pin is about .16 centimeters in diameter to do so, and continued, “How do we write it?” and “How would we read it?” His answers spoke of modern techniques, methods that could be used to produce unlimited copies of the master inexpensively. At the time of his lecture, computers were large, filling entire rooms. He later focused on the problem of how to miniaturize machines. He proposed a new technique that built nanoscale components from the bottom up (World Book Science 2009).

Feynman concluded his lecture by offering $1000 prizes for two manufacturing competitions. The first competition was to see who could create a rotating electric motor that was only .26 cubic centimeters in volume. The second competition was to shrink one page of a book to 1/25,000 scale. The first challenge was completed in 1960; however, the second challenge was not completed until 1985 when Tom Newman, a Stanford University graduate student, used electron beam lithography to shrink the first paragraph of Charles Dickens's 1859 novel *A Tale of Two Cities* (Forsight Institute 2012).

Nanotechnology as we now know it began when our tools to measure extended into the nanoscale (National Nanotechnology Initiative). In 1974, Norio Taniguchi originally invented the term ‘nanotechnology’(Nanotechnology Education Tree). But it wasn’t until 1986 that K. Eric Drexler wrote "Engines of Creation" and explained the term more fully (Regis 2004). He imagined an army of nano-sized robots that could move molecules and position them so precisely that they could produce almost any substance out of ordinary chemicals (Drexler 1986). In “Engines of Creation,” Drexler envisioned pouring chemicals into a black box of molecular assemblers and building gasoline, diamonds, rocket ships without significant expenditure of capital or labor. Drexler's vision inspired a generation of chemists, computer scientists, and engineers to focus on science at the nanoscale.

Eighteen years after Feynman's lecture, in 1977, K. Eric Drexler, a Massachusetts Institute of Technology undergraduate, invented the concept of an assembler, a nanomachine that chemically manipulated reactive molecules and combined them into more complex structures. He believed that these assemblers were capable enough to manufacture virtually any object. Drexler went to publish the first

technical paper on *molecular* (bottom-up) nanotechnology in 1981, and the first paragraph of his paper by paid tribute to Feynman's 1959 speech.

In 1981, two scientists by the names of Gerd Binnig and Heinrich Rohrer invented a microscope that allowed scientists to “see” individual atoms. They won the Nobel Prize for this in 1986. In the same year, Gerd Binnig also invented another microscope with two other scientists, Calvin Quate and Christopher Gerber that could view, measure, and manipulate materials all the way down to a fraction of a nanometer in size.

Finally, in 2000, President Clinton launched the National Nanotechnology Initiative to research new developments in nanotechnology, which continues today (National Nanotechnology Initiative).

William Powell once said, “Nanotechnology is manufacturing with atoms.” This is true, but there are two methods that explain how nanotechnology works.

The first method is the top down method, which uses a multistep procedure called selective layering. In this procedure, scientists use a base material, like a silicon wafer, (A thin disc of pure silicon) to create a nanostructure and then add thin layers of other metals, insulators, and/or other materials.

The second method is called the bottom-up method. Scientists construct nanoscale objects from the bottom-up in the same way that workers on an assembly line manufacture everyday objects—piece by piece. At first, scientists created simple nano-structures (such as a ring of atoms) by using the atoms' electric attraction to pull the atoms into place.

However, more complicated bottom-up techniques use automated procedures to speed construction. A bottom-up approach called *molecular manufacturing* uses an ordered sequence of chemical reactions to guide molecules into such larger structures as molecular gears.

In a related process called *self-assembly*, nanoscale objects form naturally because certain molecules join together due to their complementary shapes or tendencies to form chemical bonds with one another.

Nanotechnology is becoming present in industry today. There are a few things that it is used for to improve quality of the product, and the variety of different products it appears in is increasing. There are incredible goals that scientists are trying to reach. Some of these goals seem impossible, but with nanotechnology, are they really?

Nanotechnology is still relatively new, but it is starting to appear in common products. Some products that almost everyone would use include sunscreen, glass, and clothing. Sunscreen can now be purchased as a clear substance instead of white, (due to smaller particles) and won’t leave as much of a mess on your skin. Glass and clothes can avoid being dirtied (Morrison). The nanoparticles can be energized in certain ways and clean the materials without manual effort. This will save money and time that would otherwise be used to clean these products.

Nanotechnology can also be used in more industrial manners. It can make metals scratch resistant (Morrison). A careless person swinging their car door open in a

parking lot will no longer cause damage to the car parked next to him. Nanocrystals can make the metals stronger and more wear-resistant, so car parts and building structures can endure more hardships and last longer.Tennis rackets can now be significantly lighter, and at the same time stronger, than they previously were due to the carbon nanotubes (Morrison). Nanotechnology can be seen in the tennis ball, too. Clay nanoparticles are placed on the inside of the ball acting as a sealant so air can't escape (Case Western Reserve University 2010). This makes the tennis ball travel more accurately to where the player intends for it to go.

Nanotechnology helps in the process of desalination.This process may not affect us directly or at present, but we may have more of a need of it in the future as the Earth's population grows and the demand for fresh water increases. At present, it could help places that are in drought or have no access to clean water.

There are some ideas that scientist haven't accomplished yet but are working on. Engineers are trying to nanotechnology to produce smaller and more powerful microprocessors. Nanotechnology can improve the quality of virtually anything, including buildings, vehicles, and computers. According to Ralph Merkle Read, "Nanotechnology will let us build computers that are incredibly powerful. We'll have more power in the volume of a sugar cube than exists in the entire world today" (Gehl 2000). Computers could be smaller and more powerful than possible without nanotechnology.

Doctors are trying to use nanotechnology to make treatments more accurate and more personalized than they are now. The way one person reacts to a certain medicine is different from any other person's reaction. With nanotechnology, it would be easy to find an effective medication for individual people. One of the goals in the medical field is to attempt to find a cure for cancer. It's predicted that in about 7 years both cancer and heart disease will be more easily detectable and treatable. In about 15 years, it is guessed that we will be able to do cellular repairs and cure almost any disease (Boysen 2012). Surgery can be a thousand times more precise than it is conventionally, the way it is now. Nanotechnology would even help with cosmetic surgery. An example of that would be the changing of the color of your eyes. With nanotechnology, even immortality could possibly be a reasonable goal. On a much smaller scale, band-aids will also be improved. The nanoparticles of silver in the band-aid will be able to block harmful cells from an open scratch or cut.

Nanotechnology could help us solve our environmental issues. It can give a boost to alternative power sources, and nanorobots could rebuild our depleted ozone layer, clean up contaminants in water from oil spills and other types of pollution, and can help monitor the effects humans have on nature. Using nanotechnology in manufacturing can reduce the pollutions omitted in the first place. This means once we use the nanorobots to clean up the environment, it will also be able to stay clean. It can help improve the environment, tackling existing problems (called legacy problems), and creating solutions for the future.

In manufacturing, nanotechnology could be used to make products. The assemblers would have the ability to manipulate atoms and molecules at will. The labor of humans would no longer be necessary. In about 20 years, some think that we will have the ability to build anything using nanotechnology (Boysen 2012). Everything will be lighter, yet stronger.

Other things to come include space exploration and improved in military clothing (Boysen 2012). A space elevator made of carbon nanotubes may be possible in about 15 years. This would lead to inexpensive space travel. Clothing for the army is expected to be flexible and comfortable that can also double as bulletproof armor with the help of nanotechnology. The clothing can also seal out chemicals and bacteria. With clothing like this, our military would be very well protected, maybe even invincible.

With all the current and future uses of nanotechnology, it is easy to see how this tiny science could lead to a utopian future. Since nanotechnology makes surgeries safer and more efficient, humans could reasonably be cured of everything from cancer to brain injuries. Nanotechnology could potentially cure almost every disease, and it could even reverse the aging process (Bonsor 2007). Even superpowers are not beyond possibility.

Another hopeful use for nanotechnology is as “assemblers”, a technology similar to the replicators used in Star Trek. Assemblers would be nanoscopic machines programmed by scientists to manipulate atoms and molecules at will. For instance, they could create diamonds out of the graphite in your mechanical pencil. For this to work, Rice University Professor Richard Smalley states that replicator nanobots would first need to assemble other replicators, multiplying exponentially until they had the trillions of assemblers necessary to produce and change objects (Bonsor 2007). Replicating technology could be used to end world hunger, creating edible food from garbage. They could eventually replace all other forms of manufacturing, making goods cheaper, stronger, and available for everyone. With enough advancements in nanotechnology, it is conceivable that we could end up with a utopia free of sickness, famine, and even death.

While nanotechnology could potentially bring about a plethora of benefits to society, there are also many challenges and risks associated with this new technology. We still have a lot to learn about nanotechnology, and it would be unsafe to proceed without knowing potential dangers. There are also several ethical dilemmas we would have to address. Most worryingly, if nanotechnology got out of hand, we could even end up with various apocalyptic scenarios.

A significant barrier to developments in nanotechnology is simply what we don’t know about it. When dealing with this tiny technology, much of what we know about physics goes out the window. This is because many actions on the microscopic scale are governed by quantum physics, which is completely different then the classical physics we interact with everyday. For instance, the Heisenberg Uncertainty Principle in

quantum mechanics states that it is *physically impossible* to know both the position and the momentum of a particle at the same time. The more precisely one is known, the less precise the measurement of the other is (Feynman 1965). When dealing with such counter-intuitive rules on the nanoscale, it becomes extremely important to know how materials and their properties are affected.

This lack of knowledge could manifest into a major health risk if we proceeded unchecked. There's even concern that some nanoparticles could be toxic, since elements at the nanoscale behave differently than they do in their bulk form. Another worry is that nanoparticles could cross the blood-brain barrier, a membrane that protects the brain from harmful chemicals in the bloodstream (Bonsor 2007).

Advancements in nanotechnology would also bring up many ethical dilemmas. Aside from the accidental dangers involved in any new technology, there's also the fact that nanotechnology could be used to make powerful, dangerous weapons. Nanoweapons could be similar to pathological ones, wiping out whole populations on a cellular level. Steel-eating nanobots are another possibility. In fact, it's explored in 2009 action movie G.I. Joe: The Rise of Cobra, in which the antagonist uses nanobots as weapons of mass destruction. Powerful nanoweapons could potentially be even more dangerous than the atomic bomb.

Another ethical dilemma deals with the physical advancements nanotechnology could give us. As mentioned earlier, nanotechnology could improve human physiology, curing many diseases and compensating for physical deformities. But it could also easily be used to give us superhuman abilities, like night vision or super healing. The question is, after gaining all these godlike powers, would we even still be human? A more practical inquiry regards *who* would would get these abilities. Most likely, it would be the wealthy. Superhuman enhancements would further widen the gap between the rich and the poor, which could easily lead to racism directed from the wealthy superhumans toward the unaltered poorer ones (Bonsor 2007). The 1997 movie Gattaca explores a similar scenario involving genetic enhancement, in which there is mass discrimination toward the "imperfect" humans.

As mentioned before, nanotechnology could bring about many utopian scenarios. But to every silver lining, you have your dark cloud. There is also a possibility that the opposite, an apocalyptic scenario, could happen. This could happen in different forms. We could lose control of technology and it takes over our society, or our economy could crash.

What would happen if nanobots went crazy and never stopped replicating? The Grey Goo scenario is a scenario like this, where self-replicating nanobots go wrong and replicate themselves a thousand times over. They consume the world, pulling carbon from the environment to replicate. According to K. Eric Drexler's calculations, in just 10 hours, a single haywire nanobot could create 68 billion other nanobots. (Osborne 2003) There is also the Green Goo scenario. This is similar to the Grey Goo scenario, except that the robots are organic.

There is the possibility that nanotechnology could be too good. When products are perfect, there is no need for another product. For example, stain-resistant clothes, with the aid of nanotechnology, made an introduction recently. If clothes are stain-resistant then there is no need for stain removers and less of a need for laundry detergent. The stain remover and laundry detergent industries will go out of business if there is no demand for them. Also, one of the possibilities of nanotechnology is that there will be assembly lines of robots making products. If this happens, companies will choose the robots over human labor because they won't have to pay the robots a salary. The robots would eventually be cheaper for the company to have. With robots controlling the assembly lines, many manufacturing jobs would be lost (Bonsor 2007). People with no jobs won't spend money on things they don't need. The economy will decline and could possibly crash. It could be a repeat of the Great Depression, potentially worse.

Nanotechnology, "the manufacturing technology of the 21st century," has influenced many of our everyday lives, whether we realize it or not. It is a fascinating new science that works on an entirely unprecedented scale. Nanotechnology currently has amazing uses, and there are even more incredible predictions for its use in the future. Still, there are challenges and risks associated with this new technology. Will nanotechnology change us in good ways, or bad? Will it make us 'gods'? Or will it humble us? Whether nanotechnology leads us to a utopia, an apocalypse, or something in the middle, one thing is for sure; for better or for worse, nanotechnology will revolutionize society as we know it. And with it, the possibilities that we see only in the most futuristic of science fiction are within our grasp.

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