

The Possibilities of Nanotechnology for Product Design

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Nanotechnologies are being spoken of as the driving force behind a new industrial revolution sweeping the world with substantial growth opportunities. Nanotechnology is about the manipulation of matter at the level of atoms and molecules that are the building blocks of everything. Nanotechnology is set to disrupt the face of much of industry, but its influence on industry should be described as evolutionary rather than revolutionary. Despite nearly two decades of basic research, much activity in nanotechnology is still at an early state. Nanotechnology is arguably at about the same stage that information technology occupied in the early 1960s, or biotechnology at the beginning of the 1980s. It is unknown yet what is possible, but the future looks promising. However, it would be naïve to assume that the nano-scale will be the final frontier.

Nanotechnology does not correspond to an industry that can easily be identified and quantified. It is a broad conglomerate of different technological and scientific disciplines which all use the physical properties of dimensions on the nanometer scale. Nanotechnology can be regarded as genuinely interdisciplinary and connect disciplines as diverse as physics, chemistry, genetics, information and communication technologies and cognitive sciences, (the study of intelligence and intelligent systems including computer science, psychology, neuroscience, philosophy, anthropology, economics, sociology) offering the foundation of the so-called *Nano-Bio-Info-Cogno (NBIC) convergence*. It is the convergence of science and growing diversity of applications that is driving the potential of nanotechnologies.

The impact of nanotechnologies cannot be overestimated: it displaces older technologies and enables radically new classes of products and markets not previously

feasible. It promises more for less: smaller, cheaper, lighter and faster devices with greater functionality, using fewer raw materials and consuming less energy. Any industry that fails to investigate the potential of nanotechnology and to put in place its own strategy for dealing with it, is putting its business at risk. Few industries will escape the influence of nanotechnology. The industrial sectors most readily embracing nanotechnology are the ICT sector, food technology, energy technology and the medical products sectors. Nanotechnology also offers novel challenges for the reduction of environmental pollution. Faster computers, advanced pharmaceuticals, controlled drug delivery, biocompatible materials, nerve and tissue repair, surface coatings, better skin care and protection, catalysts, sensors, telecommunications, magnetic materials and devices – these are just some areas where nanotechnology *will* have a major impact.

Nanoscale materials *are* already present in a wide range of products, including mass-market consumer products. Among the most well known are glass for windows which is coated with titanium oxide nanoparticles that react to sunlight to break down dirt. When water hits the glass, it spreads evenly over the surface, instead of forming droplets and runs off rapidly, taking the dirt with it. Nanotechnologies are used by the car industry to reinforce certain properties of car bumpers and to improve the adhesive properties of paints. Other uses include: sunglasses, textiles (wind-and waterproofing), sports equipment (ski wax, tennis rackets), sunscreens and cosmetics (lotions and anti-wrinkle creams), televisions (to consume less energy). Many applications are close to the marketplace or may appear within the next decade. In addition, many new tools and techniques will become available.

Technical characteristics

Nanotechnology is a new approach to industrial production based on the manipulation of things so small that they are invisible to the naked eye and even to most microscopes, so small, in fact, that one would have to split a human hair 80,000 times before it reached a width of 1 nanometer (nm). A nanometer is one thousand millionth of a meter or 0.000000001 or 10^{-9} . The prefix “nano” is derived from the Greek word for dwarf.

Atoms are below a nanometer in size, whereas many molecules, including some proteins, range from a nanometer upwards. The size range that holds so much interest is typically from 100nm down to the atomic level of 0.2nm. In the realm below 50 nanometers, the normal laws of physics no longer apply, quantum physics kicks in and materials take on surprising new properties. Only in recent years sophisticated tools have been developed to investigate and manipulate matter at the nanoscale. A major step in this direction was the invention of the scanning tunneling microscope (STM)

Two Approaches

There are *two techniques* to manipulate and produce nanomaterials: either shrinking from the “top-down” reducing the size of the structure towards the nanoscale, carving nano structures out of larger objects, or growing from the “bottom-up” in which atoms are arranged into the desired larger configuration with nothing left over, i.e., no waste. Bottom-up techniques usually imply controlled or directed self-assembly of identical structures with atomic precision, but controlling the process is not easy and can only produce simple structures, in time-consuming processes with extremely low yields. These two methods have evolved separately and have now reached the point where the best achievable feature size for each technique is approximately the same, leading to novel hybrid ways of manufacture.

Benefits and risks

The innovations coming from nanotechnologies have the potential to solve many of the world's current problems of human health and environmental safety. However, there is much uncertainty about the direction nanotechnology may take and about the hazards to humans or the environment.

The potential benefits for the environment range from resource-efficient technologies, which reduce waste, to new ways to detoxify environmental contaminants, to the conservation of material resources and the reduction in the volume of pollutant byproducts. Especially in the field of medicine there are quite a few technological developments that promise enhanced diagnostic possibilities, new ways to monitor patients, new ways to target drug delivery, to treat diseases like cancer and to reduce side effects.

Although the potential benefits of nanotechnology are immense, so are *the dangers* that have a negative environmental and personal health impact. In considering the potential of adverse health risks two separate types of nanostructures may be identified, those where the structure itself is a free particle, and those where the nanostructure is an integral fixed feature of a larger object. Almost all health and safety concerns are related to free rather than fixed engineered nanoparticles, because they could be inhaled, absorbed through the skin or ingested, leading to cell damage.

There is still much uncertainty about emerging risks associated with nanotechnologies. It may take years for studies about exposure routes, the effects on human health and the environment to reach conclusive results. The identification of risks, the determination of the probability of exposure to the hazard and the associated consequences should remain a dynamic process based on new scientific trends, for

which a life cycle assessment will be needed, based on criteria such as toxicity, persistence and bioaccumulation.

Criminals and terrorists could make effective use of nanotechnology. Even tiny weapons could be aimed at targets remote in time and space from the attacker. This will not only impair defense, but also will reduce post-attack detection and accountability, which reduces civility and security. Nanotech weapons would be extremely powerful and could lead to a dangerously unstable arms race.

Some nanotechnologies will raise significant *social and ethical concerns*. New products and lifestyles may cause social disruption by the availability of new “immoral products”, such as very small medical devices allowing brain modification. “Gray goo” in which nanomachines spread like bacteria, reducing the biosphere to dust in a matter of days with its replicating assemblers was an early concern of nanotechnology. Gray goo will not happen by accident, but eventually could be developed on purpose.

Facing all these risks there may be a strong temptation simply to outlaw the technology. A patchwork of extreme solutions, such as round-the-clock surveillance of every citizen, may be created in response to these kinds of risks. This would not be a good idea and it will not work. Many countries are already spending millions on basic nanotechnology and in a decade advanced nanotech will likely be within the reach of large corporations. It cannot be outlawed worldwide. Solving these problems won't be easy and treading a path between all these risks will require careful advance planning. Too little or too much regulation can result in uncontrolled availability.

Visions about a nanosociety

Visions of the future development of nanoscience and technology suggest a wide variety in assessments. It is possible to identify four themes about the social

implications of nanotechnology: a positive vision, *the utopian view*; a negative view leading to a *dystopian scenario*; a concern *to overcome barriers* to developing the technology and gaining public acceptance; the need for *specific regulation* due to the uncertainty of nanotechnology on humanity and the environment.

The crux of the positive view is the ability to design and construct nanosized robots yielding entirely new devices and products, better medicine and healthier foods, a cleaner environment, better cars and aircraft as well as better lightbulbs and household appliances. Nanorobots could destroy viruses and cancer cells, repair damaged structures and leading to the end of illness, ageing and ultimately death. The entire human body could be incredibly enhanced with unbreakable bones, eagle-eye vision and a bloodhound's acuity of smell.

Nanotechnology could lead to an extremely *negative, dystopian vision of the future* leading to an accumulation of great power and concomitantly great danger, with the knowledge behind the technologies available for abuse. The precision inherent in molecular construction would make it easy to build identical copies, raising the possibility of exponential manufacturing, in which self-replicating assemblers may run wild and destructive, capable of obliterating life, rendering all normal life extinct: "gray goo". However, the spontaneous formation of artificial living systems through self-assembly and related processes, is considered highly improbable and extremely difficult to realize on the basis of current scientific knowledge.

Due to its expected positive impact on the economy, the aim of nanotechnology is to ensure that any *barriers* to the economic success of nanotechnology will be *overcome*. Some barriers are explicit: the lack of critical mass in R&D activities, the absence of specialist interdisciplinary facilities and the

potential shortfall of skilled workers. An implicit obstacle may be the misinformation and hostility toward public acceptance. A major concern is that society will not be consulted and this lack of democratic control raises concerns about the *control* and ownership of the technology, the possibility of its *monopolization* with corporate control over matter. If there is no public engagement now, it will burst on the scene when it is too late. Then too much may have been invested economically and intellectually to go back. Most importantly, the successful evolution of nanotechnology will rely on its acceptance by society.

The Precautionary Principle

In many countries the precautionary principle has long been accepted as a legitimate basis for medical and public health interventions, and is increasingly being adopted as a basis for environmental policy. This principle prescribes measures to be taken to protect people and the environment *at an early stage*, even if the scientific uncertainties regarding the risks have not yet been finally clarified. Delaying action until harm is certain may mean delaying until it is too late or too costly to avert it.

It is difficult to determine whether and at what stage of development such measures should be adopted. The dilemma surrounding the precautionary principle is the subject of a number of public discussions: “Better safe than sorry” versus “Nothing ventured, nothing gained” or even “Damn the torpedoes, full speed ahead” may offer a major test of the precautionary principle as a way to manage innovation. An open public dialogue with citizens and consumers is necessary as a basis for an objective judgment on nanotechnology. For the foreseeable future the present frameworks are sufficiently broad to encompass nanotechnologies and hence a separate regulatory framework is unnecessary. Individual regulations may need to be

modified to reflect the fact that materials have new and enhanced properties at the nanoscale.

Developing Countries

Concerns have been raised that the gap between rich and poor countries will lead to a “nanodivide”. The high entry price for new procedures and skills may exacerbate the situation of developing countries, because nanotechnology may reduce demand for their exports, notably raw materials. Several developing countries have already launched nanotechnology initiatives: India, China, Brazil. Since most nanotech products will be developed and sold in the markets of developed countries, the role of developing countries in this revolution will be modest, but they will certainly be impacted by a series of knock-on effects. Developed countries could send the *used* materials back to the developing countries for reprocessing into new products. If the costs of transportation are too high, developed countries might start to produce these products themselves, so that developing countries might lose their export markets. In either case, many resource-based industries in developing countries might come under pressure because the extraction of non-renewable resources will no longer be required. It is not clear whether these knock-on effects weaken or strengthen global value chains.

Economic Issues

In general, countries recognize the advantage if their industries are early to introduce nanotechnology. The potential of nanotechnologies in terms of economic benefits, the potential to create jobs, wealth and well-being is very high. As nanotechnology is at this moment still generally in the research phase, the long-term economic impact is difficult to quantify. The best-known figure for the future nanotechnology market is from the US National Science Foundation in 2001, which

estimated a world market for nanotechnological products of 1 trillion US dollars for 2015. In 2014 an overall share of 15% of the global manufacturing output is expected for nanotechnology. The most important regions for the sales of nanotechnology products will be Asia and the Pacific regions, followed by the US and Europe on similar levels. The potential for nanotechnology has prompted large and rapidly rising government investments in R&D in leading industrialized nations. Worldwide investment in nanotechnology R&D has increased approximately nine times in the period 1997-2005, from \$432 million to \$4.1 billion, representing an average annual growth rate of 32%. Although the number of nanotech companies increased in the 1980s, the take-off of companies took place in 1996. When it comes to the creation of new jobs, start-ups and small and medium sized enterprises contribute most. By 2015 about 2 million nanotechnology workers will be needed worldwide. Patents are central for any analysis about the economic potential of a technology. The number of worldwide patents increased continuously but with no real take-off. One of the major *barriers for innovation* in the area of nanotechnology is the lack of capital. Venture capital firms will have a key role in transferring technology knowledge from the research centers to the industry. By the end of 2004, venture capitalists had already invested \$1 billion in nano companies.

Possibilities for Product Design

Since the present industrial system of design is destroying the natural world with its belching smokestacks, chemical fumes in carpets and hazardous high-tech garbage. The current technology is the outcome of a “cradle to grave” design in which resources are pulled from the Earth, shaped into a product, used and thrown away with serious toxic side effects in the meltdown process. Since the current society has a strategy of tragedy, it is becoming time to start rethinking about the effects on our

surrounding environment. By tailoring the structure of materials at the nano-scale, it is possible to engineer novel materials that have entirely new properties never before identified in nature.

In 2002 Braungart and McDonough published "Cradle to Cradle: Remaking the Way We Make Things" that constitutes the starting point for our ideas about the possibilities of nanotechnology for product design. Unfortunately enough these authors themselves did not incorporate nanotechnology into their analysis, but we see enormous possibilities for nanotechnology to generate ecological, social and economic value in designing products which are either biodegradable or recyclable. When industry applies the principles of ecologically intelligent product design, innovative products and systems may be created that eliminate the concept of waste and allow business, society and nature to thrive and grow. On the basis of nanotechnology, products and industrial processes may be so intelligently designed that they do not need to be regulated by the government. After all, regulation itself is evidence of design failure and a license to harm so that it may dispense sickness, destruction and death at an acceptable rate. If a factory can be built on the basis of nanotechnology emitting nothing harmful, there is no need for heavy regulation.

However, currently a minimizing approach of efficiency is being followed, i.e., less negative results, beginning with a system that is 100% bad, and seeking to become only 10% bad. This eco-efficiency is not a strategy for success over the long term because it does not reach deep enough. The four "R's" of eco-efficiency: Reuse, Reduce, Recycle and Regulate only aim to slow the destructive cycle, but do not stop these processes: Less Bad is No Good.

However, nanotechnology offers the alternative of eco-effectiveness of natural systems envisioning a positive system as the goal. It starts by acknowledging that

something is only 10% positive, and is working toward 100% positive. Eco-effectiveness is based upon three principles: *Waste equals food*: materials and products are designed that are food and safe for other systems, so that they can be used over and over again and provide nourishment for something new, either as biological nutrients that safely re-enter the environment or as technical nutrients that circulate within closed-loop industrial cycles, without being “downcycled” into low-grade uses (as most recyclables now are); *Use current solar income*: it is the quality of energy that matters, while using renewable energy; *Celebrate diversity* so that healthy eco-systems are promoted.

In operational terms the Cradle to Cradle design framework is working with a protocol to evaluate and (re)design products and processes according to human and ecological health criteria, phasing out undesirable substances and replacing them with preferable ones. The human health criteria measure a substance’s safety for customers, workers and the surrounding community during production, distribution and recycling/disposal. The environmental health criteria measure a substance’s safety for the air, soil, water, climate, exposed organisms and their successive generations, and the ecosystem as a whole. Based on the interpretation of the data for all criteria, products and materials receive scores for their impact upon human and environmental health.

Some very big companies already use this design approach and are implementing plans for product recovery and reutilization. Problematic components must eventually be phased out or replaced. As a potential strategy for closing the loop on the materials/product, a product take-back program to the manufacturer will have to be developed.

Conclusions

Since nanotechnologies have an enabling character they will penetrate almost every industry over the coming years. The public debate on nanotechnology is still in its infancy. The combination of a promising technology and lack of public knowledge about the social implications of it could lead to public distrust and opposition. The debate is being fueled by a combination of strong growth in financing and patents, high scientific expectations and related social hopes and concerns.

A diverse, safe, healthy and just world with clean air, water, soil and energy is attainable by redesigning the way things have been made, without waste, and in harmony with nature. The tenets of the eco-design revolution include waste equals food, effectiveness is better than efficiency and being less bad is not good enough.

Nanotechnology is expected to have a significant impact on our economy and society within the next 10 to 15 years, growing in importance over the longer term as further scientific and technology breakthroughs are achieved. The evolution of a nano-economy, as contrasted with the present petro-economy, is an intriguing idea. More study will be needed in order to understand and map these scenarios. The readiness of a nation to prepare for large-scale economic change is a challenging task and a social responsibility. Without preparing the country by building readiness, a disservice to society will be made, that will be difficult to repair. It is becoming clear that nanotechnology becomes the next core convergent scientific advancement: undoubtedly the Nano-Economy is coming.