Nanotechnology and Future WMD

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Abstract

Although most forms of nanotechnology do not pose unfamiliar risks, one advanced field – *molecular manufacturing* – may present a source of extreme risk due to the implications of the power of its products. Molecular manufacturing will benefit from multiple advantages that other technologies, including earlier generation nanotechnologies, do not possess. Work toward this form of manufacturing is still in formative stages, but development could rapidly become easier, and it may be achieved with surprising speed once a few basic capabilities are attained. Rapid, inexpensive, large-scale manufacture of highly advanced products may have several unfortunate consequences, including new classes of WMDs (weapons of mass destruction), unstable arms races, environmental impacts, destructively enabled individuals, social upheaval, and oppressive governance. However, the technology is dual-use and also may be highly beneficial. For this and other reasons, patchwork policy solutions will be counterproductive.

Nanotechnology

Nanotechnology is a term that has grown to cover a broad collection of mostly disconnected fields. Essentially, anything sufficiently small and interesting can be called nanotechnology. Much of it is harmless. For the rest, much of the harm is of familiar and limited quality. This section will establish context by discussing a few areas of nanotechnology with potential for moderate harm, and one aspect of biotechnology that may pose high risk. The balance of the paper will focus on an area of nanotechnology – molecular manufacturing – that is likely to pose the greatest risk.

Today's early-generation nanotechnology is limited to manufacturing relatively simple structures. (The exception is semiconductor lithography, which draws on decades of R&D.) For the most part, these are used either for pure research or as components or additives for traditionally manufactured products. In general, this means that unless the structures themselves pose a risk, their applications will not pose a significantly greater risk than pre-nanotech products, or introduce new classes of risk.

Some nanoparticles have raised concerns about human toxicity or environmental damage. Nanoscale particles may be more chemically active and mobile than larger versions, and may be more persistent in the environment than many molecules. Still, they do not appear to raise novel risks or even magnitudes of risk when compared to the current manufacture of chemicals.

Some fields of nanotechnology are beginning to overlap with biology. In several ways, nanotechnology might make it incrementally easier to develop pathogens. However, biotechnology probably will be a stronger driver of capabilities than nanotechnology in this area.

Molecular Manufacturing

Molecular manufacturing is at the convergence of several powerful technologies. Living cells join molecules together in precise patterns to form functional structures. Rapid prototyping systems form parts directly from blueprints under computer control. Automated factories assemble parts into products. Molecular manufacturing will combine all of these capabilities and more.

A technology that could perform precise rapid prototyping and automated assembly on the molecular scale would be able to take advantage of several additional technical benefits. Precise, stiff surfaces can exhibit extremely low friction and wear. Smaller devices not only have increased functional density, but also increased power density and operation frequency–devices with single-nanometer features might have up to a million-fold such advantage over today's machinery. Structures in which most elements are flawless can have significantly higher strength.

A few simple, well-characterized, reliable, constructive operations, repeated many times, can be extremely powerful. That is how computers work – a modern desktop computer can do a trillion transistor operations every day virtually flawlessly. The digital character of covalent bonds implies that fabrication operations can be error-free for all practical purposes. Thus, once a small set of fabrication operations is known, a large range of billion-atom structures can be designed with confidence, just as computer chips can be built out of well-characterized transistors. This is one reason for expecting development to proceed quite rapidly beyond a certain point.

Once a molecular fabricator is built, getting exponential numbers – even kilogram quantities – of nanoscale machines to work in parallel will largely be a matter of mechanical engineering and a few dozen doubling cycles. One embodiment of the manufacturing potential is a *nanofactory* – a kilogram-scale box containing micro-molar numbers of molecular fabrication systems in regular, easily controlled arrays, producing kilogram-scale products including duplicate nanofactories in a few hours. Proposed nanofactory architectures scale easily to ton-per-hour and beyond. Since fabrication would be totally automated and use non-scarce factories, product complexity would not add to manufacturing cost.

It is worth repeating that the ability to build machines at the nanometer scale conveys massive scaling law advantages, as long as friction and wear can be avoided through superlubricity or biomimesis. Some of the advantages will depend on the material, but if and when nanofabricated diamond-in-vacuum becomes available, the active component of human-scale products will shrink almost to the vanishing point, and even the structure may be reduced by two to three orders of magnitude.

In the absence of any targeted development program for molecular manufacturing, several technologies appear to be moving toward commercially relevant single-atom fabrication with a projected arrival date of four or five decades. However, nanometer-scale covalent-solid manufacturing systems appear to represent a "sweet spot" in technology space, and development programs will likely be targeted at that spot well in advance of its incidental development. A report issued this week (see Further Reading below) by the National Academy of Sciences calls for "defining and focusing on basic experimental steps that are critical to advancing long-term goals" [toward molecular manufacturing] and for funding "experimental demonstrations that link to abstract models and guide long-term vision." This is likely to open the door for more US (and other) federal funding of relevant work.

A New Weapons Race

A nanofactory that could build high-performance products directly from blueprints in a few hours would have many applications. One obvious product family is weapons, including weapons of mass destruction (WMDs). Higher strength, power density, and functional density would improve a number of existing weapon designs. It would also enable new classes of weapons. For example, UAVs in a wide range of sizes could perform surveillance, sabotage, or antipersonnel missions far beyond what is currently contemplated.

It appears that "briefcase to orbit" systems will be possible. A small automated airplane (Helios) has been flown up to 96,000 feet. Even a small rocket should be able to attain orbit from that altitude, and a small aircraft should be able to lift it. Initial calculations suggest that the advantages of diamondoid construction would enable a human-portable system, built by a home-appliance scale nanofactory, to put a kilogram of payload into orbit.

The advantages of inexpensive rapid prototyping of complete products should not be underestimated. The development cycle of field-programmable computer chips can be up to two orders of magnitude faster than that of factory-programmed computer chips; product development cycles might speed up similarly.

For a number of reasons, a nanofactory-enabled arms race appears less stable than was the US-Soviet nuclear arms race. Rapid development of new types of weapons may outstrip the capacity of strategists to plan for stability. Temporary asymmetries caused by rapid development may tempt first strikes. The wide range of military and paramilitary options may create many pathways for gradual escalation to conflagration. Destruction caused by nanotech-based weapons could be more targeted and contained than nuclear explosions. Likewise, there may be less stigma attached to nano-built weapons. Nanofactory availability is likely to be far more rapid and widespread than nuclear proliferation. Uncertainty about the enemy's capabilities, as well as increased ability to deploy surveillance, may be stabilizing factors, but on balance the outlook for stability seems poor.

All-out war could be extremely destructive. With distributed, easily concealed nanofactories, it would not be easy to destroy an enemy's ability to fight. It would be far easier to destroy things of sentimental value, such as civilian resources – and civilians themselves. Preliminary thought about the number of modes of attack, concealment, and space/time separation between launch and attack makes the task of defending civilians appear hopeless, even if the enemy is far weaker than oneself. A mentality that welcomed martyrdom would appear to be at a distinct advantage against a nation unwilling to commit genocide.

Other Risks

In addition to its perilous impacts on weapons and war, nanotechnology manufacturing also presents issues of concern about surveillance, terrorism, environmental problems, economic upheaval, and more.

With supercomputers and sensors effectively free, worldwide surveillance networks could be created with semi-automated data processing. Unusual events could be flagged for human attention, and objects and people could be tracked through space and time. This may be very tempting to governments as they try to avoid ownership and use of advanced weapons by individuals or small groups. But it would also enable massive governmental oppression.

Should nanofactory-level technology become available to non-government entities, crime and terrorism may become significantly enabled. This could weaken or even destabilize governments and societies.

If nanofactories can build solar energy collectors and feedstock pre-processors, it is not obvious what scarcity factor will prevent waste on a massive, even global scale. For example, profligate consumption of energy could lead to large fractions of the planet being covered in solar panels. Even things that are rare today, such as sonic booms from small aircraft, may become common enough to pose environmental problems. If small products were made in large quantity, they could form quantities of "nano-litter" that could be difficult to collect.

The economic consequences of nanofactory technology are diverse and sizable. If nanofactory products are as efficient and high-performance as expected, they may rapidly out-compete other forms of manufacturing. Nanofactory manufacture near time and place of use would affect transportation and storage industries. Manufacturing industries, of course, could be wiped out. New industries and lifestyles could create indirect economic effects. Rapid economic change could weaken or disrupt societies.

A concern that has been raised about molecular manufacturing technology is that small, self-contained, self-replicating systems (so-called ‘grey goo’) might multiply in the wild and consume large fractions of the biosphere. Originally, it was feared that a laboratory accident could be enough to release such a device. However, current proposals for manufacturing systems do not include anything remotely like such a device, even during development phases. It is not yet known how much of a problem could arise from deliberate release of free-range self-replicators. They would probably be quite difficult to design, especially in a small package. They would have essentially no practical use, even as a weapon. However, it did not take long for the first computer virus to be created and released; hobbyists may be a source of concern once the technology becomes accessible to them. More analysis is needed to determine the eventual dangers posed by free-range self-replicators, with special attention paid to water-borne designs. However, the dangers of unstable arms races leading to devastating war and/or unbreakable oppression appear more pressing.

Dealing With the Dangers

There will be no simple solution to dealing with molecular manufacturing. Even a policy of massive suppression of it and all possible enabling technologies would not be immune to the possibility of internal instability on the part of the administrative group.

It is also not clear that suppression is desirable. First, the benefits of a mature molecular manufacturing technology could be immense. The ability, for example, to perform planet-scale engineering projects in a matter of months may be necessary to mitigate climate change. Rapid prototyping of nanometer-scale products could accelerate medical research in several ways, as well as providing new kinds of treatment. Huge improvements in sustainable agriculture and efficient distribution systems can be anticipated for countries in the developing world. Replacement of inefficient infrastructure, along with inexpensive solar collectors, could greatly reduce our future ecological footprint (at least until new uses are found for the newly abundant resources). Inexpensive access to space could provide numerous benefits.

More directly, widespread access to molecular manufacturing would enable widespread development of defenses against malicious uses. Although in a military context, it appears that offense will likely beat defense, it may be that widely deployed personal-scale defenses can mitigate personal-scale attacks. This possibility needs further analysis.

Preventing malicious or irresponsible people from doing intolerably bad things is only one of the problems. Another source of problems is vicious cycles in social or political systems that may result from the stimulus of near-unlimited manufacturing. Perhaps the direst peril is the unstable arms race described above. Another possible vicious cycle is wealth concentration, caused by a large disparity between manufacturing cost and value to consumer, leading to increasing ability of businesses to purchase business-friendly policy. A third vicious cycle may arise from attempts to prevent ownership of desirable technology: a black market infrastructure may develop and grow.

Unfortunately, almost no resources have been spent on studying these issues. If extensive research and analysis will be necessary to implement wise policy, there may not be time to complete them once the changes start. Large, especially international, administrative bodies also take time to create. If molecular manufacturing is physically possible, then it will happen soon, and technical and policy studies are urgently needed in advance of that date.

Conclusion

Although the possibility of high-performance molecular manufacturing has not been conclusively proved, analysis to date indicates that it will not only work, but will be far more powerful than other technologies, including other nanotechnologies. The actual development schedule is uncertain, but may be expected within the next few decades. Once a general-purpose set of digital molecular fabrication operations is developed, and exponential manufacturing is achieved, further progress toward nanofactories and advanced products may be rapid.

Molecular manufacturing is likely to be far more powerful and dangerous than other forms of nanotechnology. Some of the dangers appear comparable in scope to nuclear war. Because some of the dangers arise from systemic vicious cycles and others may result from ill-conceived attempts at policy, studies aimed at developing wise approaches to the problems need to be initiated before the issues arise.

Further Reading:

"War, Interdependence, and Nanotechnology" by Mike Treder
An analysis of factors contributing to instability in a nano-enabled arms race.
http://www.futurebrief.com/miketrederwar002.asp

"Thirty Essential Nanotechnology Studies" by Chris Phoenix
Many topics, from technical issues to organizational responses to problems.
http://crnano.org/studies.htm

"Three Systems of Action" by Chris Phoenix and Mike Treder
A framework of policy approaches needed to deal with molecular manufacturing.
http://www.crnano.org/systems.htm

Nanosystems by K. Eric Drexler
Chapter 1 describes diamondoid device performance.
http://www.e-drexler.com/d/06/00/Nanosystems/toc.html#c1
Chapter 2 applies scaling laws to nanoscale machines.
http://www.e-drexler.com/d/06/00/Nanosystems/toc.html#c2

"Nanofactory Collaboration"
Describes current work to develop a nanofactory.
http://www.molecularassembler.com/Nanofactory/
Bibliography of mechanically controlled chemistry.
http://www.molecularassembler.com/Nanofactory/AnnBibDMS.htm

"A Matter of Size: Triennial Review of the National Nanotechnology Initiative"
Report from the National Academy of Sciences that evaluates molecular manufacturing.
http://www.nap.edu/catalog/11752.html