

HSE HORIZON SCANNING INTELLIGENCE GROUP SHORT REPORT

MOLECULAR MANUFACTURING

1. Issue

Molecular Manufacturing is in its early infancy but is claimed to have the potential to revolutionise manufacturing processes in areas as diverse as energy, healthcare, agriculture and IT.

2. Background

The concept of Molecular Manufacturing has arisen from the proposals of Feynman,¹ Drexler² and others that it should be possible to control matter at the molecular level in such a way as to enable nanoscale factories to be developed. It is envisaged that these would be capable of constructing virtually any object from e.g. crockery and furniture through to complex electronic items and even human body parts, atom by atom, through controlled sequences of chemical reactions directed by molecular machines.

A set of scenarios generated by the “Center for Responsible Nanotechnology”, considers how Molecular Manufacturing might develop. Possible futures are foreseen ranging from slow, tightly regulated progress through to rapid “open source” development of the technology.³ The possibility that unintended consequences of this approach could lead to out-of-control self-replicating nanodevices consuming all living matter and resulting in the so-called “grey goo” scenario has received widespread attention in the press. While debate continues, the weight of scientific opinion seems to favour the view that the threat of such a scenario arising is very low and is manageable through effective process design.⁴ The influential 2004 report from the Royal Society/Royal Academy of Engineering on Nanosciences and Nanotechnologies⁵ concluded that “we have heard no evidence to suggest that mechanical self-replicating nanomachines will be developed in the foreseeable future, and so would direct regulators at more pressing concerns”.

Potential designs for molecular machinery components and demonstrations as to how these could be brought together for the construction and operation of a desktop nanofactory have been visualised through computer modelling and animation.⁶ However, there is much debate as to whether such a vision of Molecular Manufacturing, as being based essentially on engineering processes scaled down to the nanometre domain, is realisable in practice.⁷ A more realistic view of the area is felt by some to be that approaches derived from an understanding of how biological systems operate may be more fruitful, with examples such as that of the T4 bacteriophage attacking *E. Coli* being seen as a model for a future “nanomachine”.⁸

¹ <http://www.zyvex.com/nanotech/feynman.html>

² <http://e-drexler.com/p/idx04/00/0404drexlerBioCV.html>

³ <http://crnano.typepad.com/crnblog/2007/12/imagining-the-f.html>

⁴ <http://www.crnano.org/IOP - Safe Exp Mfg.pdf>

⁵ http://www.nanotec.org.uk/report/Nano_report_2004_fin.pdf

⁶ http://nanoengineer-1.com/content/index.php?option=com_content&task=view&id=39&Itemid=49

⁷ see e.g. exchanges on the subject at: <http://www.softmachines.org/wordpress/>

⁸ <http://www.purdue.edu/UNS/html4ever/030818.Rossmann.baseplate.html>, <http://www.scivee.tv/node/4634>

Indeed, research into the practical development of machines capable of controlling motion at a molecular level is tending to take inspiration from biological systems and already, the first “primitive, artificial molecular motors” have been constructed.⁹ Other examples of such components include a solar-powered nano motor,¹⁰ molecular pliers and scissors,¹¹ a nanorobotic arm¹² and a molecule, which “walks”, whilst carrying a package of CO₂ molecules.¹³

The National Nanotechnology Initiative’s report into “Manufacturing at the Nanoscale” suggests that “some form of directed self-assembly is necessary to achieve true Molecular Manufacturing” and points to the potential for modified viruses and proteins to act as molecular “assemblers”.¹⁴ A Technology Roadmap for “Productive Nanosystems”¹⁵ recommends areas of research into materials, tools and processes and foresees initial applications of “Atomically Precise Manufacturing” based on bio-derived, molecular self-assembly being feasible within perhaps the next 10-15 years.

The development of Rapid Manufacturing¹⁶ and desktop or home fabrication (“fabbing”) technologies such as the fab@home and RepRap projects¹⁷ are seen by some as a precursor to Molecular Manufacturing.¹⁸ It is proposed that the combination of these approaches with the so-called convergent or NBIC technologies (Nano-Bio-Info-Cogno) could lead eventually to the concept of Molecular Manufacturing being realised for the “mass customisation” of products via distributed manufacturing.

3. Implications for Occupational Health & Safety

The implications of Molecular Manufacturing in terms of workplace health & safety are likely to be similar to those highlighted already in the Horizon Scanning reports on the related fields of Rapid Manufacturing¹³ and Synthetic Biology.¹⁹ There may be concerns e.g. over the potential difficulty in predicting the characteristics of modified biological systems and issues around distributed manufacturing such as the possible use of complex and potentially hazardous materials and processes by operators unfamiliar with the H&S risks and controls required.

4. Recommendations

Molecular Manufacturing would currently appear to be at the concept development stage and while a significant amount of research effort is being directed to the field, the implementation of any practical application of the approach is likely to be some way in the future. However, given the potential of this technology to impact on manufacturing processes and the workplace in general, it is an area where HSE should maintain a watching brief.

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⁹ <http://www.nature.com/nnano/journal/v1/n1/full/nnano.2006.45.html>

¹⁰ http://www.physicalsciences.ucla.edu/research/nano_motor.asp

¹¹ <http://www.newscientist.com/article.ns?id=dn8885>, <http://www.azonano.com/news.asp?newsID=3891>

¹² <http://www.nyu.edu/public.affairs/releases/detail/1355>

¹³ <http://www.newsroom.ucr.edu/cgi-bin/display.cgi?id=1496>

¹⁴ http://www.nano.gov/NNI_Manufacturing_at_the_Nanoscale.pdf

¹⁵ http://foresight.org/roadmaps/Nanotech_Roadmap_2007_main.pdf

¹⁶ <http://www.hse.gov.uk/horizons/rapidmanufacturing.pdf>

¹⁷ http://fabathome.org/wiki/index.php?title=Main_Page, <http://reprap.org/bin/view/Main/WebHome>

¹⁸ C.Phoenix, tct Magazine, Vol.14, Issue 4, p. 37-9.

¹⁹ <http://www.hse.gov.uk/horizons/synthetic.pdf>