S&T REVIEWS

Nanotechnology & the BWC

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In preparation for the forthcoming Seventh Review Conference of the Biological and Toxin Weapons Convention (BWC), the Harvard Sussex Program has produced a series of papers considering developments in science and technology of relevance to the Convention. This paper assesses developments in the emerging field of nanotechnology.

What is Nanotechnology?

Nanotechnology is a term used to denote a number of (not necessarily related) fields that operate at a microscopic or sub-microscopic scale. It cuts across various scientific and engineering disciplines. Nanotechnologies are either 'bottom-up' assemblies – atom by atom, molecule by molecule, (e.g. nanotubes) or 'chipping away' from top-down by isolating desired parts (e.g. molecular motors). Nanotechnology leads to materials containing structures produced to have at least one dimension that measures between approximately 1 and 100 nanometres. However, nanotechnology is perhaps best understood as technologies operating at "the point at which a material demonstrates a novel functionality as a result of its small size."[1]

What (potential) applications does nanotechnology have?

The market potential of nanotechnology has been forecast to be considerable.[2] Due to the breadth of what constitutes a nanomaterial and the desirability of novel functions offered by nanomaterials they have the potential to penetrate virtually all industrial sectors.

Nanotechnology is a diverse collection of disciplines, developing materials at microscopic and sub-microscopic scales endowed with different or novel material properties.

Research activity is ubiquitous, highly networked and globally distributed.

Nano-containing and enabled products are commercially available, well established, but overall progress remains modest.

Nanotechnology has implications, both positive and negative, for Articles I, III, IV, VII and X.

Nanotechnology has already found applications, both directly and as an enabling technology in a number of different fields including health, food safety, energy, environmental remediation, information communication technology and cosmetics.[3] However, despite the claims of transformative and paradigm-shifting potential of this emerging technology, it is worth noting that progress remains relatively modest.

Health: Nanotechnologies are being utilised in enabling technologies including drug conjugation and encapsulation, direct targeting, and specific drug release modalities.[4] Advances have been made in therapeutics, including targeted delivery.[5] Techniques and applications have been developed for environmental diagnostics, disease imaging, and disease mapping inside the body.[6]

[1] UK House of Lords Science and Technology Committee (2010) Nanotechnologies and Food. HL Paper 22-I, p.11

[2] See, for example: Mackenzie, T (2009) "Technology: Under the microscope", The Guardian (London): Guardian Technology, p.1, 26th March 2009, Anon (2008) "Nanotech market to reach $3.1 trillion by 2015", American Ceramic Society Bulletin. 87(9), September 2008 & Anon (2008) "Study forecasts high growth for global nanotechnology market" Anti-Corrosion Methods and Materials. 5(5), p.288-9.

[3] More than 1300 nano-material containing or enabled products have been identified to be commercially available. See "Nanotechnology Consumer Product Inventory", Project on Emerging Nanotechnologies, Woodrow Wilson International Center for Scholars, updated 10th March 2011.

[4] Nagahara, L. & others (2009). "Nanofunctional Materials in Cancer Research: Challenges, Novel Methods, and Emerging Applications." Materials Research Bulletin 34(6), p.406-414.

[5] For example Anon (2010) "Cluster Bomb for Cancer Care: Nano-Vehicle Delivers Chemotherapy Treatments on Target", ScienceDaily 23rd August; & Anon (2010) "Nanotechnology used to modify chemotherapy drug that may improve cancer treatment", Nanomedicine, 5(7), p.1021.

[6] For more see: Barreto, JA & others (2011) "Nanomaterials: Applications in Cancer imaging and therapy", Advanced Materials 23(12), p.H18-H40.

Furthermore, nanomaterials have been developed with anti-microbial properties for use in, for example, hospital settings and in protective clothing.

Food safety: Nano-additives have been shown to be effective preservatives.[7] Nanomaterials have also been used to create new flavours[8] and nanoencapsulation has been used to mask undesirable tastes. Nano particles have also been used to monitor toxicants in food and environmental samples with high sensitivity.[9]

Energy and Environment: Various approaches to generate power have been investigated, from exploitation of piezoelectric effects[10] to the use of quantum dots to improve solar cells. Nanomaterials have been used to reduce energy consumption, e.g. novel semi conductor technology for efficient electrical transmission; mechanical lubricants to increase engine efficiency; and nanotechnology based building materials improving insulation. Nanomaterials are potential candidates for environmental remediation and environmental engineering applications.[11] Conversely, nanomaterials have raised concerns as environmental pollutants with health risks similar to those posed by asbestos, or because of potentially harmful effects by their accumulation in the environment.[12]

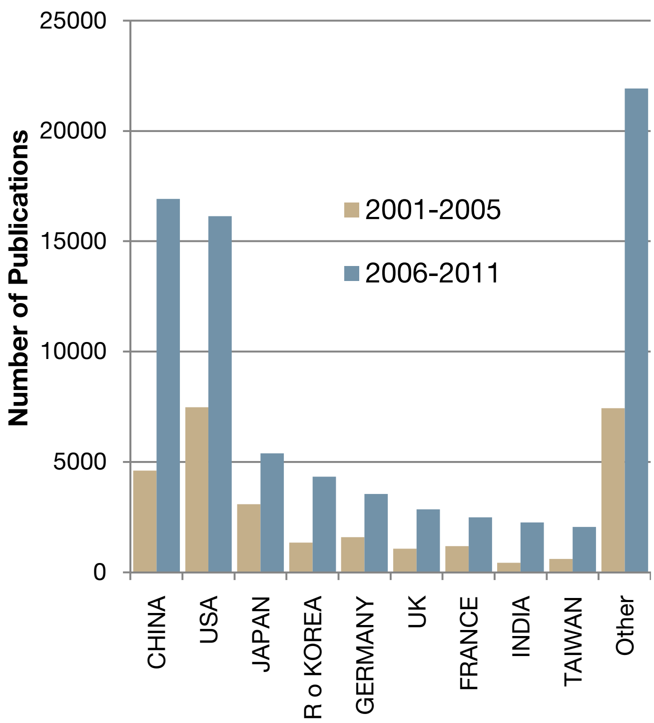
Trends and trajectories in Nanotechnology

The market potential of nanotechnology has been forecast to be considerable.[13] These predictions have, however, been disputed, most notably because of definitional question as to what constitutes nanotechnology, and disagreement about the boundary between nano-enabled, nano-containing and 'pure' nano-products.[14]

Nanotechnological research is carried out globally, with evidence of high levels of international collaboration. In Figure 2 (overleaf) countries in which papers have been authored since 2001 are shaded, the number of instances of authorship between 2006 and 2010 are represented by the size of the nodes and linkages through international co-authorship are shown by the lines connecting the nodes. Three significant clusters are apparent: North America, Europe and Asia

Figure 1 below compares the bibliometric data of those countries in the three clusters with the highest output over the two intersessional periods. In the period 2001-2005 the US had the highest level of output. In the period 2006-2011 each country has substantially increased its research output, with China now having the largest output. A striking feature of this graph is the growth of research output for the 'other countries' category.[15] This suggests a broadening of the research base geographically and in the extent of international collaboration.

Figure 1: Bibliometric comparison by country of origin over two periods of time. (Source: ISI Web of Science)

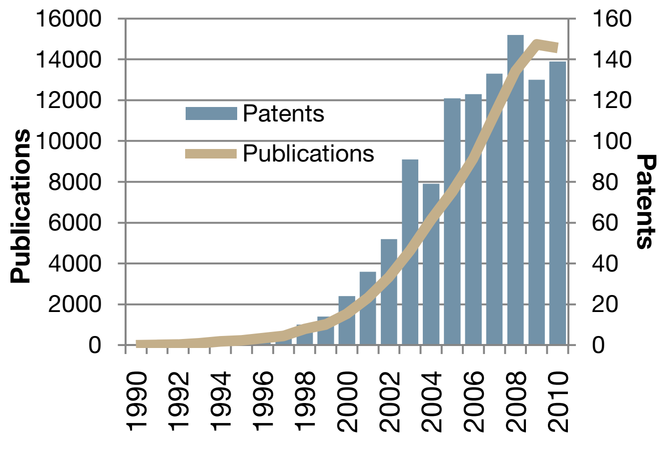


[7] Liu, D. & Gu, N. (2009). "Nanomaterials for fresh-keeping and sterilization in food preservation", Recent Patents on Food, Nutrition & Agriculture. 1(2), p.149-154.
[8] Baltes, M.H. (2008). "Nanotechnology and food safety", Journal de Pharmacie de Belgique. 63(1), p.7-14.
[9] Vinayaka, A. & M. Thakur (2010). "Focus on quantum dots as potential fluorescent probes for monitoring food toxicants and foodborne pathogens." Analytical and Bioanalytical Chemistry 397(4), p.1445-1455.
[10] Piezoelectric effects are electrical charges generated in response to mechanical stress.
[11] Li, L. & others (2006) "Synthesis, properties, and environmental applications of nanoscale iron-based materials: A review", Critical Reviews in Environmental Science and Technology, 36(5), p.405-431
[12] Potential adverse implications for human health have given rise to the field of nanotoxicology. See for example: Xia, T. & others (2009) "Potential Health Impact of Nanoparticles". Annual Review of Public Health, 30, p.137-150
[13] See footnote 2
[14] See, for example: Berger, M (2007) "Debunking the trillion dollar nanotechnology market size hype", Nanowerk.com, 18th April.
[15] The category "Other" is comprised of 76 countries in the first period and 98 in the second period.

Figure 2: Global distribution and patterns of collaborations of publications on nanotechnology (Source: ISI Web of Science)

Data from the last twenty years exhibit a notable correlation between publications on the subject of nanotechnology and patent applications with a focus on nanotechnology (see Figure 3). Both activities have grown in a marked and sustained fashion since the early 1990s.

Figure 3: Publications and patents by year (Source: ISI Web of Science and WIPO patent database)



It is, however, worth noting that the number of publications exceeds that of patents by two orders of magnitude.

Capabilities to produce nanoparticles are well established and wide spread in certain industrial manufacturing processes and processing techniques – for example, the use of homogenisers, grinders and mills in food, chemical and pharmaceutical industries.

However, we would characterise progress in nanotechnology as modest because the transformative and paradigm-shifting potential has yet to be realised. Some of the advances described here have yet to be proven beyond the conceptual stage. Targeted drug delivery is one example where it has thus far been difficult to translate or develop theoretical possibilities into practical realities.

Globally spread research and continued development in processes and techniques that draw on nanotechnological advances may soon invalidate this cautionary assessment. It is essential that developments in this international and multidisciplinary area of research are carefully monitored.

Relevance to the BWC

Article I	Article I and the Additional Understandings of toxins comprehensively cover nano-based, nano-enabled and nano-containing agents without peaceful or prophylactic purposes, along with any means of delivery which may be based on or contain nanomaterials.
Article III	The implementation and enforcement of export and transfer controls may need re-evaluation to ensure that novel products and novel applications of existing products and equipment are covered.
Article IV	Existing regulations and legislation may need to be re-evaluated to ensure that advances in nanotechnological applications are adequately captured and effectively governed under domestic laws.
Article VII	Nanomaterials may facilitate assistance and response through pre and post exposure protection, decontamination, as well as in the identification, development and production of medical counter-measures. Nano-enabled diagnostic and sensor technology may provide useful tools for assisting with responding to natural, accidental or intentional disease events.
Article X	Nanotechnology is marked by international collaboration and increasing global distribution of research activity (Figure 1, 2 & 3). The potential to penetrate virtually all industrial sectors and its dual-use potential warrants particular attention to be paid to transfer and export controls in order to avoid hampering the economic or technological development and international co-operation.

Nanotechnology has implications, for the BWC, particularly in relation to Articles I, III, IV, VII and X. For example, the increased ability of nano particles to cross biological barriers and means of delivery based on, or containing, nanomaterials are potential sources of concern. However, nano-enabled sensor technologies, and use of nanotechnologies in detection and diagnostics of biological agents, as well as medical counter-measures offer opportunities to support the operation of the convention.

Recommendations

The wide ranging nature of nanotechnology warrants further attention in future discussions of the BWC. Advances in nanotechnology, including delivery modalities and encapsulation, are currently captured under the scope of Article I. However, the breadth of applications, and nature of advances requires close and continued monitoring to ensure that the provisions of the BWC are adequately and effectively addressed. Moreover, monitoring of advances may facilitate the (further) exploitation of opportunities offered by nanotechnology to support and reinforce the objectives of the convention.

Nanotechnology profits from an increasing convergence between a number of disciplines, biology and chemistry in particular. Previously unrelated subjects and disciplines have or may become relevant to the BWC through interdisciplinary integration. It is thus important that nanotechnological advances are adequately addressed by the BWC and that nanotechnology advances do not fall in between the CWC and the BWC. This interdisciplinary nature may have further implications in terms of outreach and engagement efforts conducted under the BWC and a wider range of stakeholders may need to be considered in engagement activities.

As an enabling technology nanotechnology has the potential to take a number of industrial sectors in a new direction. Biotechnology and nano-medicine especially are emerging as vibrant areas of research, and regulatory measures will need to adequately balance permitting exploitation of novel opportunities with prohibiting potential misuse.

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For more information about the project visit http://hsp.sussex.ac.uk/sandtreviews/

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