The Use of Environmental Health and Safety Research in Nanotechnology Research

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Abstract

Environmental, health, and safety (EHS) concerns are receiving considerable attention in the development of nanoscience and nanotechnology (nano) R&D, underscored by the perspective that EHS work should be developed alongside the scientific research rather than subsequent to applications. This positioning of nano EHS suggests the importance of early understanding and measurement of the diffusion of nano EHS science. This research examines the diffusion of nano EHS publications, defined through a set of search terms, into a global nanotechnology R&D database developed at Georgia Tech. The results indicate that nano EHS research is growing rapidly although it is orders of magnitude smaller than the broader nano S&T domain. Nano EHS work is moderately multidisciplinary, but gaps in biomedical nano EHS's connections with environmental nano EHS are apparent. The implications of these results for continued monitoring of the size and cross-disciplinary connections in nano EHS are discussed.

Keywords: Nanotechnology; Environmental, Health, and Safety; Risk

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Introduction

Investment in nanoscience and nanoengineering (**nano**) environmental, health, and safety (EHS) research is among the fastest growing areas of overall nano R&D public spending. The US National Nanotechnology Initiative (NNI) allocated $350 million to nano EHS research from 2005-2009. In fiscal year 2010, the federal nano EHS budget is nearly triple the size of what it was in 2005, compared to a 37% increase in the overall NNI budget. EHS R&D investment comprises more than 5% of the fiscal year 2010 NNI budget, and a policy target of 10% of the NNI budget allocated to nano EHS has been discussed (Ferguson 2007; Kvamme, 2007). The President's Council of Advisors on Science and Technology (PCAST) added a special separate addendum report to its second review of the NNI focused on nano EHS issues and NNI investments in this area. There have been significant levels of attention in other countries on nano EHS concerns.. For example, the Royal Commission on Environmental Pollution published a report "Novel Materials in the Environment: The case of nanotechnology" in November 2008. It spotlighted nanotechnology risks and recommended stronger governance frameworks for addressing the area. (Royal Commission, 2008). Meanwhile, the Organisation for Economic Cooperation and Development (OECD) has established guidelines, coordination mechanisms (such as Working Party on Manufactured Nanomaterials or WPMN), and programs for exchanging nano EHS information (Murashov, 2009).

Why is all this EHS activity occurring in the nanotechnology R&D domain? It is generally accepted that EHS testing is important to ensure safety and minimize risk of exposure from novel nano materials and applications. The turbulent experience of EHS issues affecting the development and acceptance of some other new technologies, such as genetically modified organisms (GMOs), underscores this. There is an explicit role for funding and developing researchers with specialized backgrounds in and knowledge of EHS research methods in the nanotechnology domain to address safety, risk and exposure issues. At the same time, the number of nano EHS specialists is limited and whether there is capacity of nano EHS specialists to absorb sharp increases in the nano EHS budget, not to mention the difficulties of coordinating nano EHS budgets across agencies, is arguable (Kvamme, 2007).

Significantly, in the US, there are explicit societal goals which parallel the goals of the scientific and economic advancement of nanotechnology. The 21st Century Nanotechnology Research and Development Act (P.L. 108-153) was passed in 2003 with a mission to integrate societal concerns into nanotechnology R&D. Section 2(b)(10) of this act establishes a societal implications research program, requires nano research centers (NSECs) to address societal implications, integrates societal concerns with nanotechnology R&D, and seeks to ensure that advances in nanotech lead to quality of life improvements for all. Environmental concerns are prominent among societal aspects in this legislation along with ethical, legal, and other appropriate concerns. The tenor of this act and the subsequent NNI Strategic Plan stress the anticipation of social and EHS risks of nano science and technology (S&T) work (NNI Strategic Plan, 2007). This anticipatory nature highlights a clear message that environmental implications should be addressed as nano research discoveries are pursued, rather than in a subsequent period. The implication is that the broader domain of nano researchers beyond the dedicated contingent of nano EHS specialists should be concerned with environmental implications of nano R&D work in an anticipatory mode.

This broadened conceptualization of the positioning of EHS concerns in nano science and nanotechnology R&D reflects the changing nature of the testing, characterization, risk evaluation, toxicity activities. In the linear research and innovation model – which posits that discovery moves through various categories from research to development to production to sales in a sequential manner – EHS activities typically take place in the later stages of the model -- once applications have been developed. However, this model has been increasingly criticized for ignoring feedback loops, the importance of customer demand, linkages and alliances, and broader systems (Hobday, 2005). The high risk nature of many emerging technologies reflects an earlier placement of EHS activities such that they occur in parallel with discovery. This conceptualization of the positioning of EHS activities beside nano S&T research activities is frequently recognized by nanoscientists themselves. For example, Vicki Colvin, Professor and Executive Director of the Center for Biological and Environmental Nanotechnology, testified before the House Committee on Science in 2007 that "the urgency to nano-EHS research affects the entire NNI investment." (Colvin 2007) Likewise, Dr. Lee Ferguson, Department of Chemistry and Biochemistry at the University of South Carolina, has stressed the prioritization of addressing "environmental and health impacts of nanotechnology *as this technology is developed*. This last point is critical – we cannot afford to wait until nanotechnology is fully developed to begin assessing its risks and hazards to human health and the environment… We have a unique opportunity now – through the NNI we have begun to address the EHS risks of nanotechnology *simultaneously* with the development of this technology. We have only to look at the lessons learned from PCBs and other legacy chemical contaminants to realize the dangers of waiting until new technologies are mature to assess their environmental and health risks." (Ferguson, 2007; emphasis in the original)

The ability to associate nano EHS work with nanoscience R&D, as well as the advance of nano EHS work itself, depends to some extent on interdisciplinary connections. As an emerging field, nanotechnology is thought to draw on many scientific and technological disciplines. Porter and Youtie (2009) find that nanotechnology publications can be found in multiple locations across the "map of science," albeit with a concentration in materials science and chemistry. Nanotechnology research is not simply an amassing of unrelated disciplinary inquiries. The study shows that research in any one category of nanotechnology tends to cite research in many other disciplines, even though integration scores show that much of science and engineering is comparably interdisciplinary. Focusing on a specific nanotechnology, Rafols et al. (2009) observe that many of the interdisciplinary connections involve sharing of knowledge and standard practices and methods. This interdisciplinary aspect of nanotechnology has particular relevance for the nano EHS area. The NNI Strategy for Nanotechnology-related Environmental, Health, and Safety Research references the need for methods and characterizations that are reproducible and standardized across disciplines (NNI, 2007). In particular, the Royal Commission on Environmental Pollution's (2008) examination of the nano EHS area highlights the significance of cross disciplinary connections between the environmental side of nanotechnology EHS and the medical side:

> “The research programme should pave the way for much greater interdisciplinary co-operation, including co-operation between those engaged in medical toxicology and those in ecotoxicology, so as to enhance the development of robust test systems and also to act as a catalyst for early warnings from observations on lower organisms to be extrapolated to humans.” (Royal Commission on Environmental Pollution, 2008, p. 77).

The anticipatory and cross-disciplinary requirements for nano EHS suggest that there is a need for research that assesses the extent of diffusion and disciplinary connections. This work explores the following two questions. First, we examine the broader dissemination of nano EHS, asking to what extent has nano EHS research diffused not just within the specialized area itself but also into the broader nano science and technology domain? Second, we focus on the diffusion of knowledge across one particular cross-disciplinary boundary, in the question to what extent are there connections between “ecotoxicity,” or the fate of manmade nanoscale materials in the environment, and “medical toxicity,” or hazards to human health?

Methods

This research employs bibliometric analysis of publications in the nano EHS domain. The initial building block for this analysis involves developing a definition of what constitutes nano EHS. We begin by developing a typology of the nano EHS domain comprised of four categories:

1. The first category represents EHS research which discusses the potential "positive" EHS effects of nano. One example is the article authored by Rice University researchers about the potential of "nanorust" to remove arsenic from water. (Yean et al, 2005).
2. The second category represents EHS research which discusses the potential "negative" effects of nano. For instance, some recent research on impacts associated with carbon nanotubes finds lesions similar to those emerging from asbestos in terms of cancerous tumors in mice (Poland et al, 2008).
3. The third category represents research which discusses both the potential "positive" effects of nano and also the "potential negative" implications. This includes overview articles which summarize a particular area of nano S&T research, for example, "Nanoparticles in drug delivery: Biodistribution, therapeutic and toxicological considerations" appearing in *Toxicology* in 2006 (Garnett, 2006).
4. The fourth category represents the large number of articles that descriptively characterize nanoparticles or involve basic research in nano, but are not specific enough in any applications, hence positive or negative effects are not discussed or relevant. This is the "modal" type of article in the nano R&D domain, where scientists present interesting and novel results at the nanoscale, but do not consider (in that article) whether there are potential EHS implications.

Our work focuses on the second and third categories. We would anticipate that as nano EHS research diffuses into the broader nano S&T domain, as nano research moves more towards applications, and if scientists in that domain are aware of and attentive to EHS concerns, then the fourth category might diminish relatively in size over time (and there will be a relative growth in the other three categories).

The analysis draws on Georgia Tech's global nanotechnology database. This database was developed using the search strategy described in Porter et al., (2008) to identify publications (and patents) in the nanotechnology domain. This search strategy is based on a multi-stage boolean approach, and using it we have built global databases of 1.4 million nanotechnology-related publication records (1990-2008), including more than 508,000 from the Web of Science's Science Citation Index (WOS SCI). The focal years for this analysis of nano EHS publications will be 2004-2008 as they approximate the ramping up of nano EHS investments in the US.

Translating our categories of research articles into specific bibliometric terms is a fundamental challenge. Figure 1 illustrates the broad processes we used to develop this domain. An initial set of nano EHS search terms was constructed based on The Virtual Journal of Nanotechnology Environment, Health & Safety, and Nanomaterial Research Strategy. Drawing upon the insights from major national nano EHS strategy documents, discussions with nano EHS experts and funding agency heads, as well as group exercises with nano scientists and social scientists, these synthesized search terms were further tested and refined. Once the searching terms were identified, they were applied in a pilot test to the Georgia Tech global nano database for the year 2008. We tested the validity of applying these terms to the following WOS SCI fields – (1) author's keywords+ keywords plus+ title phrase+ abstract phrase, (2) abstract, (3) title+ author's keywords+ keywords plus; (4) abstract +title, and (5) title – by either reading the abstract or (in a few cases) the full papers of the resulting extracted publication subset to determine if the subset was or was not in-domain. The application of author or journal keywords or abstract phrases tended to be plagued by low relevance (i.e., bringing too many out-of-domain publications). As well, we found that we needed to incorporate additional search terns to ensure more adequate coverage of nano EHS publications. Sets of terms were removed, supplemented, or upgraded with additional validated terms based on trial and error. In addition to the key term approach, we also tried to seed a search from a core set of publications of highly cited nano EHS scholars (such as Gunter Oberdorster or David Warheit). This specific approach ran into issues, not only due to difficulties in author identification in publication data, but also because of the need to capture work of general nano scientists as well as nano EHS specialists in light of the focus of our research on the broad diffusion of nano-EHS work.

[INSERT FIGURE 1 ABOUT HERE]

However, from this pilot effort we developed a Boolean search term set which was then more successfully applied to the WOS SCI title field in the Georgia Tech global nano database for the year 2008. The components of the search terms can be broadly classified into three sets. The first set of EHS terms tries to capture explicit nano EHS terms. Keywords in this group include nanotoxicity, nanosafety, and nanoecotoxicity; articles including any term in this set are included. The second set of terms includes broader terms that are conditional on combination to be regarded as the nano EHS research. The third set of terms is “exclusion terms” that cull out-of-domain publications from the database. Most of these exclusion terms refer to the positive or beneficial side of nano EHS as opposed to our focus in this study on the negative impacts.

[INSERT TABLE 1 NEAR HERE]

Several tests of the results of the search strategy were performed which involved comparing the results of our Boolean search with the results of coding of papers as nano EHS by multiple investigators' review of paper abstracts (or in some cases, full papers). First, we determined that the 25 most cited papers of nano EHS articles in 2008 were captured by our Boolean search term. Second, the Boolean search was found to capture 75% of the papers that our visual review of abstracts (and some full papers) coded as nano EHS; we could not increase this percentage further by adding more search terms without also adding much more noise to the results. Third, we applied this search approach to nano publications in 2007 to confirm its applicability in a different year. The search captured roughly the same percentage of in-domain publications (determined as such by visual review of abstracts and some full papers) as was the case for 2008. Our analysis is thus based on the search approach generated through this process.

Findings

Our first set of analyses examines the diffusion of nano EHS publications into the broader nano S&T domain. We wish to understand the extent to which nano EHS research is emerging alongside that of the broader nano S&T domain. The findings suggest that the nano EHS area is relatively small in size but exhibits very fast growth. From 2004 to 2007, the number of publications in the nano EHS area more than doubles in size (n=303 nano EHS publications in 2007, n=135 in 2004), accounting for 0.5% of the total nano S&T publications in 2007, compared to 0.3% in 2004. The growth rate of nano EHS publications is 124% versus 29% for all nano S&T publications from 2004 to 2007.

Nano EHS publications can also be characterized by the types of nanoparticles which they target. This focus on nanoparticles is of interest because of the specificity of nano EHS work with respect to nanoparticles and environments such as the aforementioned work examining the effect of carbon nanotubes on mice or the effect of nanoparticle silver released in water (Benn and Westerhoff, 2008). Nanoparticle targets in this study are measured using references to nanoparticles in abstracts of nano EHS publications. We have selected a sample of nanoparticles to examine based on the "list of representative manufactured nanoparticles for testing" as reported in the OECD's Guidance Manual for the Testing of Manufactured Nanomaterials: OECD's Sponsorship Programme. (OECD, 2009, p. 48). Using this approach, we find that 12% of the 2007 nano EHS publications included one of these listed nanoparticles in their abstracts. Fullerenes (C60) were the most commonly mentioned nanoparticle in the nano EHS dataset, followed by carbon nanotubes, silver nanoparticles, and zinc oxide. Comparing this distribution to the distribution of nanoparticles in abstracts of publications in the full nano S&T domain, we see that C60, silver nanoparticles, and zinc oxide are more likely to be found in the 2007 nano EHS dataset than in the larger nano S&T publications, while carbon nanotubes are equally likely to be in both datasets. (See Figure 2.)

[INSERT FIGURE 2 NEAR HERE]

By country of author affiliation, the US has the largest number of nano EHS publications in 2007, followed by Germany, China, UK, Japan, and South Korea (see Table 2). The US, European countries, and Australia are more specialized in nano EHS while China and Japan are less specialized. In addition to differences in systematic national policy attention to EHS, an explanatory factor is that the US and other more specialized countries do more nanoscale research in fields that are prominent in EHS work such as biomedical science and environmental disciplines, whereas Chinese research tends to be concentrated in more broad-based materials and chemistry disciplines. For example, US nano S&T publication concentrations are represented by specialization figures above 1.00 (where 1.00 means the country is more specialized in a "macro-discipline" than the overall database, see description of "macro-discipline" below) in areas such as Biomedical Science (1.55), Clinical Medicine (1.46), Infectious Diseases (1.44), Geosciences (1.57), Ecological Sciences (1.37), Environmental Science and Technology (1.07) but lower specialization figures in Materials Science (.91) and Chemistry (.93). In comparison, China's nano S&T publication concentrations are represented by specialization figures above 1.00 in Materials Science (1.05) and Chemistry (1.16) but lower specialization figures in Biomedical Science (.49), Clinical Medicine (.52), Infectious Diseases (.25), Geosciences (.39), Ecological Sciences (.25), Environmental Science and Technology (.89).

[INSERT TABLE 2 NEAR HERE]

Another perspective on the overall diffusion of nano EHS research into the nano S&T publication domain is to track the prominence of EHS focal areas or "disciplines" in the cited references of nano S&T publications. If nano EHS concerns are rising alongside general nano R&D interests, we would expect to see more citations of EHS work in the typical nano S&T publication. To test this proposition, we represent disciplines, including EHS disciplines, with the Institute for Scientific Information's (ISI) journal subject categories (SCs) (Porter and Youtie, 2009). We have drawn 1000 randomly selected publications from nano S&T publications in 2006 and 2008 (the earliest and most recent years for which we have downloaded cited references). Table 3 highlights the top 10 most commonly cited SCs along with selected EHS-related SCs. The table suggests that the relative position of EHS-related SCs is not near the top, falling in the 32^{nd} to 109^{th} positions in 2006, and changes only slightly between the two years, falling into the 32^{nd} to 84^{th} position by 2008. Of course we are only looking at a two-year period in the early stages of nano-EHS activity, but these results suggests that that there is limited broad-based diffusion to date.

[INSERT TABLE 3 NEAR HERE]

The second research question of this study seeks to explore connections across disciplinary boundaries by examining the links between research on the fate of manmade nanoscale materials in the environment and research on hazards to human health. We start by observing the disciplinary concentrations within nano EHS and how these disciplinary concentrations change over time. In this portion of the analysis, SCs have been grouped into "macro-disciplines" through factor analysis of associated SCs. (Leydesdorff and Rafols, 2009). A macro-discipline analysis of the nano EHS publications shows that biomedical publications are most common, followed by chemistry, materials science, and environmental science (See Figure 2). Nano EHS publications are more prominent in the biomedical macro-discipline in 2007 than in 2004, whereas publications in the more general chemistry macro-disciplines are less prominent. Focusing on specific SCs, we see that there is a change in emphasis over time in which toxicology rises in importance from 7^{th} in 2004 to the top rank by 2007. (See Table 4.)

[INSERT FIGURE 3, TABLE 4 NEAR HERE]

The disciplinary distribution of nano EHS publications can be visualized using an overlay map of science (Leydesdorff and Rafols, 2009; Rafols and Meyer, 2009). Figure 3 shows that publications are concentrated in the materials science and chemistry areas as, is the case with the broader nano S&T publication base (Porter and Youtie, 2009). However, there is also a distinctive concentration of biomedical science and environmental science and technology SCs that is not evident in the map of the broader nano S&T publications. The agricultural science and ecological science areas are perhaps less represented with publications – despite the potential implications for nanotechnology in agricultural science – such as in precision farming sensors, nanoemulsions in pesticides, and nanotechnology in food packaging and processing (Joseph and Morrison, 2006) – and in ecological science – such as the use of nanotechnology for ecological forecasting and detection of ecological toxicity from nanomaterials. We can also examine the degree of "integration" of multiple disciplines in nano EHS by calculating an "integration score" from a similarity matrix of cited SCs for a threshold of papers with at least four cited references and at least three cited SCs. The integration score ranges from zero (i.e., a stand-alone discipline that cites no work from outside its discipline) to one (i.e., a highly integrated work that cites largely from diverse disciplines). (Porter et al, 2006; Porter et al, 2007). The mean integration score for nano EHS is 0.54 (standard deviation=.12). This figure suggests moderate levels of multidisciplinarity in nano EHS.

[INSERT FIGURE 4 NEAR HERE]

Given the Royal Commission Report's recommendation about the importance of bridging biotoxicity and ecotoxicity research in nano EHS, it is appropriate to examine the specific link between these two fields. Specifically we examine the extent to which environmental nano EHS publications cite biomedical works and the extent to which biomedical nano EHS publications cite environmental works. Nano EHS publications with SC names that incorporate “envir-“ or “ecology” are considered environmental nano EHS; publications with SC names that incorporate “bio” or “health” are considered biomedical nano EHS for the purpose of this analysis. The results from our 2007 nano EHS database show that environmental nano EHS publications are more apt to cite biomedical nano EHS works than the reverse. Less than one-fourth of the 53 biomedical nano EHS publications in 2007 cite environmental nano EHS works, whereas more than half of the 29 environmental nano EHS articles in 2007 cite biomedical works. This is an early examination of multidisciplinary cross-citation to be sure but it does suggest that the disciplinary gap is more prevalent on the biomedical side than the environmental side.

Conclusions

This research has examined the growth and diffusion of nano EHS research using bibliometric analysis of WOS SCI publications in the Georgia Tech global nanotechnology database. We were guided by two research questions: (1) to what extent has nano EHS publication activity developed alongside that of the broader nano S&T domain, and (2) how have nano EHS publications diffused across specific disciplinary boundaries. The importance of these research questions lies in the understanding the extent to which attention to EHS issues is occurring concurrently with, and in relationship to, the development of broader nano R&D (and not afterwards). This simultaneous development of EHS and nano S&T work is important to avoid problems that have plagued previous technologies as well as to ensure that risks are avoided or minimized.

The results of our research show that nano EHS publications are small in scale relative to the broader nano S&T area, though growing very rapidly. This growth rate suggests that there is the potential for nano EHS work to broaden its impact on nanotechnology S&T research. However, the diffusion of nano EHS work will face challenges, notably the challenge of scale – i.e., the magnitude of the general nano S&T body of work compared to the smaller size of nano EHS work. However, one could also argue that the bigger that the broader nano S&T gets, the greater opportunities for EHS growth and interconnection. This difference in size of the two domains will likely persist, despite the sharp increase in nano EHS investment and research. Thus, the next few years may require greater emphasis on communication and impact of nano EHS work if the goals of nanotechnology governance for simultaneous attention to nano S&T advances and nano EHS affects are to be addressed.

Second the diffusion of nano EHS work across disciplinary boundaries within this area is of particular importance to the development of nano S&T, noted specifically in the recently released report by Royal Commission on Environmental Pollution in their concern about the need for linkages between biomedical and environmental cooperation in nano EHS to "enhance the development of robust test systems and also to act as a catalyst for early warnings from observations on lower organisms to be extrapolated to humans" (Royal Commission, 2008, p. 54). Our analysis showed that the nano EHS area as a whole is somewhat multidisciplinary, with a strong presence of materials science, chemistry, biomedical science, and environmental science and technology, though some gaps show in the agricultural and ecological sciences. When focusing on the sharing of knowledge, as measured by cited references, across the biomedical and environmental nano EHS areas, our findings indicate that more bridging from the perspective of environmental nano EHS citation of biomedical references than in the reverse direction. The ability to make environmental nano EHS research available and useful to biomedical nano EHS research is a noteworthy area of future attention. Continued monitoring of the relationships of nano EHS between disciplinary boundaries, as well as across the broader nano field, will be helpful to the ongoing development of nano R&D.

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Figure 1 Flow Chart of Nano EHS Searching Strategy

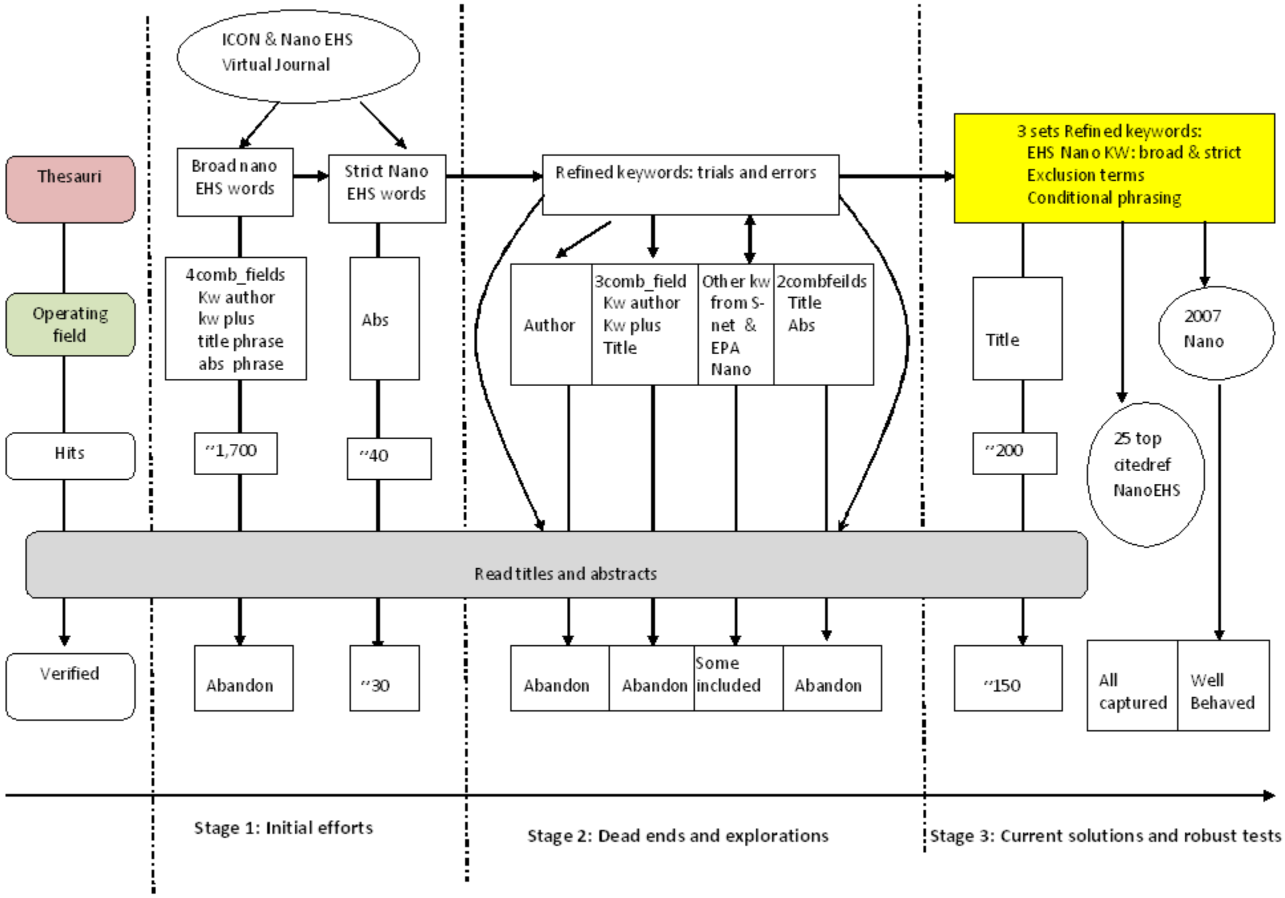
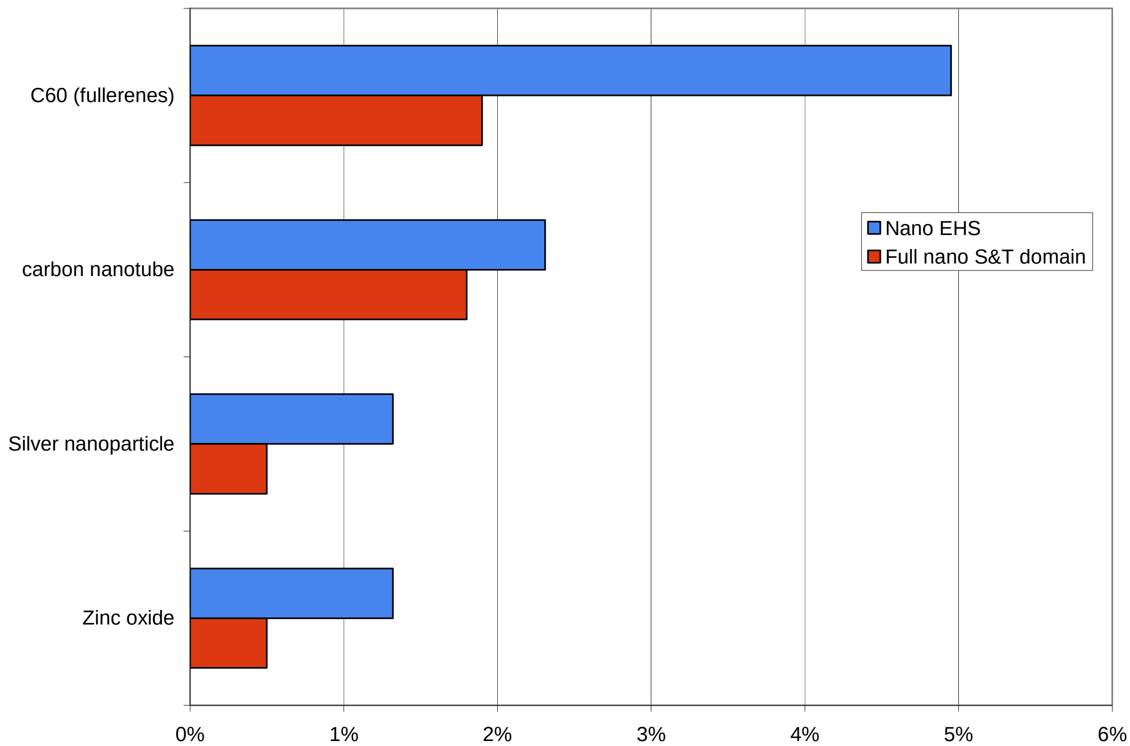
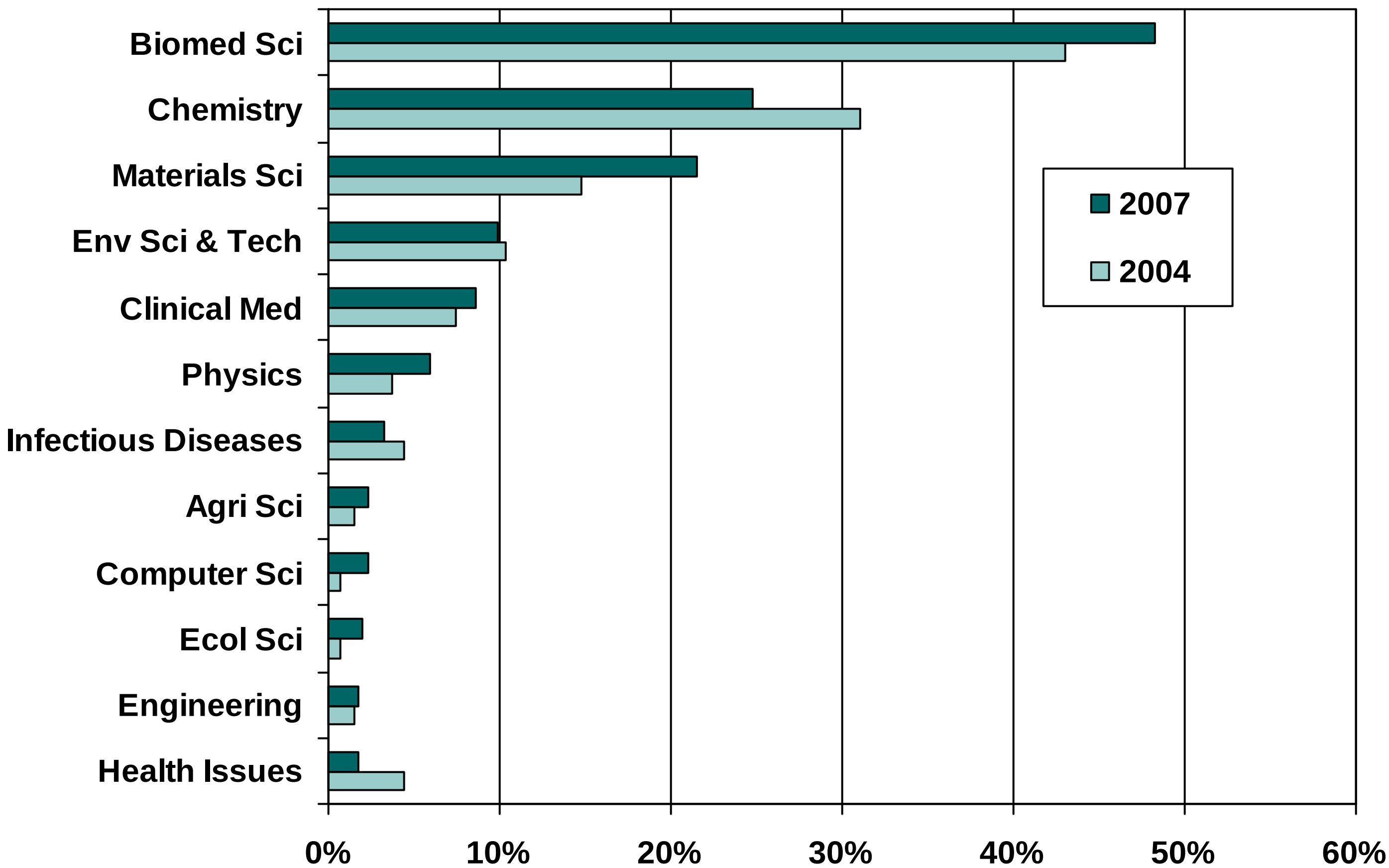


Figure 2. Nano EHS Publications by Type of Nanoparticle



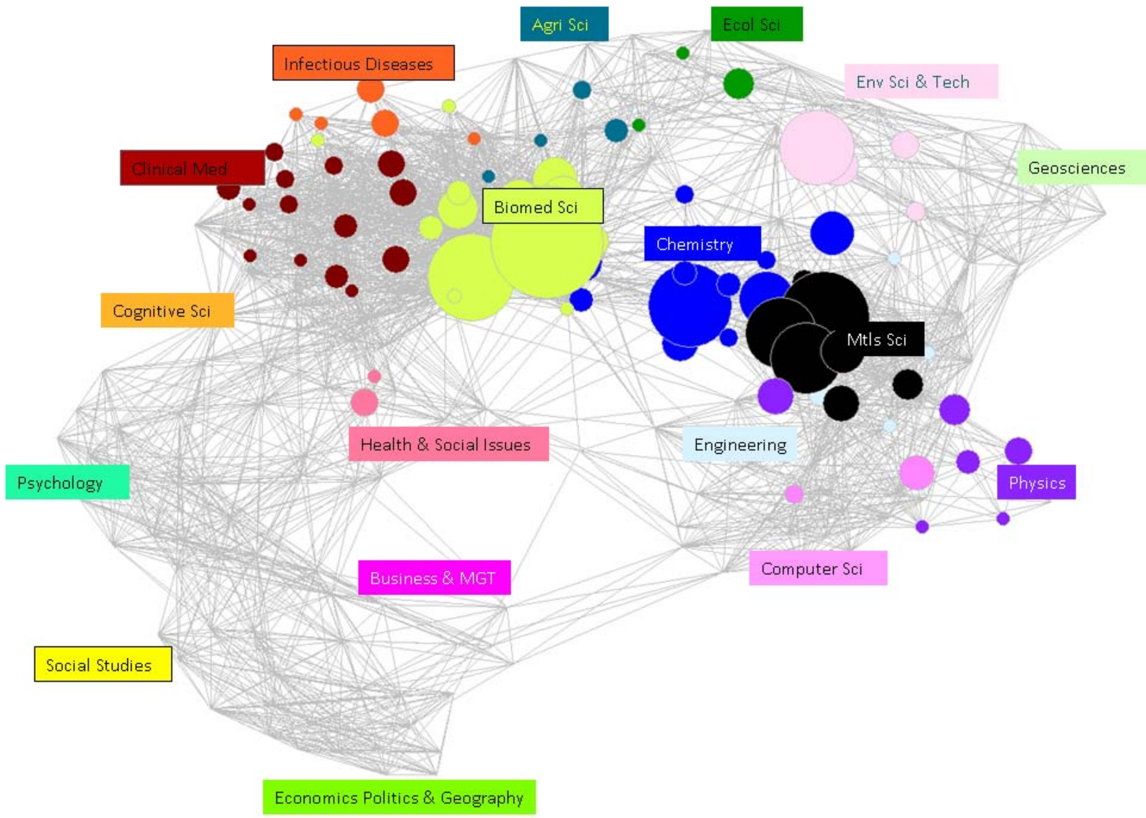
Source: Nano EHS extraction of databases described in Porter et al, 2008 (n=303 in 2007 for Nano EHS, 63,283 for full nano S&T domain).

Figure 3 Macro-Disciplines of Nano EHS Publications: 2004 and 2007



Source: Nano EHS extraction of databases described in Porter et al, 2008 (n=135 in 2004; n=303 in 2007).

Figure 4. Map of Science: Subject Categories of Risk within Nano (2007)



Source: Nano EHS extraction of databases described in Porter et al, 2008. Base map of science from Rafols and Meyers (2009), Leydesdorff and Rafols (2009).

Table 1 Search Terms on Nano EHS Paper

Search terms	**Conditional terms**	**Excluded terms**
Toxic*	Hazard, Risk, Dose	Safety glass
Danger	Exposure + others	Antimicrobial
Nanosafe*	Health, Pollut*, Contamina*, Asbestos, Environment, Nanomaterial, (various)	Less toxic
Safety	Depos, nasal, inhale, dermal absorption/ingestion, radiation	Low toxic
Cytotoxic	Migrat*, Latex*, Releas*, Interac*,	Non toxic
nanoecotoxi*	Stress, Impact, Influence, Effect	
	Governance, Technolog*	
	Stability, Commercial*, uncertain*	
	Food, Air, Ecosystem	

Table 2. Nano EHS Publications by Country in 2007

Countries	Risk Records	Total Records (1000)	Ratio	Special-ization*
USA	80	14.9	0.54	1.12
Germany	35	5.6	0.63	1.32
P.R. China	28	12.0	0.23	0.49
UK	21	3.3	0.63	1.31
Japan	20	6.1	0.33	0.69
South Korea	20	3.2	0.62	1.30
France	15	3.5	0.43	0.89
Italy	13	2.4	0.55	1.15
Australia	11	1.2	0.94	1.95
India	10	2.7	0.37	0.77

*The specialization index is the ratio of nano EHS to all nano S&T publications for a given country divided by this same ratio for the whole nano S&T publication database in 2007. More specialized in nano EHS>1.00; Less specialized in nano EHS < 1.00.

Source: Nano EHS extraction of databases described in Porter et al, 2008.

Table 3. Spread of Environmental, Health, and Safety Disciplines in Nano Science and Technology Research: 2006 v. 2008

Cited Subject Category 2006	Cited Subject Category 2008
1. Materials Science, Multi.	1. Materials Science, Multi.
2. Chemistry Physical	2. Chemistry Physical
3. Physics Applied	3. Physics Applied
4. Physics Condensed Matter	4. Chemistry Multidisciplinary
5. Multidisciplinary Sciences	5. Physics, Condensed Matter
6. Chemistry Multidisciplinary	6. Multidisciplinary Sciences
7. Physics Multidisciplinary	7. Nanoscience & Nanotech.
8. Physics, Atom. Mole. Chem.	8. Physics, Atom. Mole. Chem.
9. Nanoscience & Nanotech.	9. Physics, Multidisciplinary
33. Environmental Sciences	***32. Environmental Sciences***
39. Engineering, Environment.	***38. Engineering, Environment.***
68. Public, Envir., Occup. Hlth.	***75. Public, Envir., Occup. Hlth.***
109. Ecology	***84. Ecology***

Source: Nano EHS extraction of database described in Porter et al, 2008. N=1000 randomly selected records in 2006 and 2008.

Table 4. Top Journal Subject Categories in Nano EHS

Subject Category 2004	Subject Category 2007
1. Chemistry, Multidisciplinary 2. Pharmacology & Pharmacy 3. Materials Science, Multi. 4. Environmental Sciences 5. Biochemistry & Molecular Biology 6. Cell Biology **7. Toxicology**	**1. Toxicology** 2. Materials Science, Multi. 3. Pharmacology & Pharmacy 4. Chemistry, Multidisciplinary 5. Environmental Sciences 6. Biochemistry & Molecular Biology 7. Nanoscience & Nanotechnol. 8. Physics, Applied 9. Chemistry, Physical

Subject Categories with 10 or more publications in 2004 and 15 or more publications in 2007 are shown in this table.

Source: Nano EHS extraction of database described in Porter et al, 2008 (n=135 in 2004; n=303 in 2007).