# Nanotechnology Startup Concerns, Information Needs, and Opportunities to Proactively Address Environmental, Health, and Social Issues

## *Focus on firms in Connecticut and New York*

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***Authored by:***

**Deanna Lekas**
Master of Environmental Management 2006
Yale School of Forestry and Environmental Studies

***Advised by:***

**Reid Lifset**
Associate Director of the Industrial Environmental Management Program
Yale School of Forestry and Environmental Studies

**David Rejeski**
Director of the Project on Emerging Nanotechnologies
Woodrow Wilson International Center for Scholars

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## I. Introduction

This paper involves an investigation into how nanotech startup firms are dealing and could deal with uncertain environmental and health issues related to the production, distribution, and use of their products. Nanotechnology offers numerous benefits for improved material performance in everything from electronics to healthcare to sporting goods and sunscreen. However, at the same time, this emerging technology presents uncertainty as to potential environmental and health risks of product development, use, and at end-of-life. Many organizations including the UK Royal Society, U.S. Environmental Protection Agency (EPA), and NGOs such as the Woodrow Wilson International Center and Environmental Defense, are calling for increased research efforts to explore the uncertain and uncharacterized risks while many nanotechnologies are still in the early stages of development. Some firms that develop or use nanomaterials have begun wondering what they should do, whether they should anticipate regulations on nanomaterials or products, and what information they need to address potential risks or uncertainties.

To this end, this paper attempts to offer some insights on what firms are thinking on environmental, health, safety, and social issues related to nanomaterials and the sources of their concerns. A small survey of nanotech firms in Connecticut and New York and existing literature serve as the basis for this analysis. The findings from this study may assist external organizations (government, NGOs, industry groups) in their understanding of how to disseminate information to these firms. I then propose recommendations for the internal audience (the nanotech firms themselves) on how they could deal with potential concerns or risks. I offer thoughts on which firms should be concerned based on their line of business and the kind and type of material they produce or use based on potential risks of nanoparticles identified by toxicity studies. Finally, I propose suggestions on ways that small nanotech firms could adjust their processes and improve their environmental, health, and safety management using lessons from other small and medium-sized enterprises' (SME) experiences. These efforts could help firms proactively deal with concern areas. The hope is that the outcome of this paper will be something that will be useful for both external groups and internal management in SMEs in their efforts to prevent adverse effects from nanomaterials in our environment, bodies, and communities. Please note that this paper is a preliminary attempt to characterize potential risks and ways to deal with them, and is not intended to serve as an authoritative source of information. The suggestions presented here reflect a synthesis of information as well as my own best guesses of higher priorities for firms on this topic.

To help set the stage for this assessment, the next few paragraphs offer background on SMEs and the importance of getting the right information to nanotech startups. Over 3,500 firms are involved in some aspect related to micro or nanotechnology (*Small Times* 2005). As noted in *Small Times* magazine, "the vast majority of nanotech companies worldwide are small startups or university-led initiatives," (Garrett 2005). As of last February, there were about 1,200 operating nanotech startups globally (Baker and Aston 2005), and this number continues to grow. Company involvement in nanotechnology includes everything from research and development of nanomaterials, nano-based products, and equipment for nano-production, to trade magazines, and firms that offer legal expertise, venture capital investment, and intellectual property strategizing on nanotechnology. With such a broad range and large number of companies entering this field

at such a fast rate, it is important that companies have the right information to consider the potential environmental impacts and health concerns to employees and consumers using nanomaterials. Small startups may not have sufficient access to information or the resources or capacity to evaluate environmental and health impacts as do larger companies (like GE and DuPont developing nano-based products).

This report tries to relate and apply examples from SME experiences to nanotech startup experiences. Many of the studies in the academic literature focus on SMEs in Europe. This is probably because they comprise such a large share of the corporate world – accounting for 99% of all companies and 65 million jobs in the European Union (European Commission 2003).
In the United States, small businesses also dominate in numbers – representing "99.7% of all employers" and totaled 22.9 million in 2002, according the U.S. Small Business Administration (SBA 2005). However, it is important to note that countries define SMEs in different ways. The United States includes far more companies in its SME definition. It considers firms with fewer than 500 employees as SMEs, and defines micro businesses as employing less than 10 people; small businesses as having 10-99 employees; and medium-sized businesses as having 100-499 employees (Kozak 2005). The European Commission defines SMEs as those with fewer than 250 employees, and with an annual turnover not exceeding EUR 50 million or an annual balance sheet total not exceeding EUR 43 million (European Commission 2003). For European countries, micro, small, and medium-sized companies employ less than 10, 50, and 250 people, respectively.

Prior to conducting this study on Connecticut and New York-based nanotech startup firms, I settled on a few hypotheses. I hypothesized that overall small nanotech firms would be unaware of or have not considered the environmental and health risks of their operations or their downstream products. This would be due to either, or a combination of, a lack of time, resources, or understanding. I anticipated that firms would be open to evaluating such impacts with help or information provided by EPA or nonprofit organizations. I believed that there would be many lessons from environmental management literature on SMEs that could apply to nanotech firms. Lastly, I anticipated that firm concern for environmental, health, safety, and social perception issues would be low, particularly for those that have already commercialized their products. I suspected that they would not see a need to invest time and resources in environmental or health issues if they were already able to sell their products and were not facing government restrictions. At the same time, I thought that companies in the research phases may also not want to devote resources to these issues because of their limited nature (despite the fact that these firms may have greater feasibility to do so at earlier stages of development).

Using Connecticut and New York nanotech startups for this study is appropriate considering the existence of a wide range of enterprises already involved in nanotech in these states. Small, private nano enterprises in Connecticut and New York include those in the financial community (analysts and venture capital firms), those developing or using nanotechnologies (within the biotechnology, healthcare, energy, government/defense, materials/chemicals sectors, communications), a number of professional/industry organizations and educational institutions, and organizations providing services (e.g., engineering/R&D, legal/intellectual property, recruiting) to the nanotech community (*Small Times* 2005). Interestingly, the State of Connecticut, with the support of Governor M. Jodi Rell, passed a bill

requiring the Commissioner of Higher Education to "review the inclusion of nanotechnology, molecular manufacturing and advanced and developing technologies at institutions of higher education," (CGA 2005). In addition, the co-founder of the Connecticut Nanotechnology Initiative, Susan Duncan, believes that "Connecticut is well-positioned to be a leader in the nanotechnology sector." She says: "our State is home to burgeoning biotech, pharmaceutical, fuel cell, aeronautics, and defense industries; world-class research; academic institutions; a well-educated workforce; funding sources and a culture of innovation," (Nanodot 2003).

New York State is also taking the lead in promoting the growth of nanotechnology. New York's Center for Economic Growth has created a *New York Loves Nanotech* consortium to promote further R&D, education, industrial development, and investment around nanotechnology in the state. According to the consortium's website, over $10 billion has already been invested in New York's Tech Valley in the eastern part of the state (NYLN 2006).

## II. Method

The research for this paper involved two main components. I first investigated information needed by nanotech SME firms to proactively address environmental, health, and safety issues. To evaluate these information needs, I surveyed a small sampling of firms in Connecticut and New York to understand (a) what concerns they have (if any) on these issues, (b) what information they need, (c) how best to convey that information to them (e.g., what form is the most useful and which messengers do they trust), (d) how handling or concern for environmental, health, or safety issues varies by nano firm, and (e) what perception they have of public knowledge on nanotechnology. I identified a list of private nanotech firms to survey in Connecticut and New York using the "2006 Small Tech Business Directory" developed by *Small Times* and with the help of the Connecticut NanoBusiness Alliance (Tinker 2006). Appendix A and B provide information on the firms contacted in Connecticut and New York. I included all private firms in CT and NY from those directories that (a) are engaged in nanotech-based research or production, and (b) for which I had contact information. I excluded private firms involved in the legal, capital, journalism, or other non-production activities related to nanotechnology. I then developed a questionnaire to find answers to the above questions. Appendix C provides the general questionnaire that I developed and adjusted slightly for specific companies based on publicly available information located prior to the initial contact.

The second component of this paper involved a review of literature on environmental management efforts by SMEs, particularly in addressing uncharacterized risks. Based on the literature, I tried to apply the lessons learned from the environmental management experiences of SMEs to small nanotech firms. Both of these components will help us better understand how we can anticipate that nanotech firms will deal with these issues with the right information, and what environmental management or policy strategies may be effective. It will also help us evaluate how receptive nanotech startups will be to the actions of other stakeholders (government and state agencies, insurance industry, investors, nonprofit organizations, and consumers) in encouraging or requiring these firms to consider the potential environmental and health risks of nanotechnology.

## III. Assessment of Companies' Primary Concerns

This section first discusses primary concerns of nanotech SMEs and SMEs in general on environmental, health, or social issues based on existing literature (including prior surveys). It then presents findings from the survey and interviews conducted for this report, and other relevant literature and internet research.

### A. Review of Findings from Other Company Surveys

Firms reveal varying levels of concerns on potential environmental, health, safety, and social implications of nanotechnology. An extensive European survey of nano SMEs and startups, that included responses from 380 companies, revealed that environmental and social impacts of nanotechnology rank *low* among companies' concerns (European Commission 2005). Firms' consideration of public social acceptance and environmental and health regulations were "not considered important barriers for the application of nanomaterials by SMEs," with just 3% and 7%, respectively, of respondents considering public social acceptance and environmental and health regulations as barriers. The authors of this study conclude that: "this shows that there is a lack of conscience/awareness on the potential risks of such aspects for the nanomaterial branch among SMEs." This is surprising considering European countries tend to take more precautionary measures in dealing with new technologies, such as genetically modified food.

The European NanoBusiness Association (ENA) recently released its survey of 142 European businesses (although not limited to SMEs) on their attitudes of the impact of nanotechnologies on their businesses, the role of regulation, and perceptions of nanotechnologies. This survey had a slightly different finding than that of the European Commission survey just described. When asked what needs to be studied (in regards to nanotechnologies), the vast majority of respondents affirmed that health and environmental impacts needed to be studied (see Table 1). SMEs accounted for about 18% of the surveyed European businesses.

**Table 1: Responses to ENA Survey Question: *What needs to be studied?***

| % of Respondents | Responses given in survey |
|---|---|
| over 80% | Possible health effects of nanoparticles or other nanostructures |
| about 80% | Effect of release to the environment of any chemical |
| about 78% | Effect of release to the environment of nanoparticles or other nanostructures |
| about 65% | Possible health effects of materials containing nanoparticles or other nanostructures |

Source: ENA 2005.

As result of these and other survey findings, ENA concludes that "uncertainties about health, safety and environmental effects, and the public perception of nanotechnologies, is restricting available capital, and making many larger companies (and their legal teams) nervous about launching products involving nanotechnologies until these issues have been clarified," (ENA 2005). The divergent findings from these two European studies, completed in the same year, may suggest that the uncertainties surrounding environmental, health, and social perception issues of nanotechnology pose a greater concern to larger corporations and those that are not

already using nanomaterials than SMEs. Perhaps this could be attributed to the different ways that the surveys were conducted (with the ENA stressing environmental, health, and social perception issues more), and/or the European Commission presenting more barriers to the application of nanotechnology that weighed more heavily on SMEs. In addition, the ENA survey focused on environmental and health issues more specifically than did the European Commission study.

SMEs in general have been the source of many environmental management studies. This is not surprising considering small businesses account for such a large share of companies. As one study indicates, "the prevalence of SMEs and the unique problems and opportunities associated with their size has made them a targeted track for business – environment research," (Walley and Stubbs 1999).

General SMEs' concern about their environmental performance and impact seems to be full of contradictions between concern for the environment and actual practices. A study of SME employers in 1999 by the Barnsley and Doncaster Training and Enterprise Council found that 77% of the responding SMEs "considered environmental issues to be important in running their business," (Simpson et al. 2003). A similar finding came out of the Hillary 1995 survey of small companies. In this study, 70% of SMEs expressed that they were "'fairly' or 'very' concerned about their environmental impact," but only 34% "sought advice from support services" (Hillary 1995 and Hillary 1998, as cited in Simpson et al. 2003). In a survey of SMEs in the London Borough of Croydon, SME managers reported a high degree of concern for the environment, but at the same time, they showed a low level of awareness of environmental management developments and did not have formal practices in place to improve their environmental performance (Merrit 1998).

A study by Simpson et al. 2003 showed that 77% of surveyed companies "thought environmental issues were business issues and 63% of respondents directed resources to planning and acting upon environmental issues. Yet, 75% of respondents were of the opinion that environmental responsibility and environmental improvements was a financial cost to the business," (Simpson et al. 2003). Few of these SMEs felt that improved environmental practices would save them money or "improve customer relationships"; however, a few years earlier, 41% of firms reported to having customers ask about their environmental performance (Hillary 1998, as cited in Simpson et al. 2003). These studies demonstrate a disconnect between concern and action on the environment.

The table below summarized the results from these different surveys.

**Table 2: Findings from Surveys of SMEs on Environmental Management Issues**

| % of Respondents | Response | Reference |
|---|---|---|
| ***Positive Response to Environmental Management*** | | |
| 94% | agreed or agreed strongly that "all businesses have a responsibility to protect the environment" | Merrit 1998 |
| 77% | consider the environment an important factor to their business | Barnsley and Doncaster Training and Enterprise Council 1999 |
| 70% | concerned about their environmental impact | Hillary 1995 |
| 77% | "thought environmental issues were business issues" | Simpson et al. 2003 |
| 63% | "directed resources to planning and acting upon environmental issues" | |
| ***Neutral to Negative Response to Environmental Management*** | | |
| majority | unaware of developments in environmental management (e.g., new standards, energy support offices, etc.) and do not have formal practices in place | Merrit 1998 |
| 93% | choosing other issues as more important barriers than environmental and health regulations to the application of nanomaterials | European Commission 2005 |
| 66% | did not seek advice to reduce environmental impact | Hillary 1995 |
| 75% | considered "environmental responsibility and environmental improvements…a financial cost to the business" | Simpson et al. 2003 |
| 88% | did not think that environmental management practices would cut costs | Hillary 1998, as cited in Simpson et al. 2003 |
| 74% | did not think it would improve customer relationships | |

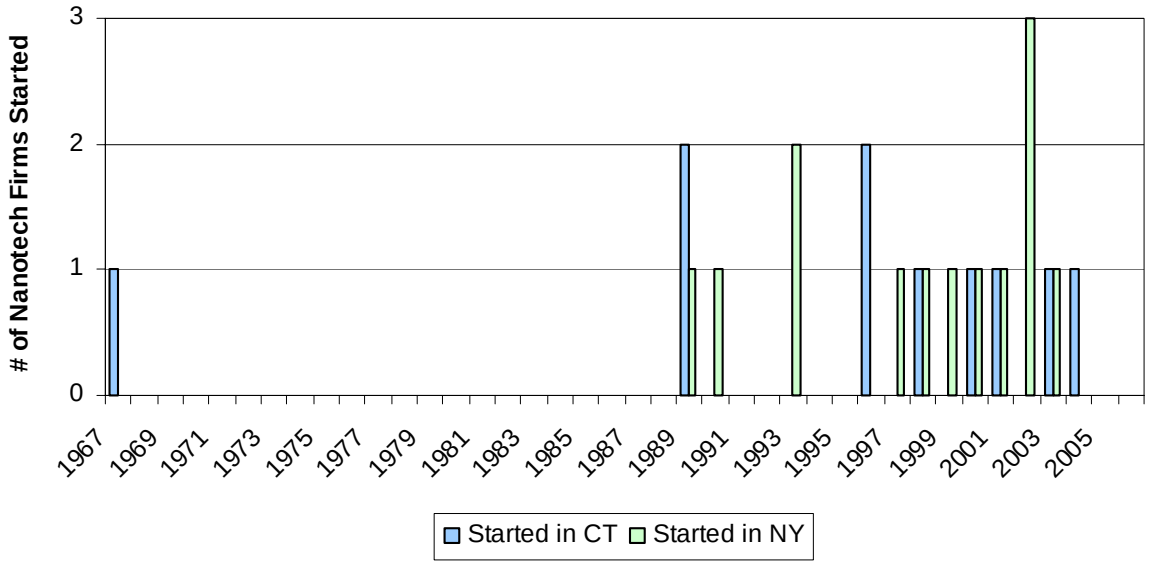
Note: Interestingly the vast majority of these SME surveys were conducted in the UK.

## B. Results from Nano SME Survey

The survey developed for this report was distributed through personal emails to twenty-two firms (ten firms located in Connecticut and twelve firms in New York). I sent the surveys primarily to company presidents and chief executive officers (CEOs). Seven firms completed the survey electronically; two firms participated in phone interviews; six were unable to complete the survey for varying reasons (confidentiality concerns, lack of personnel, time constraints, or company instability); and seven did not respond in any form. Thus, the overall participation rate was about 41% (nine out of twenty-two). The firms that participated were Foster Corporation, MysticMD Inc., Protometrix Inc., and 454 Life Sciences in Connecticut, and Advion Biosciences Inc., Cornerstone Pharmaceuticals, NanoDynamics Inc., Nanoprobes, and Starfire Systems in New York. In Appendix D, I provide a timeline of the founding of the surveyed nanotech startups across various industries in Connecticut and New York. The figure below illustrates the concentration of nanotech firm startup[1] in these two states, particularly over the last ten years.

[1] These firms are those engaged in nanomaterial use or production, or that use nanotechnology. Therefore, this does not include private firms involved in the legal, capital, journalism, or other non-production activities related to nanotechnology.

**Figure 1: Number of Nanotech Firms Started in Connecticut & New York in Last 40 Years**




Note: The firm founded in 1967 refers to a company that develops a variety of dental products. It is likely that the nanotech component of their business began many years after the company's founding.

In the sections that follow, I present some of the qualitative findings from the survey and discuss relevant insights from SME literature as they pertain to the different questions. For the selection of survey questions presented below, I provide the responses received. I do not attribute the responses to the corresponding contact person or firm in order to avoid confidentiality concerns and because this study intends to provide insights on nanotech SMEs collectively, and not to necessarily single out firms. Note that where SME respondents did not give answers to particular questions, fewer than nine responses are listed below.

***Concerns by Nanotech Startups on Environmental, Health, and Safety Issues***

Responses from participants in the survey conducted for this paper indicated that there is a wide spectrum of concerns by small nanotech-based firms about potential environmental and health issues related to their operations. A few firms voiced concern and very proactive management around these issues. Others claimed to have environmental, health, and safety issues under control or considered them non-issues. The affirmative to negative responses I received to the following questions are listed below.

*(a) Does your firm have any concerns about potential environmental, health, and safety issues associated with your operations? (b) If so, what types of concerns do you have on these issues (e.g., worker safety, production, product use, etc.)?*

- (a) "Yes." (b) "We pay close attention to workplace safety including ventilation, air quality, worker protection, safety training, etc. We communicate to employees and customers all of the information that we have on the proper manufacture, handling, storage, and use of our products."

- (a, b) “Yes, we work with a number of chemicals, and we care for employee safety, as well as environmental regulations.”
- (a) “Of course, like any new product or new chemical.” (b) “We have [material safety data sheets] MSDS sheets on all products. Handling is in accordance. We also conduct some in vitro and in vivo testing.”
- (a) “Always and in compliance with required regulations including FDA.” (b) “Exposure to toxins.”
- (a) We take what we believe are suitable precautions. Our scale is very small.” (b) “Inhalation, transdermal absorption, the usual.”
- (a) “We have policies and procedures in place.”
- (a) “We have a pretty clean system. It’s pretty standard. As far as manufacturing, there’s not a lot of toxic waste generated, materials that ship are not phenomenally toxic.” (b) “Worker safety. It’s always an issue in any manufacturing environment – ergonomic issues, and scheduling breaks - #1 concern.”
- (a) “No, we are a ‘green’ company with little or no wastes.” (b) “Very concerned and proactive.” “We have a full-time safety officer and won an award for New York State (SHARPS program) for our outstanding safety and health record over the last three years. We take this subject very seriously.”
- (a) “No.”

Keith Blakely, CEO of NanoDynamics, acknowledged concerns about environmental and health issues (or at least the lack of nanomaterial risk information) in his testimony to the U.S. House of Representatives Science Committee. He said: "The federal government, as the largest single investor in nanotechnology research, must take the lead in identifying the appropriate gaps in EHS information and organize appropriate, objective, and economically sound studies to assess the risks and rewards of nanomaterials processes and applications," (NanotechWire 2005).

Innovest’s review of a number of nanotech firms found that privately-owned startups “appear to be cognizant of the risks and a number of them are conducting themselves in a manner that would be considered favorably in our analysis. Other firms are a cause for concern because in this early stage, poor handling of risk by any player could result in perception problems that would affect entire markets.” Generally, I have found that most companies seem to be proactive and concerned about avoiding risks, while fewer seem to be unaware and/or unconcerned about them, as evidenced further by the responses to the survey questions below.

*Is your firm taking any steps to evaluate or reduce potential environmental, health or safety risks associated with nanotech? Why or why not?*

- “We are participating and cooperating with both private sector and government sponsored initiatives to assess, understand and address any issues associated with our products or with nanomaterials in general.”
- “Yes, mostly from a production standpoint – reducing emissions and hazardous waste. It also helps reduce costs.”
- “Yes, we participate in the SHARPS program. Our certification precludes the need for OSHA inspections, for example.”

- "We conduct some in vitro and in vivo testing. Yes, [we take steps to reduce risk] if risks are identified."
- "Related to our own work yes."
- "No, not specifically. We're just too small and believe, right now, that the risk is minimal. We're using what we might consider standard safety measures for potentially hazardous materials."
- "I don't know."
- "No. We view all materials as safe."

It is positive to see that a few of the firms are actively trying to deal with any adverse issues related to nanomaterial production and use. With this diversity of responses and a diversity of types of organizations, there does not appear to be any significant correlation or particular commonalities between those who responded and had concerns and other company characteristics (e.g., particular line of business, materials produced, how long they have been operation, or the number of people they employ). The sample size is also too small to be reliable. However, the firm that revealed the most proactive stance on these issues is one that appears to have been the most successful at commercially its nano-based products, and appears to have strong leadership behind its actions. Thus, SME success and leadership may be two predictors of greater environmental and health safety management and performance. Because one respondent noted that they "view all materials as safe," it is clear that there is a need to raise awareness.

The differing nature of the survey responses may also be indicative of firms at different stages within the "firm life cycle," (Lifset 2006). For instance, many of the firms are small because they are still startups, while others have already grown internally and may be better able to deal with environmental and health issues as part of their core business. Other SMEs may want to make themselves more favorable to acquisition by a larger firm by better managing environmental, health, and safety aspects. SMEs may follow four possible fates: (1) they do not survive, (2) they "license their technologies to larger firms" and pursue new innovations, (3) they are acquired by larger firms, or (4) they become medium-sized firms (Rejeski 2006b).

***Barriers to Addressing Uncharacterized Risks***

SME respondents to a barrier question in the survey cited a few challenges to dealing with environmental or health issues related to their nanotech operations. These included lack of resources and lack of necessary information. One firm CEO, however, indicated that his firm does not face any barriers. The specific responses from the firms are presented below.

*What are the barriers you face with respect to taking into account these risks, especially those that are uncharacterized?*

- "Mostly lack of resources. We're small and not profitable, so we can't afford the luxury of dedicating resources to the topic."
- "More information and better guidelines would be very helpful. The industry seems conflicted about whether nanotechnology represents a credible EH&S risk."
- "Cost of characterization."

- "There are no barriers. Key is executive leadership and zero tolerance for unsafe conditions or practices."

Other studies have also pointed to the challenges for SMEs in trying to improve their environmental performance. They have pointed to the lack of awareness on environmental issues or regulations and limited access to information; limited human and financial resources; lack of time; and "perceptions…that the environment constitutes a threat, rather than an opportunity," (Walley and Stubbs 1999). A study of SMEs in the food business, found that barriers to complying with regulations included (in order of importance to respondents): lack of motivation, lack of trust, lack of management systems, lack of knowledge time, lack of awareness, external factors, and money (Yapp and Fairman 2006). Post and Altman 1994 cite industry and organizational barriers to environmental change for firms in general (not SME-specific), which also pertain to nanotech SMEs. Industry barriers described include capital costs, community concern, regulatory constraints, information, and technical knowledge; organizational barriers refer to attitudes of personnel, top management, quality of communication, and historical practices.

***Information Needs***

All of the nanotech startup respondents that had concerns indicated that they need specific information and guidance to proactively address environmental, health, or safety issues related to their use of nanomaterials, and/or consideration of upstream or downstream impacts. They indicate that they want specifics and want to understand regulations and long-term toxicity effects. The following answers were received in response to the information question below.

*What information does your firm need to proactively address environmental, health, and safety issues?*

- "Clear, succinct safety guidelines and precautions."
- "[We] need to understand regulations. Also need to fully understand the long term health implications of some of our chemicals."
- "MSDS, toxic aspects of solvents, preferred disposal means, etc."
- "Further studies on biological affects of extended exposure to these materials."
- "Toxicity data."
- "Material safety data sheets."

Helping nanotech firms get the right information will address some of the barriers to SME consideration of environmental issues. For instance, studies have affirmed that many small companies have a "lack of awareness of environmental legislation, and the complexity of the legislation can further confuse matters and deter businesses from fully grasping the implications," (Stokes and Rutherfoord 2000, as cited in Simpson et al. 2003). Nanotech startups may follow a similar tendency to that of SMEs in general, in thinking that their role in affecting the environment is small. This was partially evidenced in the European Commission 2005 survey (described in Section III.A. above) in which SMEs ranked environment and health regulations and social acceptance as low on the list of barriers to nanomaterial application. Some SMEs underestimate their impact on the environment and "therefore do not realize the extent to

which environmental legislation affects them," (Stokes and Rutherfoord 2000, as cited in Simpson et al. 2003). In turn, this could lead to more reactive (instead of proactive) environmental management.

Helping to keep nanotech startups informed will also help deal with some of the other SME barriers to environmental management -- that of keeping up to date and the lack of time and resources to deal with such issues. In the Simpson et al. (2003) study "only 24% of respondents agreed that it was easy to keep up to date [with environmental legislation] and 71% found it difficult to keep up to date. 48% of respondents knew who to call for help with environmental matters, but 45% did not." This indicates a need to even simply inform nanotech SMEs on *who* to call for *what* information.

***Best Forms for Distributing Information***

In order to get a sense of how firms would like to receive information about questions or concerns they have on environmental and health issues, I asked firms' opinions of the form and approach they would prefer. The results show that online tools are the preferred method by startups for receiving information. This is probably because firms may consider such tools to be easy to use, less time intensive and less costly than attending a conference or having an onsite consultation. One firm expressed particular openness to and interest in learning more about the issues specific to nanomaterials and devoting some time to it.

The following responses were received when asked:

> *What is the best way to convey information to you or your firm? What form is the most useful (presentation, report, online tools, on-site consultation, etc.)?*

- "Attending a couple hour presentation would be good – similar to what we did with UCONN[2] (but that was not nano-centric). Online, internet based information is great – if the site and content are well designed. After the presentation and reviewing online content, an on-site 'inspection' may be deemed necessary or useful."
- "Online tools are generally the easiest."
- "Probably online tools. Email is likely the best way to convey information."
- "Through electronic media."
- "Internet."

I would suggest that an email listserv for firms or a central website run by a nanotech organization would be another useful avenue for firms to access information on precautionary measures they should take and for updates on toxicity / risk assessments and regulatory developments. Conferences are certainly a great way to stay connected on 'what's hot in nano,' but they are typically involve expensive enrollment fees and traveling costs. Although firms reap the benefits of networking and advertising their products at conferences, they may still be too pricey for them to attend. Trade magazines may also serve as another tool for communicating with SMEs. From my own rudimentary analysis, *Small Times*' coverage of stories on environmental or health risks or public perceptions of nanotech appears to have

[2] This firm participated in an EH&S training for chemistry at the University of Connecticut (UCONN).

increased significantly in the last year. It is possible that the rise in exposure corresponds with the Woodrow Wilson Center's release of a number of reports on nano risk and perceptions, EPA's increased attention to the issues, and increased nanotech hearings on Capitol Hill. The climate around these topics appears to be changing.

Despite recognizing that SMEs face many similar issues and common concerns, the SME environmental management literature suggests even more tailored forms for conveying information to firms. It is important to remember that there is huge variation among SMEs and that we should avoid characterizing them as "homogeneous, 'little big organizations,'" (Walley and Stubbs 1999), but offer information that is meaningful for them specifically. Merrit 1998 also discusses the importance of considering the breadth of diversity among SMEs, and work with it, when offering strategies for improving their environmental performance. For instance, some nanotech SMEs may be open to receiving on-site training on health and safety precautions for working with nanomaterials, while others may feel informed or prefer to read mailings or online documents. Palmer and France 1998 conducted a study on the effectiveness of the UK government in informing and educating small organizations about environmental management. They found that targeted mailings were the most effective form for promotion and engaging SMEs on environmental management schemes, as compared to site visits, helplines, or conference displays. The 1995 and 1998 Groundwork studies found that "SMEs show a preference for advice that is company specific, face to face and preferably delivered on site" (Hillary 1995 and 1998, as cited in Simpson et al. 2003). This support would need to be affordable and offer quantifiable benefits (Rowe and Hollingsworth 1996).

***Best Messengers for Distributing Information***

The government seems to be the preferred and most trusted messenger among respondents. This is interesting considering other studies have shown that many SME firms express skepticism of government regulation or its application to their own firms (Yapp and Fairman 2006) and that the recent U.S. study of public perceptions of nanotechnology revealed 'low public trust in government' (Macoubrie 2005). One firm did question what information the government could offer to firms developing *new* nano-based products. I received the following responses about the messenger trusted most by nano SMEs.

*Who would you trust to convey that information to you (government, industry associations, academics, peers, other)?*

- "EPA (or other government agency) and respected industry leaders would be our preference."
- "The government is the most authoritative source. However, if industry groups could sift through the bureaucracy and put the regulations into English, it would really help."
- "All of the above."
- "We would prefer government-funded academic research studies on biological affects."
- "Safety officer… [and] regulatory bodies, for sure."
- "I would most trust industry sources based upon sound science, and not with commercial or political interests."

- "Since many of the products are new, how can we get useful data from, e.g., the government?"

Academic literature also offers suggestions for messengers and ways that they should interact with small firms on environmental management. For instance, Rowe and Hollingsworth 1996 recommend "Training and Enterprise Councils and similar providers, such as local authorities…to promote sustainable activity in the business community."

It is important that informed groups try to reach out to small nanotech firms. With the potential for regulations specific to nano, it will be important for EPA, FDA, or others to educate SMEs on what they might expect. In the UK, Defra recently invited firms that are working with nanomaterials to voluntarily share information to improve understanding. In the United States, a similar effort is now underway. EPA is considering a Nanomaterials Voluntary Program, or NVP, to gather information from companies on how they manufacture and use materials (Gardner 2006). This might help to facilitate a more cooperative sharing of information between government and industry.

***View of Public Information Level on Nanotech***

Survey respondents indicated that they perceive the public to be *not* well-informed about nanotechnologies. The following responses were received:

*Do you think that the general public is well-informed about nanotechnologies in general (on scale of: not at all, not much, moderately, pretty much, very much)?*

- "I think that the general public is very uninformed. When people ask us what [Our Company] does, we usually avoid the nanotechnology word altogether and just refer to our technology as advanced materials and coatings for some specific applications that might resonate with them."
- "Not much. The concept is over most peoples' heads. It comes down to manufacturing, which is something people understand."
- "Probably not. In fact, I remember seeing something about how nanomaterials were being used by a company making paint. They used the paint like any other paint even though it contained nanomaterials. I'm not aware of what additional safety issues are inherent in nanomaterials above other materials."
- "Close to not at all. What is worse, the pervading assumption by some unknowledgeable lay persons as well as environmental safety persons is that 'all nanoparticles are toxic and should be treated as hazardous materials.'… Nanoparticles have been used in foods for many years, e.g., salad dressings. Each has its own chemical identity, properties, and toxicities. Some prediction of toxicity of uncharacterized nanoparticles can be gained by considering their components, although each complete nanoparticle should be characterized individually. For example, quantum dots contain toxic cadmium, and these quantum dots have been shown to be toxic in vivo. Many gold nanoparticles are well tolerated in vivo, probably since gold is inert, and has also been used for arthritis treatments for many years. I must however reemphasize that every nanoparticle is different, and one should not glibly put them all into one class, even 'all gold nanoparticles.'"

- "Little."
- "Not at all."
- "There's hype – that's for sure. I would not say that the general public is well informed. Of those nanomaterials on the market already, they're engineered into products. They're no different than any other chemical that needs to be tested."
- "In general, no. It is simply a buzzword. Most of the limited knowledge is from the electronics industry which does have some significant wastes and environmental issues due to the large scale use. Ours is microfluidics and must less of a concern. However, as this field grows it will be important to manage potential wastes and risks."
- "Not very informed at this time."

This is consistent with many other studies and articles that also point to the lack of awareness or knowledge on the part of the public on nanomaterials. In fact, positive or negative social perceptions of nanotechnology could affect the acceptance of nano-based products by the public and the fate of the nano SMEs. Perception risk may in fact present a threat that is even more tangible at this time than that of other nano-related uncertainties. The authors of Innovest's Valuation of Nanotechnology Producers report explain that "perception risk is considered to have the greatest capacity to impact both products and markets. In essence, the science may show little risk but if the public becomes nervous about the safety of nanotech, demand could be abated," (Innovest 2005). As stressed in one of the responses above, it is necessary to differentiate between nanoparticles.

Various studies have surveyed the public (Macoubrie 2005, Cobb and Macoubrie 2004) and companies (ENA 2005) about their perceptions of nanotechnologies. Recent findings reveal that people want more information about nanotechnology and want the government to go beyond voluntary standards to manage possible risks (Macoubrie 2005). In response to the question: *what are the biggest challenges for nanotechnology*, Tim Harper, chief executive officer and founder of the nanotech research firm Cientifica answered:

> "The perception problem. Because people cannot understand nano, this technology is a little removed from the public domain. Companies and governments need to come together and make people aware of this technology." (Krishnakumar 2005)

It is interesting that many startups play up the "nano" side of their business through their name or marketing materials on their website and membership in various nanotech organizations, while others try to down play the fact that they use of create nanomaterials. New York seems to be on the play up "nano" side of the spectrum. Besides its "New York Loves Nanotech" consortium and website, the state is home to the private firms including: ApNano Materials, Nanocs Inc., NanoDynamics, Nanoprobes Inc., Nanocrystals Imaging Corp., Integrated Nano-Technologies LLC, and Applied NanoWorks. In contrast, among the nanofirms in Connecticut that I surveyed for this report, only one, U.S. Nanocorp, uses "nano" in its name. While some companies may feel they gain competitive advantage or higher venture capitalist support through highlighting their nanotech edge, other companies avoid even mentioning "nano" on their corporate websites. Many of the companies listed in the *Small Times* directory as involved in nanotech, do not make any mention of nanotech or nanomaterials in their website descriptions of their technologies or products. And as one SME president indicated in the survey response, her

company even avoids mentioning nano when telling people what they do so as not to turn people off that might not understand nanotech.

Public education on the benefits of nano is needed to prevent the potential for fear or a backlash later. The nano SME, Evident Technologies, stands out in its ability to communicate about nanotech and in clearly explaining its company's processes and products (which is why they chose the name evident). As explained on Evident's corporate website: "in a highly complex, emergent field like nanomaterials, it's critical to make things clear," (Evident 2006). On most companies' websites, however, the language used to describe the business, technology, or products is highly technical and confusing to someone interested in learning more about nanotech or what these firms do. As Nathan Tinker, Senior Director of The Nanotech Company and Darrell Brookstein, Managing Director, explain in their paper on "Nano-Savvy Journalism," many companies make their business sound overly complex because they think it will create more "gee-whiz" and wow investors (Tinker and Brookstein 2005). Most of the managers of these companies are Ph.D.s who may be more accustomed to communicating about complex topics with others in complex ways. But to the general public, they need to talk in more simplified terms, especially when they are speaking about something that is still so new but that will be making its way into items that we wear, eat, and use on our skin.

Despite these observations, I do not mean to suggest that it is the SMEs' responsibility to educate the public consumers about nanotechnology. I think most of that responsibility falls on the government, media, or larger public firms with greater capacity and with well-known and respected reputations. For instance, companies that may help alleviate public concerns on nanotechnology include those who work with nanomaterials today and have been leaders in dealing with environmental issues in the past (e.g., DuPont with its proactive charge in leading the industry in phasing out CFCs, Xerox with its take back program and waste reduction efforts, GE with its Ecomagination campaign and clean and renewable technology development).

To briefly summarize the survey findings discussed in this section, the nanotech SME respondents expressed the following in their responses.

- *Concern:* They demonstrated varying levels of concern about environmental, health, and safety issues associated with their operations.
- *Evaluating and reducing risk:* Firms demonstrated a wide range of efforts from proactively trying to assess and address EHS issues to doing nothing.
- *Barriers:* Not all SMEs responded to the barrier to action question, but those that did cited lack of resources, lack of necessary information, and no barriers at all.
- *Information needs:* Firms expressed the need for specific information on safety precautions, toxicity, and anticipated regulations.
- *Form:* All the SMEs preferred online tools for conveying information.
- *Messenger:* Most firms revealed their preference for and trust in receiving information from a government agency.
- *Public:* All the firms feel that the public is very uninformed about nanotechnology.

## IV. Assessment of Areas on Which Nano SMEs Should Focus

Based on information needs expressed by nanotech firms and based on identified areas of concern or risk related to nanomaterials, this section is intended to help guide nanotech firms. This section of the paper is divided into three parts. The first part uses existing knowledge on potential nano-related risks to identify *which* types of firms should be concerned. The second part seeks to inform those firms on *what* areas they should focus on most. The third part discusses *how* to address those risks or areas of concern in two ways: (1) by adjusting processes early on to prevent or reduce risk, and (2) by managing those risks using lessons learned from other SME experiences and the environmental management literature on effective strategies. These recommendations are directed to an "internal" audience of the nanotech SME firm. As prefaced earlier, I have used a variety of sources to draw these conclusions. Please note that the information presented here reflects a synthesis and my best guesses of priorities for firms in dealing with these issues.

### A. *Which* Firms Should Be Most Concerned

The degree to which nanotech SMEs should be concerned about potential risks depends in large part on the (a) *type of nanotech business* they operate (i.e., whether they use or produce nanoparticles), (b) *state of the nanomaterial*, and (c) *kind* of material they are using or producing.

*Type of Nanotech Business*

The nanotech firms that face the greatest concerns are those that are actually using or producing nanomaterials or nanoparticles. Some of the firms surveyed for this report are engaged in nanotechnology, but are not working directly with nanomaterials. Based on studies by Lux Research on the areas of the nano value chain that present potential risk, firms that should be most diligent about health and environmental issues are those using nanoparticles, intermediates with nanoparticles, and final products with nanoparticles; those that face less risk are firms that use or produce nanoporous materials, intermediates with nano features, final products with nano features, or equipment (Innovest 2005). Among the companies that I surveyed, 86% fall into the categories of potential concern; this percentage was lower among actual respondents (see figures below). Other nanoscale activities include developing nanoscale instrumentation or using nanoscale technology.

**Figure 2: Nanotech Activity Among Surveyed Firms**

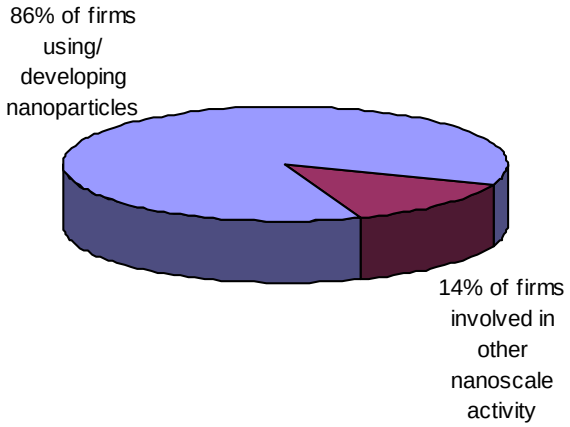
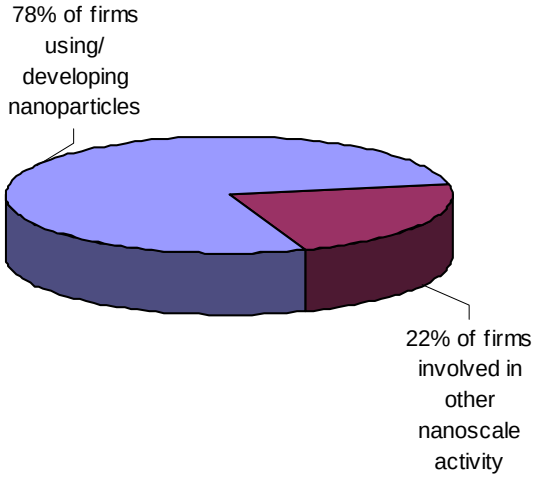



**Figure 3: Nanotech Activity Among Respondents**



*State of Nanomaterial*

The degree to which nanotech SMEs should be concerned about potential risks depends in large part on the type of material they are using or producing and the state or form of the material. Although there is still much uncertainty as to specific effects of nanomaterials on humans and the environment, most agree that the level of concern depends on nanomaterial type, surface area, surface chemistry, and form (e.g., is the material in a free form and easily released and potentially inhaled, or is it contained in another form such as a coating or a product like NanoDynamics' golf balls). These characteristics affecting the level of toxicity resulting from nanomaterials create "real challenges for toxicology since many of the models used to predict the toxicity of materials relate toxicity to mass," especially when "the mass-based approach is the basis for most U.S. environmental regulations," (Innovest 2005).

More and more materials are being developed in the active state, where materials are more in a free form, as compared to passive state, where materials are contained within a product. A timeline of nanotechnology prototyping and commercialization, proposed by Michael Roco, indicates that in 2001, most nanomaterials were passive nanostructures in coatings, polymers, and ceramics. Nanomaterials had become "second generation" active nanostructures ("transistors, amplifiers, actuators, adaptive structures") by 2005. We can expect to witness "3D nanosystems" in 2010 and possibly "molecular nanosystems" by 2020 (Roco 2002). According to Innovest, this "transition from passive to active" and "future transitions will change the risk picture both quantitatively and qualitatively," (2005). Swiss Re makes the distinction between nanoparticles in powder and liquid states, where liquids are "easier to restrain and do not spread as easily," while powders are "disseminated by the slightest disturbance in the air," (Swiss Re 2004). This could be an issue for workers in production facilities, labs, and distribution exposed to powders on a daily basis.

*Kind of Nanomaterial*

Firms producing or using single-walled carbon nanotubes, cadmium-selenide quantum dots, and fullerenes may need to be most concerned about the potential toxicity and environmental fate of their materials or products. This is based on a product safety analysis performed by Lux Research (and presented in Innovest's 2005 report), which examined factors of toxicity, reactivity, biodegradation, agglomeration, and bodily and environmental harm/mobility on a weighted scale for ten different kinds of nanoparticles. Other nanomaterials might be more hazardous at specific points in the life cycle. For instance, multi-walled carbon nanotubes show evidence of toxicity and resist biodegradation; zinc oxide and titanium dioxide nanoparticles and dendrimers resist degradation and are somewhat a risk in other areas. Materials, such as titanium dioxide used in sunscreen and lotions, and nano-crystalline and nano composite drugs, may still warrant more attention. Nano-crystalline and nano composite drugs could present problems "because many of them are going through the FDA on fast track as an existing drug rather than a new structure that requires a more thorough review," (Innovest 2005).

Table 3 presents a brief summary of the some of the toxicity studies that have been performed on specific nanomaterials. Most of these risk analyses have involved toxicity testing with animals; still much uncertainty remains on how they will affect humans. DuPont, already the corporate leader in researching and testing nanoproduct toxicity, recently engaged with Environmental Defense to carry out further analysis. And EPA released a nanotechnology white paper in December 2005 that included risk assessment and discussion of research the agency plans to carry out (U.S. EPA 2005). Still, as even an SME leader, Keith Blakely of NanoDynamics, pointed out to the U.S. House of Representatives Science Committee, the government allocated less than four percent of its nanotech budget (National Nanotechnology Initiative) to exploring potential environmental and health impacts (NanotechWire 2005).

**Table 3: Comparison of Research Findings by Nanomaterial and Exposure**

| Nanomaterial | Type of Exposure | Effect from Exposure | Test Subject | Reference |
|---|---|---|---|---|
| nanotubes | inhalation at high doses | blocked lung airways, which led to a 15 percent death rate | rats | Warheit et al. 2004 |
| | instilled in lungs | inflammation | mice | Lam et al. 2004 |
| uncoated fullerenes | exposure through concentrated water | translocation into brain; oxidative damage and glutathione depletion | juvenile largemouth bass | Oberdörster 2004 |
| nano-sized copper particles | via gastrointestinal tract | "heavy injuries" on kidney, liver and spleen -more severe for males | mice | Chen et al. 2006 |
| nanoscale zinc powders | high dose via gastrointestinal tract | heavier renal damage and anemia than microscale zinc powders | mice | Wang et al. 2006 |
| ultrafine nanoparticles | inhalation | concentrations of nanoparticles in the lungs and brains | rats | Oberdörster et al. 2004 |
| titanium dioxide | dermal as sunscreen | possible DNA damage and harm to damaged skin | sunscreen samples | Dunford et al. 1997 |
| airborne ultrafine nanoparticles | (a) inhalation<br>(b) dermal exposure | (a) enters blood and lymph circulation and central nervous system; (b) absorption into lymph circulation and potential for inflammation | review of studies | Oberdörster et al. 2005 |

Note: This table is not inclusive of all toxicity studies on nanomaterials.

## B. *What* Firms Should Be Most Concerned About

This section discusses the areas on which nano SMEs should focus their attention in the environmental, health, safety, and social perception arena of nanomaterial use or production. Knowing where the potential risks (environmental, health, safety, and perception or public acceptance) of nano lie, will help SMEs know where to focus their attention to deal proactively with these issues.

***Potential Nanomaterial Risks***

Materials behave differently at the nanoscale. This quality contributes to the unique, beneficial properties—such as increased conductivity, flexibility, and strength—that arise with nanomaterials. Yet, this changed behavior also could potentially pose some risk to humans and the environment. Although nanoparticles occur in nature, artificially engineered nanomaterials are more potentially harmful because natural particles either dissolve quickly and "lose their particle form" or quickly agglomerate into larger particles, thereby changing their properties (Swiss Re 2004). In contrast, manufactured particles are designed so that they do not agglomerate, which also increases their potential for exposure in various routes.

*Human Exposure*

Human exposure to nanoparticles can occur in three primary ways: through dermal exposure, ingestion (swallowing), or inhalation.

As far as dermal exposure, Swiss Re explains that there is a debate about whether nanoparticles can "permeate the skin and be absorbed in the blood." The use of different testing methods seems to contribute to the countering findings. For instance, some experiments use skin detached from a living being and its blood supply, which makes it difficult to test for absorption impacts (Swiss Re 2004). Potential risks from dermal exposure might become an issue for workers in SME firms that develop or use titanium dioxide to manufacture sunscreens or lotions applied directly to the skin. If it is found that nanoparticles applied on skin can be absorbed into the bloodstream, those individuals that could be at risk are product users and workers during product testing. Nano SMEs using or developing skin products should be cognizant of this avenue of exposure. However, because there is still much uncertainty about the potential risks through this avenue, I would suggest that rather than taking precautionary measures, SMEs should perform and advocate for more product testing. Certainly, those firms developing these products probably consider their products safe, but it will be important for them to have full information and adjust processes early on to avoid recall later.

Swallowing of nanoparticles could occur through food, medicine, or even dentistry products, which now make use of nanomaterials.[3] Ingestion of nanoparticles could become problematic if the particles are absorbed by tissues or organs and then travel throughout the body (Swiss Re 2004). The negative effects of ingestion of nanoparticles have not been widely studied. However, a few recent studies have examined the toxicity of nanoparticle ingestion:

- Researchers in China found that nano-sized copper particles caused "gravely toxicological effects and heavy injuries on kidney, liver and spleen of experimental mice" when exposed through the gastrointestinal tract (Chen et al. 2006). The photos of the organs exposed to nano versus micro particles presented in this *Toxicology Letters* article are startling. Gender also played a role – male mice had more severe symptoms than female mice from exposure to nano-copper. The authors explain that nano-sized copper particles are used "as the additive in lubricants, polymers/plastics, metallic coating and inks," and that they are "likely to enter the environment and human body via different

[3] In fact, one of the Connecticut SMEs surveyed for this report (Pentron Inc.) develops nano-based restoratives and adhesives for teeth.

paths such as effluent, spillage during shipping and handling, consumer products and disposal, etc."

- Another recent experiment studying nanoparticle exposure on mice was performed in China. Experiments by Wang et al. 2006 suggested that high dose oral exposures of nanoscale zinc powders "could induce heavier renal damage and anemia" than microscale zinc powders, while high doses of microscale zinc powders "could induce more severe liver damage" than nanoscale powders.

These few studies suggest that ingestion may be an area of concern and on which nano firms may need to take precautionary measures to protect workers from potential ingestion of nanoparticles. However, the authors of the two studies described above conducted the experiments in what seems to be worse case scenarios with high dose exposures. It is likely that further testing will help enlighten the potential risks associated with this exposure route.

Inhalation appears to pose the greatest risk, or at least it has been the most highly studied. The reinsurance company, Swiss Re, points to studies that "have repeatedly shown that certain inhaled particles can also enter the bloodstream," and that "some nanoparticles, when inhaled, were transported directly to the brain," (Swiss Re 2004). Based on the available information, firms should be concerned most about worker exposure to nanoparticles via inhalation. Swiss Re also notes that the transport of nanoparticles could be more hazardous than the actually production of the particles, which usually take place in a closed environment (Swiss Re 2004). Inhalation is a more indirect, but an easier route of exposure than dermal or oral exposures in the sense that an individual makes a conscious decision to apply a product to their skin or to take medicine or eat food that may contain nanoparticles; however, with inhalation, one has less control.[4] Some studies examining respiratory affects include the following findings:

- Lam et al. 2004 found that carbon nanotubes instilled in the lungs of mice caused inflammation.
- A study also found that conventional and widely used respirators (N95 half-mask filtering facepieces certified by National Institute for Occupational Safety and Health, NIOSH) do not adequately protect against nanoparticle penetration. Balazy et al. 2006 demonstrated that "nanoparticle penetration through a face-sealed N95 respirator may be in excess of the 5% threshold, particularly at high respiratory flow rates. Thus, N95 respirators may not always provide the expected respiratory protection for workers."
- DuPont researchers tested nanotube inhalation exposure and found that rats exposed to high doses of nanotubes had blocked airways in the lungs, which led to a death rate of about 15 percent (Warheit et al. 2004).
- Oberdörster et al. 2004 discovered concentrations of nanoparticles in the lungs and brains following inhalation exposure by rats. Oberdörster et al. 2005 explained that inhalation of ultrafine nanoparticles can also translocate to the central nervous system.

In addition to exposure to nanomaterials themselves, others point out that other materials used in nano production also pose significant risks. For instance, David Carnahan at NanoLab noted that some of the most significant exposure and risk are to welders dealing with chemical

[4] This brings up another issue of where people may not necessarily be making conscious decisions to use nano-based products because they may not know that nanoparticles are contained in these products.

inputs (such as oxygen and acetylene) for carbon nanotube production. He feels that welders inhale more nanoparticles when welding metals than laboratory personnel (Carnahan 2005).

*Environmental Exposure*

Exposure of nanoparticles in the environment could occur through releases into air and water. Although many nano-based materials are being developed to help decontaminate water, there is the potential that particles could be hazardous in the environment. In addition, nanoparticles are "used in all kinds of disposable articles that, sooner or later, have to be recycled or removed as waste," (Swiss Re 2004). Because many of the particles will be new to nature, it is hard to predict their effects over time. Environmental fate and transport, specifically looking at "persistence, distribution among media, transformation," is one of the risk areas that Environmental Defense suggests needs further research (ED 2005).

*Environmental Impacts Across the Life Stage*

There are other environmental impacts associated with nanoparticle use and production across the supply chain that should also be mentioned. The potential impacts and level of concern varies from resource extraction to end-of-life. Potentially harmful environmental effects related to nanomaterial and nano-based product development over the supply chain are discussed briefly below.

- *Extraction*: Some of the environmental impacts at this stage involve intensive resource extraction (i.e., disrupting large amount of material and land to access needed resources) and high energy and water use. For nanomaterials, the impacts from this life stage are probably not very different from those that occur during extraction for developing larger scale materials or products.
- *Production*: As compared to most products (that are larger in scale), nanomaterials present different risks and concerns. For instance, whereas the production of most materials leads to concerns about greenhouse gas and criteria air emissions, nanomaterial production's contribution to those emissions is less than that for conventional products (Steinfeldt et al. 2004). Nevertheless, to get the desired purity that is needed for nano or micro-materials, a significant amount of energy, chemicals, and water inputs are still required (Williams et al. 2002). Increased water use leads to increased wastewater effluents and potential contamination to waterways. Nanoparticles in waterways could have ecological impacts if nanoparticles are disruptive to habitats or cause harm to living organisms.
- *Transportation:* Transporting nanomaterials or nano-based products is unlikely to involve more severe impacts on the environment than those resulting from transportation of conventional materials or products. Many SMEs sell and ship their products internationally, which has an environmental toll (e.g., high fuel use, greenhouse gas and criteria air pollutant emissions), but that is the case for most products in our global economy. The case where transportation could present more harm, is if there were an accident or a spill of nanopowders on route, for example, with the accumulation and migration of nanoparticles across land or water.
- *Use*: This is an area of the supply chain or product life cycle that appears to actually have environmental benefits (Lloyd and Lave 2003). Nanomaterials are lighter and more durable than many of the materials they will be replacing (e.g., aluminum, steel). When they are

used in such products as composites for vehicles, they allow cars to get higher gas mileage and thus lower emissions. Nanomaterials also reduce other material use needs.

- *End-of-Life*: At end of life, the volume of waste is not at issue, but rather the potential for toxicity in the environment. There are not many studies available on these downstream effects. The impacts are still highly uncertain since most products containing nanoparticles have not yet made their way to disposal. However, if nanoparticles accumulate in the environment, such as in rivers and streams, wildlife could suffer (as demonstrated by Oberdörster's 2004 findings of damage to fish exposed to nanoparticles in water). The nanomaterials that might present the greatest risk at end of life are those that are unable to biodegrade. According to Lux Research (cited in the Innovest report, pg. 34), the nanomaterials that resist biodegradation are single- and multi-walled carbon nanotubes, cadmium-selenide quantum dots, zinc oxide nanoparticles, titanium dioxide nanoparticles, and dendrimers. Fullerenes and dendrimers show the most evidence for environmental harm or mobility.

The table below presents a summary of comparable levels of environmental and health concerns at various stages of the supply chain or nano-based product life cycle. The cells shaded red indicate areas of the highest potential concern, followed by orange, and yellow. The cell shaded green for environmental impact during product use ranks low as compared to other conventional products.

**Table 4: Comparable Levels of Environmental and Health Concerns Across Supply Chain**

| Life Stage | Environmental Concerns | Health Concerns |
|---|---|---|
| Extraction* | Low-Moderate | Low-Moderate |
| Production | Low-Moderate | High |
| Transportation | Low-Moderate* | High |
| Use | Low | Moderate |
| End-of-Life | Moderate | Low-Moderate |

*The concerns or impacts at this life stage do not appear to be very different from that for conventional materials/products.

*Perception Risks*

As discussed earlier, negative public perceptions of nanotechnology could become a significant risk to firms using or producing nanoparticles.

Some have made the analogy of nanotech to biotechnology and asbestos, warning that nanotech could follow a similar fate and face a product backlash (*Economist* 2004, Kulinowki 2004, Mnyusiwalla et al. 2003, and Bond 2006). Others do not feel the fate will be so drastic because nanotechnology covers a broader range of industry sectors and because public awareness is low (Innovest 2005). Others not only disagree with the analogy, but have gone so far as to call it a "disanalogy" (Sandler and Kay 2006). One of the points that Sandler and Kay 2006 make is that "the basis of most intrinsic objections to [genetically modified organisms] GMOs (i.e.,

objections that there is something inherently wrong with them, not just something too risky about them) cannot be applied to most nanotechnologies." A Professor from Edinburgh, Anthony Seaton, recently expressed concerns at a "Nanoparticles for European Industry" conference, that nanoparticles could similarly affect the human respiratory system as did asbestos.

However, there are lessons to be learned from biotech and asbestos that can be applied to nanotech. With biotech there was a "scarcity of communication between those who developed and control the technologies and the public regarding what the technologies are, their potential risks and benefits, and how the risks would be managed," (Sandler and Kay 2006). Nanotech firms can avoid potential backlash, by better communicating with the public about their technologies and products, focusing on the benefits that they will have for society and helping them to make informed decisions. Innovest suggests that "consumers and markets may be more willing to deal with risk if perceived benefits are clearly defined early." Mnyusiwalla et al. 2003 suggest that we need to "close the gap between the science and ethics of nanotechnology" (in other words, that studies of social, environmental, health, economic, legal implications need to catch up to the pace of the science and innovation on nanotech). Similarly, asbestos, CFCs, and other previously considered man-made "wonder" products should teach us that we should be careful and ensure that health, environmental, social and other implications are properly evaluated today. Environmental Defense cautions:

> "If the public is not convinced that nanotechnology and nanomaterials are being developed in a way that identifies and minimizes the risks to human health and the environment, we can be virtually assured of a backlash that will delay, reduce, or even prevent the realization of many of the potential benefits of nanotechnology." (ED 2005)

The table below attempts to summarize some of the key points from this section about suggested areas of EHS and social concerns for nano SMEs.

**Table 5: Summary of Suggested Areas of Concern for Nanotech SMEs**

| Area | High Concern | Moderate Concern | Lower Concern |
|---|---|---|---|
| **Business Type** | Producing or using nanomaterials | | Dealing with nanotechnology, but not producing or using nanomaterials |
| **Material Kind** | single-walled carbon nanotubes, cadmium-selenide quantum dots, and fullerenes | multi-walled carbon nanotubes, zinc oxide nanoparticles, dendrimers, titanium dioxide nanoparticles | nanoclay particles, nanocrystalline drug formulations, silicon nanowires |
| **Material State** | Working with materials in free form | | Passive |
| **Product Type** | Nanomaterials in a free or "active" form (e.g., nanopowders) | | Contained in a coating (or another "passive" form) |
| **Should be concerned about workers and human users of product** | Single-walled carbon nanotubes, multi-walled carbon nanotubes, cadmium-selenide, quantum dots, fullerenes | Zinc oxide nanoparticles, dendrimers | Nanoclay particles, titanium dioxide nanoparticles, nanocrystalline drug formulations, silicon nanowires |
| **Risk Areas** | Worker health; Public perception | Environmental fate and transport | |

## C. *How* Firms Could Address Risks

This section discusses ways that nano SMEs can adjust processes and apply environmental management strategies early on to prevent or reduce some of the risks presented in Part B. It is likely that firms' abilities to address risks will evolve as they grow. The desire of some small nanotech firms to ultimately make themselves favorable to acquisition by a larger company may encourage them to proactively manage environmental and health issues associated with their operations.

### *Process Recommendations*

*Incorporate Life Cycle Thinking*

SMEs should try to think holistically about their operations –both the impact of their production process upstream and downstream. Firms could work with suppliers of equipment and material inputs to find ways to minimize costs to the environment and to prevent worker health risks in handling and transporting materials. In Innovest's evaluation of firm valuation, they ranked firms highly "that are partnering with equipment manufacturers to incorporate *life cycle* concerns into the production optimization strategy," (Innovest 2005). This suggests that firms can and should be thinking about the life cycle of their production or product, even if they do not conduct a formal life cycle assessment. This is especially important as they transition from laboratories to commercial production.

To evaluate downstream impacts, companies could deal with uncertainties of health or safety impacts or the environmental fate of nanoparticles by doing independent product testing or internal analyses. ApNano, one private firm surveyed for this report, has begun to test its products and received especially high scoring from Innovest on product stewardship. Their product testing on acute toxicity followed the European Commission's Good Laboratory Practice (GLP) Directives.[5] Lux Research 2005 recommends that "corporations and start-ups assess nanotech EHS issues based on existing risk management frameworks – substituting informed, conservative proxies for definitive data – to make wise commercialization decisions." Product testing of course is not without added time and cost. However, it may be worth SMEs voluntarily making the investment today to prevent repercussions later.

*Follow Best Practices for Worker Health and Safety Precautions*

There are still many unknowns on human exposure to nanoparticles, but based on my limited knowledge on ways that workers can protect themselves adequately from respiratory exposure to nanoparticles, I propose a few suggestions. First, I would suggest that to the extent that firms are able, they should evaluate their existing practices of manufacturing and distributing nanoparticle inputs and products. During manufacture of nanoparticles in laboratories and production facilities, it is important to ensure that the laboratory environment is a closed system and adequately ventilated. Because existing face masks (the N95 filtering-facepieces) have recently shown to not adequately protect against nanoparticle exposure (Balazy et al. 2006), firms should equip their researchers and workers with the least permeable masks on the market. Swiss Re suggest that nanoparticles be "handled with the same care given certain bio-organisms or radioactive substances," and that "adequate protective measures, such as a nano-compatible 'glove box,' will probably have to be developed to ward off possible dangers" (Swiss Re 2004). Because workers distributing nanoparticles may wear little to no protection, they should also be equipped with proper respiratory masks. This is particularly important because nanoparticles in powder form can be easily disturbed and inhaled.

Firms should recognize that Material Safety Data Sheets (MSDS) used for larger counterpart materials might not be appropriate for nanosized materials. New nano-specific Material Safety Data Sheets (MSDS) should be developed. Currently, firms are using the same MSDS for nanopower titanium dioxide as for the large particle form (Swiss Re 2004). MSDSs designed to deal with changed properties at the nanoscale would include lower exposure limits for nanoparticles.

The Project on Emerging Nanotechnologies (a partnership between the Woodrow Wilson International Center for Scholars and Pew Charitable Trusts) is in the process of developing a "short web-based training course for people working with nanomaterials," (Rejeski 2006a). This type of tool would certainly help guide and inform SMEs on precautionary and proactive measures they should take. As the survey responses indicated, firms are open to and want information. They also would prefer the electronic medium of this training format.

[5] "GLP define a set of rules and criteria for a quality system concerned with the organizational process and the conditions under which non-clinical health and environmental safety studies are planned, performed, monitored, recorded, archived and reported," (European Commission 2006).

*Control Emissions and Waste of Nanoparticles*

Because of the potential hazards associated with nanoparticle inhalation and fate in the environment, firms should take precautionary measures (if they are not already) to control release of particles into the air, water, or wastestream.

*Increase Educational Efforts*

In addition to addressing worker and product safety measures, SMEs should focus their attention on better informing both the public about what they are doing *and* their employees about the potential risks. It is unlikely that employees are very aware of potential hazards in the work environment through nanoparticle exposure. They should be informed about what is known (and not yet known) so that they take proper care of themselves when handling these materials (e.g., wear their mask and protective gear, wash hands thoroughly, etc.).

Firms that are producing end products to consumers, like those you would find in your neighborhood CVS or your local sporting goods store, could educate the public about their technology and products in order to improve public perceptions and increase acceptance. This could involve increasing the clarity on corporate websites and marketing materials and even educational efforts on labels (e.g., "this product contains carbon nanotubes, which offer advanced properties"). Access to information is growing rapidly and people are asking for it in so many realms (e.g., FDA is starting to require food manufacturers to indicate whether their products contain wheat). The public may demand increased transparency. It is companies' best interests to explain what it is in their products, especially those for use on skin and in food.

*Prepare for Potential Nano-specific Regulations*

SME firms need to worry about complying with existing environmental regulations (Toxic Substances Control Act, Clean Air Act, Clean Water Act, and the Resource Conservation and Recovery Act) and health and safety regulations (Occupational Safety and Health Act and Food, Drug, and Cosmetic Act), but regulations specific to nanomaterials have not yet been developed. Current regulations focus on volume and mass of chemical or material and are not suited for evaluating nanotechnology. Davies 2006 suggests that a "new law may be required to manage potential risks of nanotechnology." SMEs can anticipate that this new type of regulation would place the burden on manufacturers of nano-based products and require them to create and submit a "sustainability plan" to the EPA showing that their product meets adequate safety levels (Davies 2006). The proposed sustainability plan might involve: 1) "a life cycle analysis of the material or product; 2) testing results; 3) proposed future reporting requirements; 4) proposed labeling of the product; 5) proposed restrictions, if any, on the product; and 6) an explanation of why the product risk, if any, is acceptable," (Davies 2006).

SMEs can prepare or modify existing practices in order to ease the transition when restrictions become reality. Cientifica poses three questions that businesses using or producing nanomaterials should be able to answer "to understand the potential impact of future liabilities or changes in legislation": (1) "Are there intrinsic risks associated with any of my current or future products and over what timescale? (2) What regulation is likely, and how will this apply to my products? (3) How will the above affect my business model?" (Cientifica 2005).

It is understandable that it will be difficult for small firms to monitor science and public policy developments. However, various industry associations, such as the NanoBusiness Alliance can probably help keep SMEs informed.

Roughly 40% of SMEs in the food industry in Europe "believe that an increase in environmental legislation would have no impact upon their business," (Yapp and Fairman 2006). This indicates that a fair number of SMEs are not even concerned with existing or potential regulation that could affect them. "Studies found that SMEs had a lack of expertise and knowledge to undertake such [risk] assessments and resulted in failure to take action," (Yapp and Fairman 2006). This suggests that small firms are unlikely to act without knowledge, reinforcing the need to get information to them as it becomes known.

***Management Recommendations***

Once potential risks and precautionary process measures have been identified, the question remains: how can nano SMEs manage those risks with limited capacity and resources? In this section, I apply lessons from other SME experiences with environmental management using academic literature with relevance to small nanotech startups.

*Become or develop a champion within your firm*

Studies often show that firms that have improved their environmental performance or that have been environmental leaders have been aided by a champion within their company. Walley and Stubbs 1999 define an "environmental champion" as an "individual within an organization, who champions environmental progress within that organization." Post and Altman 1994 studied the "greening of U.S companies" and found that those that were successful and most innovative had a visible environmental champion within the organization. Heidi Douglas, President and CEO of MysticMD Inc., seems to be someone who is thoughtful, open-minded to EHS information, and could play the role of a champion. Nanotech startups will benefit from having someone who is open to learning about environmental and health impacts of their process and products and acting to reduce them.

Nearly all of the SMEs surveyed indicated that their company does have someone who handles EHS issues. The following responses were given to the question: *Does your firm have someone devoted to environmental, health and safety issues?*

- "Yes."
- "We contract that out."
- "We have a full-time safety officer."
- "We have a global EHS person."
- "These responsibilities are spread over 3 people in our firm."
- "Yes, but he has other responsibilities for Production and Facilities."
- "No, we're too small.
- "Not full time."

It is important that this person is also cognizant of the differences between handing nanomaterials (where harm is based more on surface area, surface chemistry, and kind) as compared to larger-scale materials (where harm is typically based on volume and mass).

*Utilize training that engage employees*

Training for SMEs offers many benefits. Because many small nano firms are still young with employees that have not been working at these firms very long, there is opportunity for early education and greater recognition of environmental, health, and safety issues. It is important to get employees involved and engaged with EHS issues. Providing training on proper safety precautions and environmental management during employee orientation training is one good approach. An SME case study by Walley and Stubbs 1999 showed that "new employees, having been exposed to environmental policy and procedures as part of their induction training, seemed to embrace the environmental ethos faster than existing ones." Heidi Douglas suggested that a training on nano EHS issues–similar to an EHS training her company underwent for chemistry laboratories—would be useful (2006).

*Recognize that addressing environmental and health issues early on will offer competitive advantage and reduce risk*

For nanotech SMEs, as with SMEs in general, it is important to overcome the perception that SMEs that adopt good environmental practices face additional costs; instead these efforts can and do lead to competitive advantage and reduced risk. Well-respected business professors continue to profess that companies can secure competitive advantage in the marketplace through sound environmental management efforts (Porter and van der Linde 1995, Reinhardt 2000), which often stimulates internal innovation. A survey of SMEs in South Yorkshire, England by Simpson et al. (2003) found that there are "some fundamental misunderstandings and difficulties" in achieving environmental good practice by these firms. As the study explained: "most organizations surveyed believed environmental issues to be issues affecting their business. However, the meeting of these requirements was seen as a cost that was not transferable to customers in terms of added benefits and few organizations could show that it led to a competitive advantage," (Simpson et al. 2003).

In the realm of nanotechnology, the situation may be different. Because there is much uncertainty on environmental and health issues related to nanomaterials, and because much of the public feels uniformed on nanotechnology (Macoubrie 2005), firms could secure a competitive advantage and help build their reputation by reducing fear. They could assure the public that not only are their products safe, but that their firms strive to improve their own environmental performance and the health and safety of employees, customers, and the community. Firms could attain the competitive advantage that Porter promotes, if their customers appreciate the benefits of environmental responsibility. Because of the uncertainties surrounding nanotechnology, it is possible that this added value will be welcomed (in other words: that customers would be willing to pay for it). In addition, innovative efforts by firms to proactively deal with environmental and health issues in advance of new regulations may also offer competitive benefits for firms.

*Seek information and assistance on EHS implementation*

Many startups and SMEs have limited resources that prevent them from having the necessary information to make decisions on issues that they might not consider part of their core business. In an example of a small firm that was trying to reduce its paper use and become a paperless office, "the availability of affordable knowhow" proved to be a significant factor in helping the company succeed in attaining its environmental goals (Walley and Stubbs 1999). To

gather the necessary information and knowhow, the company "sought the advice and assistance" from another organization, the National Centre for Business and Ecology, a group that provides environmental expertise to organizations in the UK. In a fashion similar to how this company benefited from outside assistance, nanotech startups might also be willing to seek and welcome help from other organizations.

## V. Conclusion

Without government regulation and without full clarity on the potential adverse consequences of nanoparticles in our bodies and the environment, nanotech firms can play a significant role in helping to increase that clarity. As discussed in this report, it is important to help nanotech startups access the right and necessary information to help them proactively deal with environmental and health issues (e.g., to test their products and educate employees on hazards). This report provided a review of what small nanotech startups are thinking in Connecticut and New York about environmental, health, safety, and social perception issues. It tried to make parallels with other nano SME and general SME surveys and studies from the academic literature to better understand their concerns and how to provide information to them. The survey revealed that nanotech SMEs have varied concerns on EHS issues; some have been more proactive than others in assessing these issues within their own businesses; some have slower based on their small size, barriers of lack or resources or information, while others seemed in control of dealing with the situation. Firms expressed a strong preference for receiving information through an electronic or online venue, and from a government source. These firms also indicated that they feel the public is very uniformed about nanotechnology.

Among the three main routes of human health exposure to nanomaterials, inhalation of airborne particles currently seems to present the greatest hazard. Worker exposure during research on and production of nanomaterials or nano-based products via inhalation, thus far, appears to be the area that nano firms should focus on most. Across the life stage, the production and transportation phases appear to present the highest potential risk of human health exposure to nanoparticles. Opportunities for firms to adjust their processes include: incorporating more life cycle thinking and product testing (like ApNano has done), better controlling worker exposure, and increase educational efforts on nanotechnology with employees and potential customers. To better manage for these potential risks, firms should develop a champion who is concerned and likely to pay attention to the issue, stay abreast and open to new information, and prepare themselves for regulation. These efforts—on the part of the nanotech SMEs and on the part of external organizations and agencies assisting these firms—could help alleviate concerns and increase public acceptance of the nanoparticles brewing in Connecticut and New York.

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## Appendix A: CT-Based Nanotech Startup Firms Contacted

| Category / Name | Contact Person | City, Phone, Email | Participated in Survey | Products | Any On Market [a] | Year Founded | Number of Employees and Revenues |
|---|---|---|---|---|---|---|---|
| ***Biotechnology/ Life Sciences/ Healthcare*** | | | | | | | |
| 454 Life Sciences | David Smith, PhD, VP of Manufacturing | Branford, CT 203-871-2300 info@454.com | Yes – phone interview | technologies for sequencing the genome | No | 2000 | ▪ Over 120 ▪ $15 million |
| Protometrix Inc. | Dr. Barry Schwitzer, R&D Director | Branford, CT 203-848-1100 | Yes – phone interview | integrated proteomics technologies to improve human health | No | 2001 | ▪ 30 in Branford [c] |
| Cellular Genomics Inc | Louis Matis, MD, President and CEO | Branford, CT 203-315-1222 lmatis@cgipharma.com | No – told that unable to participate because company going through transition phase | small molecule kinase inhibitors for a oncology/angiogenesis and autoimmune/ allergic/inflammatory disease indications | No | 1998 | ▪ 52 (+ 44 researchers) ▪ Unknown |
| Pentron [b] | Monica Roy Smith | Wallingford, CT 203-265-3930 mroysmith@pentron.com | No – indicated that information requested was proprietary | teeth restoratives and adhesives | Yes | 1967 | ▪ 150 ▪ Unknown |
| DiagXotics | | Wilton, CT (203) 762-0279 info@healthcareprovidersdirect.com | No - told that few people in office | detection kits for infectious diseases for animal health using oligonucleotide modified gold nanoparticles | No | 1989 | Unknown |
| Genomas | Gualberto Ruaño, MD, PhD, President & CEO | Hartford, CT 860-545-4574 admin@genomas.net | No response | diagnostic and prevention technologies | No | 2003 | ▪ 5 (+ 2 researchers) ▪ Unknown |
| ***Energy / Environmental Utilities*** | | | | | | | |
| US Nanocorp Inc. (overlap with Inframat) | David Reisner, Co-founder, President & CEO | Farmington, CT 860-678-7561 | No response | high-density, high-surface area nanostructured materials, such as nanophase nickel hydroxide and nanophase manganese dioxide | Unlikely | 1996 | Unknown |
| ***Government / Defense*** | | | | | | | |
| MysticMD Inc. | Heidi Douglas, President and CEO | Groton, CT 860-961-8052 hdouglas@mysticmd.com | Yes – by email | security, medical and performance coatings using carbon nanotube formulations | No | 2004 | ▪ 4 ▪ Less than $100,000 |
| ***Materials / Chemicals*** | | | | | | | |
| Foster Corp | Tony Listro, Director of Engineering and Product Development | Putnam, CT 860-928-4226 tlistro@fostercomp.com | Yes – by email | nanocomposite formulations with increased rigidity and stiffness | Yes | 1989 | ▪ 60 ▪ confidential |
| Inframat Corp. | David Reisner, CEO | Farmington, CT 860-678-7561 dreisner@inframat.com | No response | nanomaterials for infrastructure (nanocoatings, magnetic nanocomposites, medical implantable devices, and catalysts) | Yes | 1996 | ▪ 21-30 ▪ $1.6M in 2002 (Bernard 2003) |

Source: Corporate websites, Interviews or survey responses, CT Business News Journal 2005, or where noted in table.

[a] This column refers to companies that have products on the market that contain nanomaterials or particles.

[b] Note that Pentron is listed in this table because they are a private firm, with fewer than 500 employees, engaged in nano-based product development. However, they were founded not as a nanotech startup, but as a firm making dental products.

[c] Protometrix has 30 employees at its laboratories in Branford, CT; however, it merged in 2004 with Invitrogen, which has 5000 employees. Together with Invitrogen, revenues are $1.2 billion globally.

## Appendix B: NY-Based Nanotech Startup Firms Contacted

| Category / Name | Contact Person | City, Phone, Email | Participated in Survey | Products | Any On Market[a] | Year Founded | Number of Employees and Revenues |
|---|---|---|---|---|---|---|---|
| ***Biotechnology/ Life Sciences/ Healthcare*** | | | | | | | |
| Advion Biosciences Inc. | Dr. Jack Henion, founder, Chief Scientific Officer, and Chairman | Ithaca, NY 607-266-0665 henionj@advion.com | Yes – by email | TriVersa™ NanoMate® and ESI Chip® System | Yes | 1993 | ▪ over 130<br>▪ confidential |
| Agave Biosystems | | Labs in Ithaca, NY; Offices in Austin, TX 607-272-0002 agave@agavebio.com | No – declined by email | nanoscale engineered devices and systems and sensor systems | Yes | 1998 | Unknown |
| Nanocs | Dr. Eric Sun, CEO | New York, NY 917-400-4863 info@nanocs.com | No response | Carbon nanotubes; nanocoating glass slides; biofunctional nanoparticles; nanoproduction systems, spectrometer, flat panel display, and others | Yes | Unknown | Unknown |
| Cornerstone Pharmaceuticals Inc. | Robert G.L. Shorr, Ph.D. D.I.C. CEO | New York, NY 212-302-9424 rob@cornerstonepharma.com | Yes – by email | Emulsiphan™ nanoparticle tumor targeting technology | No | 2001 | ▪ 13<br>▪ 0 |
| Evident Technologies Inc. | Dr. Clinton Ballinger, CEO | Troy, NY 518-273-6266 info@evidenttech.com | No response | *Nanomaterials:* EviDots - Quantum Dot Material Systems; EviComposites - Quantum Dots in Polymers<br>*Life Sciences:* EviTags - Water Stabilized Quantum Dots for Biotech; EviFluor - Quantum dots fluors | Yes | 2000 | Unknown |
| Nanoprobes Inc | James F. Hainfeld, Ph.D., President | Yaphank, NY 631-205-9490, hainfeld@nanoprobes.com | Yes – by email | Nanogold® | Yes | 1990 | ▪ 17<br>▪ confidential |
| ***Government / Defense*** | | | | | | | |
| Integrated Nano-Technologies LLC | Michael Connolly, PhD, President, CEO and Chairman of the Board | Henrietta, NY 585-334-0170, Info@integratednano.com | No response | self assembled nanoscaled circuits | Unclear | 1999 | ▪ ~125<br>▪ Unknown |
| ***Materials / Chemicals*** | | | | | | | |
| Starfire Systems Inc | John T. Kuznia, CPA, Controller & HR Manager | Malta, NY 518-899-9336 KuzniaJ@starfiresystems.com | Yes – by email | silicon carbide ceramic forming polymers and material systems | Yes | 1989 | ▪ 30<br>▪ confidential |
| NanoDynamics Inc. | Keith Blakely, CEO | Buffalo, NY 716-853-4900, kblakely@nanodynamics.com | Yes – by email | nanomaterials, NDMX golf balls, remote fuel cells, apparel | Yes | 2002 | ▪ ~ 100<br>▪ not disclosed |

| Category / Name | Contact Person | City, Phone, Email | Participated in Survey | Products | Any On Market[a] | Year Founded | Number of Employees and Revenues |
|---|---|---|---|---|---|---|---|
| ApNano Materials Inc | Dr. Menachem Genut President and CEO, co-discoverer of the inorganic fullerenes | New York, NY 212-302-2070, Menachem@apnano.com | No – unable to participate prior to project completion | NanoLub™ lubricant, nanospheres and nanotubes made from inorganic compounds | Yes | 2002 | Unknown |
| Applied NanoWorks | Tim Ullman, Operations Manager | Watervliet, NY 518-266-5443 eburnett@appliednanoworks.com | No – due to time constraints | semiconductors, metals and oxides in 2-9 nm sizes and a variety of form factors (colloids, powders, encapsulated and embedded matrices)--aluminum oxide, cerium oxide, silicon dioxide, titanium dioxide, zinc oxide, zirconium dioxide, nanophosphors | Yes | 2003 | ▪ 4, plans to add 30 in two years (D'Errico 2006)<br>▪ Uncertain |
| ***Consumer Products*** | | | | | | | |
| Nanocrystals Imaging Corp. (includes Nanocrystals Technology, L.P., NCT; Nanocrystal Imaging Corp., NIC; Nanocrystal Lighting Corp., NLC) | Rameshwar N. Bhargava, Ph.D. | Briarcliff Manor, NY 914-923-1142 rbhargava@nanocrystals.com | No response | Quantum confined atoms within nanocrystals; x-ray imaging; lighting | No | NCT in 1993; NIC in 1997; NLC in 2002 | Unknown |

Source: Corporate websites, Interviews or survey responses.

[a] This column refers to companies that have products on the market that contain nanomaterials or particles.

## Appendix C: Questions for Nanotech Startups in Connecticut and New York

***Background information about your firm:***

1. How long has your firm been in operation?
2. How did your firm get its start? Did it spin out of a university?
3. How many people does your firm employ?
4. What are the annual revenues of your firm?
5. What does your firm produce?
6. Do you sell any product(s) using nanoparticles yet or are your products still in the research phase? If you are selling products, do you sell domestically and/or internationally?

***EHS related questions:***

7. Does your firm have someone devoted to environmental, health and safety issues?

8. Does your firm have any concerns about potential environmental, health, and safety issues associated with your operations using or producing nanomaterials or nano-based products?

   If so, what types of concerns do you have on these issues (e.g., worker safety, production, product use, etc.)?

9. What information does your firm need to proactively address environmental, health, and safety issues?

10. What is the best way to convey information to you or your firm? What form is the most useful (presentation, report, online tools, on-site consultation, etc.)? Who would you trust to convey that information to you (government, industry associations, academics, peers, other)?

11. Is your firm taking any steps to evaluate potential environmental, health or safety risks associated with nanotech? Why or why not?

12. Is your firm taking any steps to reduce those risks?

13. What are the barriers you face with respect to taking into account these risks, especially those that are uncharacterized?

14. Do you think that the general public is well-informed about nanotechnologies in general (on scale of: not at all, not much, moderately, pretty much, very much)?

## Appendix D: Timeline of SME Nanotech Startup Activity in CT and NY

| Year Founded | Firm | Primary Industry | Commercial [a] |
|---|---|---|---|
| 1967 | Pentron [b] | Healthcare - Dentistry | Yes |
| 1968 | | | |
| 1969 | | | |
| **1970-79** | | | |
| **1980-88** | | | |
| 1989 | Foster Corp. | Materials/ Chemicals | Yes |
| | Starfire Systems Inc. | Materials/ Chemicals | Yes |
| | DiagXotics | Healthcare | Yes |
| **1990** | Nanoprobes Inc | Biotechnology/ Life Sciences | Yes |
| 1991 | | | |
| 1992 | | | |
| 1993 | Advion Biosciences Inc. | Biotechnology/ Life Sciences | Yes |
| | Nanocrystals Technology, L. P. | Consumer Products | No |
| 1994 | | | |
| 1995 | | | |
| 1996 | Inframat Corp. | Materials/ Chemicals | Yes |
| | US Nanocorp Inc. | Energy/ Environmental Utilities | Unlikely |
| 1997 | Nanocrystal Imaging Corp. | Consumer Products | No |
| 1998 | Agave Biosystems | Biotechnology/ Life Sciences | Yes |
| | Cellular Genomics Inc (CGI) | Biotechnology/ Life Sciences | No |
| 1999 | Integrated Nano-Technologies LLC | Government/ Defense | Unclear |
| **2000** | 454 Life Sciences | Biotechnology/ Life Sciences | No |
| | Evident Technologies | Biotechnology/ Life Sciences | Yes |
| 2001 | Protometrix | Biotechnology | No |
| | Cornerstone Pharmaceuticals Inc | Biotechnology/ Life Sciences | No |
| 2002 | NanoDynamics | Materials/ Chemicals and Consumer Products | Yes |
| | ApNano Materials Inc. | Materials/ Chemicals | Yes |
| | Nanocrystal Lighting Corp. | Consumer Products | No |
| 2003 | Genomas | Biotechnology | No |
| | Applied NanoWorks | Materials/ Chemicals | Yes |
| 2004 | MysticMD Inc. | Government/ Defense | No |
| 2005 | | | |

Key: Cells shaded blue refer to firms in Connecticut; cells shaded light green refer to firms in New York.
Note: Table includes surveyed nanotech firms only. Nanocs (NY-based SME within in Materials/ Chemicals primary industry) is missing from the table because I was unable to locate the founding date.
[a] This column refers to companies that have products on the market that contain nanomaterials or particles.
[b] Pentron was founded as a company developing, manufacturing, and marketing dental products. It is likely that the nanotech component of their business began many years after its founding in 1967.