UNIVERSITY OF CALIFORNIA SANTA BARBARA
BREN SCHOOL OF ENVIRONMENTAL SCIENCE AND MANAGEMENT

Current Practices and Perceived Risks for Environmental Health, Safety, and Product Stewardship in the Nanomaterials Industry

A Group Project submitted in partial satisfaction of the requirements for the degree of Master's in Environmental Science and Management for the Bren School of Environmental Science & Management

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The Group Project is required of all students in the Master's of Environmental Science and Management (MESM) Program. It is a three-quarter activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Final Group Project Report is authored by MESM students and has been reviewed and approved by:

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Dr. Patricia Holden DATE

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5 List of Acronyms

BSE	Bovine spongiform encephalopathy
CEIN	Center for Environmental Implications of Nano Technology
CEO	chief executive officer
CNS	Center for Nanotechnology in Society at UCSB
CPC	condensation particle counter
CTO	chief technical officer
CNT	carbon nanotube(s)
DEFRA	Department of Environment, Food, and Rural Affairs
DTSC	Department of Toxic Substances Control
DWCNT	double-walled carbon nanotube(s)
EHS	environmental health and safety
ELPI	electrical low-pressure impactor
ENM	engineered nanomaterial(s)
ENP	engineered nanoparticle(s)
EPA	Environmental Protection Agency
EU	European Union
FDA	Food and Drug Administration
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
FIOH	Finnish Institute of Occupational Health
g	gram
GM	genetically modified
HEPA	high-efficiency particulate-absorbing
HSE	Health and Safety Executive
HVAC	heating, ventilating, and air conditioning
IARC	International Agency for Research on Cancer
IRSST	Institut de Recherche Robert-Sauvé en Santé et en Sécurité du Travail
ISO	International Organization for Standardization
kg	kilogram
MEMS	microelectromechanical systems
mg	microgram
MSDS	material safety data sheet
MWCNT	multi-walled carbon nanotube(s)
NEAT	Nanoparticle Emission Assessment Technique
NIOSH	National Institute for Occupational Safety and Health
NICNAS	National Industrial Chemicals Notification Scheme
NNI	National Nanotechnology Initiative
OECD	Organization for Economic Cooperation and Development
OPC	optical particle counter
OSHA	Occupational Safety and Health Administration
PEN	Project on Emerging Nanotechnologies
PPE	personal protective equipment
PR	public relations

PTE	part-time equivalent
R&D	Research and development
REACH	Registration, Evaluation, Authorization, and Restriction of Chemicals
SiO_2	silicon dioxide
SMPS	scanning mobility particle sizer
SWCTN	single-walled carbon nanotube(s)
TiO_2	Titanium dioxide
UCLA	University of California, Los Angeles
UCSB	University of California, Santa Barbara
ug	microgram
UK	United Kingdom
ULPA	ultra-low particulate air
US	United States
USDA	United States Department of Agriculture

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7 Abstract

This report presents findings of an international survey of sixty nanomaterials companies regarding their self-reported environmental health and safety (EHS) and waste management practices, adherence to guidance documents, and individual views on risks. Nanotechnology involves engineered materials with dimensions of 1-100 nanometers. The numbers of industries using/producing engineered nanomaterials (ENMs) are increasing and ENM-specific EHS practices lag behind ENM production. Evaluating worker safety practices can indicate the overall environmental performance in firms. ENM producers and users face unknown EHS risks due to the limited knowledge of ENM behavior and toxicology, and most ENMs are unregulated. More information on ENMs in industry is needed to inform policies that protect humans and the environment. A database of companies handling ENMs was developed from internet research, previous survey participation, and personal contacts. The survey instrument, a questionnaire modeled from a 2006 baseline study, was modified based on recent studies and guidance documents, and was administered through telephone interviews and online. Responses were coded analyzed with Fisher's exact chi-square statistics, and relationships between variables were determined. Select findings include effects of company age, size, years handling ENMs, and the type of ENMs handled on EHS practices. Participants' views on risks were also analyzed.

8 Executive Summary

Motivated by the tremendous growth of the engineered nanomaterials (ENM) industry, the safety of nanotechnologies is garnering significant attention worldwide. Various governmental agencies, industries, and nonprofit groups are in the process of determining which environmental health and safety (EHS) practices will best protect workers, consumers, surrounding communities and the environment. Without sufficient information or regulation, ENM industries could act independently to avoid or reduce risk, resulting in inconsistent methods for protecting worker safety and environmental health.

Nanotechnology describes engineered materials at dimensions of 1 to 100 nanometers (i.e. at the "nanoscale") (NIOSH, 2009). At the nanoscale, familiar substances can exhibit different physical, chemical, and optical properties. Consequently, nanotechnology has the potential to make significant contributions to many fields, ranging from biotechnology to energy, and transportation to agriculture. Nanotechnology also presents new opportunities to improve how we measure, monitor, manage, and minimize contaminants in the environment. However, environmental health and safety (EHS) and product stewardship practices specific to ENMs are still being developed. Due to the limited knowledge of the behavior and toxicology of ENMs, producers and users of nanomaterials face unknown environmental health and safety issues. As a consequence, a variety of perceptions of ENM risk, and practices addressing these risks have emerged.

This report presents the findings of an international survey of nanomaterial producing companies on their EHS practices and individual views on risk. This survey was conducted by a team of researchers at the Bren School of Environmental Science and Management, University of California Santa Barbara (UCSB) as a project of IRG 7 of the University of California's Center for Environmental Implications of Nanotechnology (CEIN) and in conjunction with the NSF Center for Nanotechnology in Society at UCSB. The survey targeted approximately 500 individual companies worldwide with an oversample of North America. The sample omitted academic or government facilities. The survey was actively solicited between September 2009 and January 2010. The survey was primarily conducted over the phone, but an online version of the survey was also used to collect responses. The questionnaire consisted of 65 primarily close ended questions and was divided into nine sections capturing company information, product information, general and nano-specific EHS information, exposure monitoring, exposure controls, waste management, and risk perception. Information was self-reported and no direct verification was performed.

Data were coded for statistical analysis with responses to unstructured or semi-structured questions coded based on prevalent themes. The frequency response data for each individual question of the survey was analyzed. A depth analysis of variable independence and linear relationships between questions was performed by executing chi-square testing. Response categories were treated as independent or dependent variables to determine relationships between responses and associated significances.

A total of 487 potential participant companies were identified and invited. After the initial invitations were mailed, the research team learned that eight of these companies no longer existed and thirty of these companies reported that they did not work with nanomaterials. These thirty-eight companies were removed from the sample for a new sample size of 449. Of the 449 companies contacted, sixty companies completed the survey for an overall response rate of 13.4%. Companies from North America had the highest response rate (17%), while rates from European companies were lower (10.5%). The overall response rate of Asia was the lowest (8.8%). However, the only respondents from Asia were from Japan and China.

One of the central findings of this report was a correlation between smaller, younger companies and their EHS and nano-specific EHS practices. Younger companies were more likely to report having a nano-specific EHS program, and at least one part-time employee in the nano-specific EHS program. In regards to waste stewardship, younger companies were more likely to report disposing of their nanoparticles as hazardous waste and to list them separately as "nanomaterials" on waste manifests. Smaller and younger companies were more likely to advertise or otherwise disclose to their customers that their products contain nanomaterials. Smaller companies were also less likely to report a lack of information being a barrier to implementing nano-specific EHS practices. Also, larger companies are more likely to report having more employees that work directly with nanomaterials compared to smaller companies. This may indicate that larger companies who tend to have fewer nano-specific controls are more likely to have a greater number of employees potentially at risk of being exposed to nanomaterials.

Additionally, the type of nanomaterial handled or manufactured significantly related to company behavior. For example, carbon nanotube (CNT) handling companies tended to report participating in more nano-specific EHS activities. Despite the fact that these companies tend to fall into the larger and older company category, these companies were more likely to report having a nano-specific EHS program, having a nano-specific waste program, and to monitor the workplace for nanomaterials. Given that CNT companies occupy an important toxicological niche within the nanomaterial market, this information has important implications for future regulation. In another specific nanomaterial industry, nano-clay companies were less likely to report handling additional types of nanomaterials. Results also indicated that companies that reported handling nano-clays tended not to view themselves as handling ENMs. Furthermore, nano-clay companies were less likely to report having a nano-specific EHS program and to dispose of their materials in separate containers. The lack of nano-specific EHS practices within nano-clay companies may be related to their tendency to not consider their products as engineered nanomaterials.

Based on the survey results, it was concluded that companies with headquarters located in the United States were less likely to advertise or otherwise disclose that their products contained nanomaterials. The survey also asked if respondents worried that nanotechnologies may encounter unwarranted public backlash, similar to the reaction to genetically modified foods in Europe. Companies from the United States were more likely to disagree with this statement, implying that they were not worried about a repercussion. A possible explanation for this is that companies may fear a negative public reaction to the presence of nanomaterials in their products. If a fear of backlash is indeed what is keeping US companies from advertising or otherwise disclosing the presence of nanomaterials in their products, then there is a divergence between the respondents' beliefs and their practices in this particular case.

Although every effort was made to sample across companies of different sizes, industries, regions, and nations, the sample population interviewed for this survey may not represent the nano-industry as a whole. Also, because the survey was voluntary, there was a self-selection bias in the companies that chose to participate. Furthermore, some companies participated through internet surveys, and these respondents generally did not provide additional information or clarification. Finally, the information regarding company characteristics and environmental health and safety practices were self-reported and not subjected to verification by a third party. To enhance the use of this data in the future, the sample population should be expanded and further data analysis should be performed.

9 Phase I

Nanotechnology is the understanding and control of engineered materials at dimensions of 1 to 100 nanometers (i.e. at the "nanoscale") (National Institute for

Occupational Safety and Health [NIOSH], 2009). Engineered nanomaterials (ENMs) are designed to exhibit novel or enhanced properties, presenting opportunities to create new and better products. At the nanoscale, familiar substances can exhibit different physical, chemical, and optical behaviors. Nanotechnology also presents new opportunities to improve how we measure, monitor, manage, and minimize emerging contaminants in the environment. Consequently, nanotechnology has the potential to make significant contributions to many fields, ranging from biotechnology to energy, and transportation to agriculture.

9.1 Nanoparticles and Nanotechnology: An Introduction

Already, ENMs are used in a variety of consumer products such as cosmetics, stain-resistant clothing, coatings and electronics (Project on Emerging Nanotechnologies [PEN], 2009). Other applications of emerging nanotechnology include the detection and treatment of cancer, and nano-membranes that purify water (National Nanotechnology Initiative [NNI], 2009). The novel properties that create the industrial potential of ENMs may coincide with other uncharacterized properties that generate new risks to workers, consumers, the public, and the environment. These concerns have been raised regarding the potential environmental and health effects of ENMs whose many properties are different from their constituent elements.

Although ENMs continually appear in more products, there is a lack of information on the hazards of these new materials, especially in regards to their environmental effects (Behra & Krug, 2008). Research and development in the ENMs sector has grown faster than knowledge of the associated risks. Therefore, the need for regulation is unknown (Conti *et al*., 2008; Cable, 2005).

The exposure routes for ENMs through environment and human systems, as well as risks associated with exposure to ENMs, are uncertain (Scheringer, 2008; Renn & Roco, 2006). Because of these uncertainties, the assessment of risk in nanotechnology relies heavily on hypothetical assumptions and speculation (Renn & Roco, 2006). This absence of reliable science causes concern with widespread ENM usage. Recent estimates suggest more than 800 products on the market contain ENMs, and their usage in consumer products is growing (Marquis *et al*., 2009; Maynard, 2007). The available health information, in addition to being limited, can in some cases even be contradictory (Linkov *et al*., 2009). Even so, current academic literature is useful for identifying specific causes of these knowledge gaps in ENM risk and regulation (Maynard *et al*., 2006; Behra & Krug, 2008).

The deficit of knowledge regarding the aspects of ENMs include: 1) life-cycle assessment, 2) persistence and interaction of ENMs in the environment, 3) long-term effects on human health, 4) regulatory uncertainty, 5) uptake of ENMs by organisms, and 6) proper instruments for monitoring and assessment (Renn & Roco, 2006; Behra & Krug, 2008; Maynard, 2007). Another concern is the low level of public awareness about the use and concentration of ENMs in common household products (Scheringer, 2008). Similarly, predicting the effects of ENMs in wastewater treatment plants, waste incineration plants, and in the environment relies on limited empirical data (Boxall *et al*., 2007; Scheringer, 2008). In addition, there is minimal data on the toxicity of ENMs to organisms (Scheringer, 2008; Behra & Krug, 2008; Renn & Roco, 2006).

9.1.1 Common Nanoparticle-types

In order to consider EHS risks, it is important to have a general knowledge of the types of nanoparticles and their applications. The following is an overview of the most common classes and types of nanoparticles manufactured and used in industry. In addition, a description is included of the nanoparticles' use, manufacturing, novel properties, and toxicology.

9.1.1.1 Carbonaceous Nanoparticles

The following description of carbonaceous nanoparticles includes an overview of carbon nanotubes, fullerene structures, and carbon black. Of the carbonaceous nanoparticles, fullerenes are the most widely used type of carbon-based nanotechnology in industry (Lux Research Inc., 2007). A variety of fullerene structures exist which include nanotubes, fullerene rings, and some polymers and dimers. Carbon nanotubes, both single-walled and multi-walled, are fullerene tube structures with a significantly increased strength and flexibility (Harris, 2009). These two features have increased the attention by industry, and have become an integral component to carbonaceous nanoparticles in manufacturing structural components (Lux Research Inc., 2007). Polymers and dimers, while frequently composed of carbon structures, additionally contain functional groups and chemical binding sites specifically tailored for unique uses. Furthermore, carbon black has been used in industry for decades, but, as a nanoparticle, it poses similar health concerns due to its size and structure.

9.1.1.1.1 Carbon nanotubes: Single-walled and multi-walled

Composed solely of carbon atoms, carbon nanotubes are arranged hexagonally in a tube form. In industry they are used in composite materials primarily for strength (Harris, 2009). This application affords a wide range of possible uses that include displays, electronic circuits, sensors, and imaging tools (Lux Research Inc., 2007). Specifically, single-walled carbon nanotubes (SWNTs) are one cylinder that is approximately one nanometer in diameter (Harris, 2009). Multi-walled carbon nanotubes (MWNTs) are cylinders inside one another with diameters that range from 5-100 nm. Double-walled carbon nanotubes (DWNTs) are common and important in the commercial environment. The varieties of DWNTs include short, long, open, and closed tubes of different mirror image, or chiral, structures (Pradeep, 2007).

In production since 1983 and 1987 respectively, SWNTs and MWNTs are much stronger than traditional solid carbon fibers that can be made of similar sizes (Lux Research, 2007). SWNT are estimated to be approximately one-hundred times stronger than steel while only weighing one-sixth the weight (Lux Research Inc., 2007). They are also very pliable in movement, being elastic and durable. Their strength, lightness, and flexibility promote the use of carbon nanotubes in industry (Harris, 2009).

Carbon nanotubes pose a possible threat to human health and the environment. Preliminary studies show that aerosolized carbon nanotubes have been found to be more harmful than carbon black or quartz dust. Exposure to SWNT and MWNT resulted in immuno-responses, inflammation, and possible carcinogenic effects to mammals (Handy & Shaw, 2007). Their fibrous characteristics have led scientists to conjecture that their behavior may mimic that of asbestos (Poland *et al.*, 2008), and the National Institute for Occupational Health and Safety (NIOSH) recommends using caution when handling carbon nanotubes that are not incorporated into a product (Lux Research Inc., 2007). Potential routes of workplace exposure to CNTs include inhalation, dermal exposure and ingestion. A recent study by Yeganeh *et al.* (2008) showed that proper engineering controls result in sufficient protection of worker safety and health.

9.1.1.1.2 Fullerene Structures

Fullerenes are generally hexagonal or pentagonal structures of carbon atoms that create a cage or sphere. The original creation was termed a "buckyball" (Pradeep, 2007). Each structure is approximately one nanometer and is pure carbon. Other chemicals can be attached to the surface of the carbon structure with the creation of functional units. Since fullerenes have a distinct size and structure, the addition of functional groups is a uniform process resulting in a consistent product (Lux Research Inc., 2007). Also, fullerenes have multiple bonding sites that make them strongly reactive nanoparticles and high-quality catalysts (Pradeep, 2009) A polymer binding between fullerene molecules can make a strong and dense structure (Lux Research Inc., 2007).

Fullerenes are chemically reactive, resist biodegradation, and may pose a risk to human health and the environment. Potential routes of exposure to fullerenes include inhalation, dermal exposure and ingestion. Initial toxicology studies showed that the lowest concentration to harm liver and skin cells was 20 parts per billion. In addition to human health effects, fullerenes tend to agglomerate and remain in soils or groundwater for extended periods of time (Boxall *et al*., 2007). However, the effects on soil, microbes, and microbial structures appear to be limited (Nowack & Busheli, 2007). As with other nanoparticles, the toxicity of fullerenes are strongly dependent on the functional groups added to the molecules. Consequently, some fullerene structures are non-reactive and have low toxicity, and others are strongly reactive and can be highly toxic (Nowack & Busheli, 2007).

9.1.1.1.3   Carbon Black

Carbon black is a nanometer-sized, black, powder or granular substance produced by incomplete combustion or thermal decomposition of gaseous or liquid hydrocarbons under controlled conditions (International Carbon Black Association [ICBA], 2006). Unlike other emerging nanomaterials, carbon black has been commercialized for decades, being used as filler and reinforcement in rubber materials such as tires, wiper blades, and other industrial rubber products (Lux Research Inc., 2007; ICBA, 2006). Carbon black also can be used as pigments for ink, and in coatings and plastics given its colloidal particle structure, color, and conductivity (ICBA, 2006).

The primary route of workplace exposure by manufacturers and handlers of carbon black is inhalation. Other potential routes of exposure include, dermal or eye contact (NIOSH, 2005). One significant concern surrounding the health of manufacturers is the presence of polycyclic aromatic hydrocarbons found in manufactured carbon black.

Because it is one of the nanostructured materials which workers have been handling for many of years, many scientific health studies have researched the effects of carbon black exposure. Even with the large amount of research that has been performed, there are mixed opinions over the carcinogenicity of carbon black in humans. Cohort studies of carbon black production workers have been performed in the USA, Germany, and the United Kingdom (Dell *et al.*, 2006; Sorahan *et al*., 2001; Wellman *et al*., 2006). Dell *et al.* found that carbon black exposure in humans not to be connected with increased levels of cancer or mortality but this has not been verified for high levels of exposure. Wellman *et al*. found that carbon black is potentially indirectly linked to increased rates of lung cancer. Finally, Sorahan *et al.* also speculated on possible indirect links to lung cancer, but failed to link cumulative exposure to elevated risks. Valberg *et al*. (2006) performed a review of epidemiological data on carbon black exposure, and found no clear evidence of carcinogenicity. The International Agency for Research on Cancer's (IARC, 1996) review of human and animal exposure to carbon black reported that there was sufficient evidence in experimental animals for the carcinogenicity of carbon black, but inadequate evidence in humans. As such, the IARC classifies carbon black as possibly carcinogenic to humans (IARC, 1996). The Occupational Health and Safety Administration (OSHA) and the National Toxicology Program have classified carbon black as a human carcinogen.

9.1.1.2   Silica

Silica, also known as silicon dioxide (SiO_2), is manufactured in many forms including precipitated silica crystals, amorphous gels, fumed silica and colloidal silica. Silica-based aerogels are nanoporous materials which are excellent insulators due to their low thermal conductivity (Lux Research Inc., 2007). In the pharmaceutical industry, hollow silica shells may encapsulate other materials for drug delivery applications. In the coatings industry, the hydrophobicity or hydrophilicity of silica nanoparticles can be structurally altered to allow antireflecting, antifogging or antifouling properties (Lux Research Inc., 2007). Similar to their bulk counterparts, silica nanoparticles are also used as fillers in composite materials and as additives in plastics and rubber (Lux Research Inc., 2007).

Potential routes of workplace exposure to silica include inhalation, and skin or eye contact. Crystalline silica dust can cause silicosis, a lung disease that occurs from inflammation and scarring of the lungs and is characterized by shortness of breath and fever. In 1997, after reviewing epidemiologic studies, the IARC concluded that there is sufficient evidence in humans for the carcinogenicity of inhaled crystalline silica from occupational sources (NIOSH, 2002).

9.1.1.3 Quantum Dots

Quantum Dots (QDs) are nano-sized, semiconductor crystals that can exhibit fluorescent, optical, electrical and magnetic properties depending on their composition and size. Metals such as lead and cadmium are commonly used to create QDs. A variety of shell structures can be applied to functionalize or conjugate the quantum dot core for different applications (Hardman, 2006). Luminescent quantum dots have applications in biological imaging and molecular diagnostics (Lux Research Inc., 2007). Magnetic quantum dots have applications in computing and solar cells. With display technology, alternative energy sources, and biotechnology and pharmaceutical technologies driving quantum dot applications, Lux Research Inc. (2007) projects the market for quantum dot manufacturing to reach $62 million by 2011.

Given the diversity of semiconductor elements that make up quantum dots, their toxicity varies significantly (Hardman, 2006; Zhang *et al*., 2008). Environmental conditions such as oxidative, mechanical, and photolytic stability also change the potential toxicity of quantum dots (Hardman, 2006). From an environmental health and safety perspective, quantum dots pose a risk to both manufacturers and users (Lux Research Inc., 2007). Potential routes of workplace exposures to quantum dots by manufacturers, researchers, and/or clinicians include dermal contact, inhalation, or ingestion (Zhang *et al*., 2008). While quantum dots have not been approved for therapeutic or diagnostic purposes, another important theoretical route of exposure is use of quantum dots for medicinal purposes.

9.1.1.4 Metals

The most common types of nano-metals are silver, platinum, gold, aluminum, and nickel (Wilde, 2009). Silver is most known for its use as an antimicrobial agent. Platinum can be used as a catalyst, although it is expensive relative to current alternatives. Gold is most known for its potential in biological systems and targeting tumor cells for destruction (Kumar, 2007). At the nano-size, aluminum is unstable and has potential uses in explosive-type technology (Wilde, 2009). Nickel, which is a less expensive alternative as a catalyst, is used in fuel-cell technology (Wilde, 2009).

Metal in nano-form has promise for a wide variety of novel uses such as antimicrobial agents, biological assays, and propellants (Lux Research Inc., 2007). Similar to other nanoparticles, the most valuable property that nano-metals exhibit comes from their larger surface area to volume ratio. This property makes nano-metals a beneficial class of catalysts. Metals are excellent conductors of electricity (Wilde, 2009). Potential routes of workplace exposure to nano-metals include inhalation, dermal exposure or ingestion.

Typically nano-metals are presumed to be non-toxic in human applications (Lux Research Inc., 2007). As a result, most products on the market today that contain nano-silver have been approved through the Food and Drug Administration or the Environmental Protection Agency's responsibility of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). FIFRA indicates that any product advertising antimicrobial properties shall be reviewed, approved, and regulated by the EPA. However, in larger doses to rats in toxicological testing of nano-silver mitochondrial and enzyme functioning was impaired (Handy & Shaw, 2007).

One of the strongest criticisms of the use of nano-silver concerns its end-of-life cycle. Nano-silver is more likely than other nano-metals to enter wastewater from washing clothing embedded with nano-silver, or to leach out of landfills (Benn & Westerhoff, 2008). Since many products will eventually be disposed of through physical waste streams, a potential exists for nano-silver to enter the environment. With its high efficacy as an antimicrobial product, nano-silver has a strong possibility of disrupting many natural microbial processes. Therefore, as a byproduct in the wastewater system, nano-silver may also pose a new concern for wastewater treatment plants that use microbes to process and break-down wastes (DiSalvo, 2008).

9.1.1.5 Metal Oxides

Metal oxide compounds encompass a diverse range of nanoparticles including single-metal oxide nanoparticles, such as titanium oxide, zinc oxide, iron oxide, and cerium oxide. More complex multi-element oxide nanoparticles, such as indium tin oxide, are also in production. Metal oxide nanoparticles provide unique magnetic, electrical, and conductive properties that are useful in key applications of structural ceramics, catalysis, abrasives, pigments, coatings, and cosmetics (Lux Research Inc., 2007).

For over twenty years, zinc oxide and titanium dioxide nanoparticles have been added to some sunscreens to reduce their visible white color while still offering the same UV-light attenuating properties as sunscreens containing coarser materials. Also, zinc oxide nanoparticles have been incorporated into cotton fabrics for their deodorizing and antibacterial properties (Padmavathy & Vijayaraghavan, 2008).

Many groups have studied the uptake and toxicity of metal oxide nanoparticles in vivo and in vitro in microorganisms, plants, and animals (Grassian *et* *al.*, 2007; Jin *et al.*, 2008; Ray *et al.*, 2009). Grassian *et al*.(2007) showed an inflammatory response of mouse lungs exposed to inhalation of titanium dioxide nanoparticles. Additional research has shown adverse effects of zinc oxide, titanium dioxide, and silicon nanoparticles on the growth of *E. coli*, *B. subtilis*, and nitrifying bacteria (Pal *et al.*, 2007; Sondi & Salopek-Sondi, 2004; Choi & Hu, 2008; Adams *et al.*, 2006).

From an environmental health and safety perspective, metal oxides pose a risk to both humans and the environment. Potential routes of workplace exposures to metal oxides by manufacturers, researchers, and users of end products include dermal contact, inhalation, or ingestion (Beckett *et al.*, 2005). The release of metal oxides from consumer products, such as sunscreens or washed apparel, can affect the environment and the health of people exposed to environmental contamination (European Agency for Safety and Health at Work, 2009).

9.1.1.6 Component Nanoparticles: Dimers, Polymers, and Dendrimers

Dimer structures can be utilized in creating component nanoparticles by joining two monomer molecules into one structure by hydrogen bonds (Lux Research Inc., 2007). Dimer structures are common in biochemistry and hold many uses in the construction of nanoparticles. They are frequently seen in the synthesis of nano-gold as well as nano-lattices and in the synthesis of intermediate nanoparticles (Pradeep, 2007).

Polymers are made by combining a variety of nanomaterials to form larger structures for ease of use in various applications (Wilde, 2009). As a class of macromolecules, polymers have a repeating structural unit connected by covalent bonds. Polymers are the building block of composite nano-sized particles. Since nanomaterials are effective due to their high surface area to volume ratio, they are also able to adhere with polymers to create dense structures. For example, nano-sized clays can also be used with polymers to create light and dense materials useful in car manufacturing (Lux Research Inc., 2007). Additionally, nano-metals can form ceramic nanoparticles with the addition of polymers (Lux Research Inc., 2007).

A frequent use of polymers is in the manufacturing of dendrimers, which are branched polymers with unique and complex structures (Pradeep 2007). Dendrimers are formed by adding branching molecules or by bonding already formed branches to a single molecule. Dendrimers are manufactured to increase reactivity and conductivity, and to reduce toxicity (Pradeep, 2008).

Dendrimers resist degradation and may be a threat to human health and the environment. Highly variable in structure and function, the toxicity of dendrimers depends on the type of functional groups and components attached to the dendrimer. For example, functional group modification is a necessary step in reducing the cytotoxicity in drug delivery systems (Nathan *et al*., 2009). Nair *et al*. (2009) have shown that the further addition of gold to composite dendrimers reduces toxicity.

9.1.1.7 Clays

Considered a nanoparticle for being a size of less than 100 nanometers, nano-clays are a unique class of nanoparticles. Unlike nanoparticles that are engineered or designed for unique properties, clays can be naturally occurring minerals (Nowack & Bucheli, 2007). They can be treated similarly to polymers due to their small size and are an essential building block for modified nano-applications (Manitiu *et al*., 2009). These applications usually include construction materials such as plastics or durable composites.

Nano-clays can be disk-shaped platelet structures. These disks can be manufactured as an ordered structure of alternating layers of clay and polymer or formed as a heterogeneous mix (Manitiu *et al*., 2009). By adding clay, the composite is afforded additional stiffness, fire resistance, gas permeability, and heat stability (Lux Research Inc., 2007). For manufacturing applications, the nano-clays are incorporated into an organic mix of nylon, polystyrene, or epoxy resins.

Once nano-clays are incorporated, there is minimal risk to consumers and the environment. Therefore, the environmental health and safety of clays pertains more to worker safety than the end product (Lux Research Inc., 2007). Potential routes of workplace exposure to clays include inhalation, ingestion and dermal or eye contact. In its solid composite form, the clay is strongly bonded to polymers and other particles, and not a concern for worker exposure. Worker safety is a concern when nanoparticles become aerosolized and thus, potentially inhaled (Norwack & Bucheli, 2007). Recent studies have found clay flakes to pose less of a hazard for workers than silica particles, but Lux Research Inc. (2007) recommends continued safety precautions.

9.2 Current Recommended Best Practices for Nanomaterials

Government guidance documents are an important source of recommendations for management practices in nanomaterials. Though guidance documents are from multiple agencies in several countries, they have many recommendations in common. First, specific definitions of nanomaterials are essential despite varied nomenclature within the industry (NIOSH, 2009; Occupational Health and Safety Research Institute [IRSST], 2009). Next, nanomaterials should be treated as hazardous until proven otherwise because the risks associated with nanomaterials are uncertain due to a lack of toxicological research (IRSST 2009; Health Safety Executive [HSE], 2009; Federal Council, 2009). Third, industrial hygiene in a facility that handles nanomaterials should have the following hierarchical approach: 1) substitution, 2) engineering controls, 3) administrative controls, and 4) personal protective equipment (PPE) (NIOSH, 2009; IRSST, 2009; Federal Council, 2009). All guidance documents agree that using best management practices and minimizing exposure potential is the best approach for EHS until more exposure risk data is available (NIOSH, 2009; HSE, 2009, IRSST 2009, Federal Council, 2009). The following is a summary of recently published, publically available, guidance documents.

9.2.1 Approaches to Safe Nanotechnology (NIOSH, 2009)

NIOSH's purpose in publishing Approaches to Safe Nanotechnology was to 1) raise awareness of occupational health and safety issues identified through research; 2) use the best available information to provide recommendations that are continually updated; 3) aid information exchange between NIOSH and external partners; 4) reply to requests for information industry and others; and 5) discover and categorize information gaps.

NIOSH (2009) defined nanotechnology as involving "the manipulation of matter at nanometer scales to produce new materials, structures, and devices." The document also differentiated between nanoparticle sources, but stated that it is not yet clear whether a source-based definition is meaningful from a health and safety point of view.

As an emerging field with many uncertainties, nanotechnology may pose occupational health risks due to the unique properties of nanoparticles. Inhalation is thought to be the most likely exposure route, though nanoparticles may also enter through the skin or by ingestion. Some animal epidemiological studies suggested that exposure to engineered nanoparticles (ENPs) may have adverse health effects similar to exposure to particles with similar composition and properties. Mass is typically a hazard indicator in standard-scale chemistry, but some studies have implied that surface are and activity may be better predictors of hazard in nanoparticles. Other potential safety concerns involve risk of fire, explosion, and catalytic reaction due to properties of materials at the nanoscale.

Exposure assessment and characterization are important components in an industrial hygiene program, but there is no national or international standard for measurement of nanomaterials in the workplace. Current research suggests that surface area, particle size, and surface chemistry may be important when characterizing nanomaterials. Workplace monitoring may be carried out using traditional industrial hygiene methods, such as discrete or continuous sampling, though many available measurement instruments are not designed for use with nanomaterials. Sometimes several instruments must be used congruently to collect all necessary data. NIOSH has developed the Nanoparticle Emission Assessment Technique (NEAT) for qualitative measurement in the workplace. The document suggests that, until more information becomes available, protective measures should be developed and implemented using a hazard-based approach.

The potential for occupational exposure and factors affecting exposure to nanomaterials are also addressed. The document lists the key elements of a hierarchical risk management program. NIOSH (2009) suggested that the first step of the risk management program is the elimination or substitution of the hazard. If the substance is not able to be eliminated or substituted, engineering controls, such as isolation and ventilation with HEPA filters and well designed filter housings should be implemented. If the administrative controls and workplace practices cannot remove the hazard, managers should use formal procedures with guidelines for good workplace policies for both management and workers. If further protection is needed, workers should use personal protective equipment (PPE) such as lab coats, gloves, and eye protection, and, as a last resort, respiratory protection.

A respiratory protection program should include training, fit testing, and regular maintenance. Studies show that respiratory filtration is an effective protection measure on particles as small as two nanometers. NIOSH has published a guide on respirator selection, and has also indicated that dust masks do not provide adequate respiratory protection for nanoparticles.

According to the document, there is no specific guidance currently available regarding nanomaterial cleaning procedures, but the pharmaceutical industry has developed recommendations for drug production that may be useful. Industrial standard hygiene practices should be used, such as the use of a high-efficiency particulate-absorbing (HEPA) filter vacuum for powders and liquid traps for nanoparticles in solution. Energetic cleaning methods, such as sweeping or compressed air, should be avoided. When developing cleaning procedures, the possibility of exposure should be considered.

Another important facet of an occupational health and safety program is occupational health surveillance. Health screening is an important component of a monitoring program to identify possible exposure routs not captured by avoidance measures. NIOSH has developed a document about medical screening from an occupational health and safety perspective.

9.2.2 Action Plan: Synthetic Nanomaterials (Federal Council, 2009)

Federal Council’s Action Plan: Synthetic Nanomaterials was created by several Swiss Federal agencies: Federal Department of Home Affairs; Federal Department of Economic Affairs; and Federal Department for the Environment, Transport, Energy and Communications. This document established a regulatory framework regarding synthetic nanomaterials. This framework included sections concerning effects on humans and the environment, health protection in the workplace, and risk assessment and regulation.

According to the action plan, there is not currently enough information about the effects on humans and the environment for an accurate risk assessment. The lungs are the most likely source of nanoparticle uptake, though they may enter through the skin as well. This document concluded that the possible effects of nanomaterials on human health and the environment must be given high priority in future research.

For health protection at the workplace, this document states that unbound nanoparticles are the most likely to cause occupational exposure and that substances with unknown properties should be treated as potentially hazardous. It also suggests that companies use an established protection strategy with a hierarchical approach: 1) substitution, 2) technical measures (engineering controls), 3) organizational measures (administrative controls), and 4) personal protection. While the definition of nanomaterials and the knowledge of potential risks are not sufficient establish regulations, risk assessments based on available information are essential to set initial guidelines.

The Federal Council also provides the "Precautionary Matrix for Synthetic Nanomaterials." This matrix addresses specific framework conditions such as nano-relevance, information on the life cycle, potential effects, exposure of human beings, and input to the environment. The Council also produced another document, "Guidelines on the Precautionary Matrix for Synthetic Nanomaterials" detailing more specific instructions on using the matrix.

9.2.3 Best Practices Guide to Synthetic Nanoparticle Risk Management (IRSST, 2009)

The Quebecois governmental organization, the Institut de Recherche Robert-Sauvé en Santé et en Sécurité du Travail (IRSST), also known as the Occupational Health and Safety Research Institute, created Best Practices Guide to Synthetic Nanoparticle Risk Management. This guidance document was created to assist research organizations and companies in cultivating safe development of nanotechnologies in Quebec. The guide benefits employers, employees, and stakeholders of the prevention network, such as inspectors, hygienists, medical staff, and technicians. The IRSST defines nanoparticles as engineered particles ranging from one to 100 nanometers and excludes incidental nanoscale particles. This document reports general information on the makeup, synthesis and properties of some specific nanomaterials as well as nanomaterials in general.

The most likely route of uptake for nanomaterials is through inhalation, though absorption through the skin is possible, as well as ingestion. Nanoparticle toxicity is based on many factors such as surface area, number and size of particles, and chemical composition. The uncertain risks of nanoparticle exposure justify the use of exhaustive measures to limit exposure and protect worker health. Safety risks of nanoparticles include explosions, fire, and catalytic reactions.

This document also specifically addresses environmental risks of nanoparticles. Nanoparticles are likely present in the environment due to factory releases, leaks, spills, and the use composite nanomaterials. Nanoparticles can be extremely mobile in the environment and therefore can end up in the food chain. While nanoparticles are likely to aggregate or agglomerate, they can also be transported long distances in the air. Therefore, this guide recommends that all effluents containing nanomaterials be treated before they are returned to the environment or incinerated.

The guide defined a risk analysis as needing a thorough knowledge of the types of materials handled, their toxicity, potential exposure, and safety risks. Because not all of this information is currently known with respect to nanomaterials, this guide suggested a structured and case-by-case approach. In order to help control the risk factors, nanoparticle type should not be grouped as one substance with understood and documented risks, but should be considered separate entities. The guide also suggested using a hierarchical approach involving facility design, substitution/elimination, engineering techniques, administrative measures, and PPE. Reduction of safety risks involves knowledge of the nanoparticles used, and environmental factors that can spark fires or explosions. In order to control environmental risks, the guide stressed the importance of limiting nanoparticle emissions into the environment, as it is difficult to monitor and eliminate nanoparticles once they have been released.

This guidance document includes a conceptual industrial prevention program for working safely with nanoparticles in a facility (Appendix A). It also addressed working with nanoparticles in a university research lab. The authors stated that the main preventative aspects remain the same, but university labs may face some specific challenges such as: senior executive commitment, hierarchical concerns, risks specific to creating new nanoparticles, frequent influx of new students and evolving research, and little performance evaluation. The document concluded with the authors' recommendation to use a preventative, if not precautionary, approach to prevent nanoparticle exposure.

9.2.4 Risk Management of Carbon Nanotubes (HSE, 2009)

The Risk Management of Carbon Nanotubes was written by the Health Safety Executive (HSE), a British governmental agency. It focused on the manufacture and manipulation of CNTs and was released by the HSE in response to new toxicity information about CNTs. The risk management principles described in this guidance document may also apply to other nanoscale, biopersistent fibers with a similar aspect ratio.

The HSE explained that CNTs can vary in chemical composition and can exist as MWCNTs or SWCNTs. Some CNTs have a shape similar to asbestos fibers as well as a similar ability to persist in the lungs. The new evidence suggested that long, straight MWCNTs with a high aspect ratio produce an inflammatory reaction when injected into mice. Carbon black and short and tangled MWCNT fibers resulted in little to no inflammation, which implies that the shape of the fibers is the important factor in disease development. This research raised the level of concern about CNTs, but the findings only apply to long and thin CNTs or possibly other long and thin nanomaterials.

Because toxicology and worker safety information are incomplete, the regulatory response is to take a precautionary approach. As a result, the principles of risk assessment and failure to carry out a proper risk assessment may cause an enforcement action by HSE. All people potentially exposed to CNTs should be given sufficient training and information. CNT materials should always be provided with health and safety information and a warning that the product contains CNTs. The HSE viewed CNTs as substances of very high concern and suggested that the precautionary approach include engineering controls, administrative measures, PPE, and emergency procedures. The authors also recommend that CNTs be classified as hazardous waste and incinerated at a high temperature.

9.2.5 Summary

Overall, the recommendations of the government guidance documents were very similar. Differences were minor, and mainly due to the fact that the documents had slightly different objectives. As recommendations were analogous, the above guidance documents were all taken into consideration and reflected in design of this survey.

9.3 Regulation of Nanomaterials

While many countries around the world have government and consortium nanotechnology programs in place, few countries have enacted regulations for nanomaterials or the underlying nanotechnology. For the few regulations that do exist, there is no consistency between countries in identifying and regulating the industry as a whole.

Starting in 2008, Canadian companies or institutions that manufactured or imported more than 1 kg of a nanomaterial into Canada were required to submit information on methods of manufacture and use, physical and chemical properties, and toxicological data. Introduced as a proposed mandatory information gathering scheme, Health Canada and Environment Canada will use the collected information for directing the development of regulatory frameworks and risk assessments of nanomaterials (Environment Canada, 2007).

On October 31, 2008 the US Environmental Protection Agency (EPA) issued a federal register notice regarding CNTs that reminds manufacturers and importers that they must notify EPA at least 90 days prior to the manufacture or import of new chemical, such as CNTs, for commercial purposes (TSCA Section 5 regulations, found at 40 C.F.R 720.22). This notice comes as a result of the EPA considering CNTs to be chemical substances distinct from graphite or other allotropes of carbon listed on the TSCA Chemical Substances Inventory (United States Environmental Protection Agency [US EPA], 2008).

Pursuant to Assembly Bill (AB) 289, which was signed into law in 2006, the California Department of Toxic Substances and Control (DTSC) is requesting relevant information regarding analytical test methods, and fate and transport in the environment for certain chemicals of concern from persons and businesses that produce chemicals in California or import chemicals into California for sale (California Department of Toxic Substances and Control [CA DTSC], 2010). Over the past year, DTSC has been exercising its authority under *Health and Safety Code*, Chapter 699, sections 57018-57020 to identify existing information gaps and develop existing knowledge of CNTs. Their rationale included widespread commercial use and a data deficiency for toxicity, physicochemical properties and fate and transport. As of January 22, 2010, seventeen companies submitted information for the carbon nanotube information call-in.

In November 2009, the member states of the European Union (EU) agreed on a new regulation for cosmetic products that requires individuals or companies to supply the European Commission with safety information for any new cosmetic products containing nanomaterials (European Parliament, 2009; Bowman et al., 2010). In addition, manufacturers with cosmetic products already on the market will be required to submit similar information to the European Commission. This movement is significant because it is the first piece of legislation to incorporate rules relating specifically to the use of nanomaterials in any products (Bowman et al., 2010).

Currently, Australia does not have a mandatory register of companies that import, manufacture, supply or sell nanomaterials. Additionally, there is no obligation to label products. However, in November 2009, the Australian Government requested public comment on the National Industrial Chemicals Notification Scheme (NICNAS) proposed regulatory reform of industrial nanomaterials (National Industrial Chemicals Notification Scheme [NICNAS], 2009).

As evidenced above, current and proposed regulation of nanomaterials varies depending upon the amount and type of nanoparticle handled. Information gaps related to nanoparticle toxicity, fate and transport, and analytical test methods make it difficult to comprehensively regulate nanotechnology.

9.4 Previous Surveys Related to Engineering Nanomaterial Handling Practices

Since the Conti *et al*. (2008) study, there is a continued interest in the academic community to address the knowledge gap that exists in the nanomaterial industry. Researchers have tried to fill that gap by acquiring knowledge of current handling practices, as well as companies' understanding of effective nano-material handling practices. Part of this effort has involved the implementation of industry oriented surveys, both domestic and international. While this research is unique in its focus on industrial environmental health and safety (EHS) practices as well as risk perception, it is not the only study in the last few years that has involved surveying industry on these topics. The following surveys are related to this study, and were considered during the literature review and survey design portions of the project.

9.4.1 Surveys of Environmental Health and Safety

A survey of foundational importance to this survey is the study published using the data and analysis by Conti *et al*. (2008). Conti *et al.* (2008) invited 357 different nanomaterial companies and labs to participate in an international survey of nanomaterial workplace EHS. Researchers conducted interviews with 82 invitees, yielding an overall response rate of 23%. As a pioneering study, the survey was exploratory in nature and the majority of the questions asked were open-ended. The survey covered such topics as occupational health and safety, nanomaterial waste and exposure, and risk characterization. The importance of the Conti *et al*. (2008) study was that it established much of what is known about reported nanomaterial industry EHS today. The open-ended, exploratory survey enabled a wide variety of responses to characterize the industry. Also, the study was crucial for exploring the connection between general health and safety programs and nano-specific health and safety programs. The relationship between these two industry characteristics was previously unknown.

Schmid and Reidiker (2008) contacted 197 Swiss companies to conduct a survey of EHS professionals, of which 54 companies worked with nanomaterials. The object of this exploratory survey was to determine which sectors in the Swiss industry used nanomaterials. This information was used to gain a better understanding of the potential for human exposure. The main industrial applications covered in the study were cosmetics, foods, paints, powders, and surface treatments. The study found that, generally, the safety measures were higher in powder-based than in liquid-based applications. Finally, the survey determined a list of compounds commonly used at the nanoscale. Much like the Conti *et al.* (2008), this survey helped establish a basic understanding and standard of safety practices within the Swiss nanomaterials industry. In contrast to the Conti *et al*. (2008) study which focused primarily on North America and Asia, the Schmid and Reidiker study focused exclusively on Swiss companies.

Balas *et al*. (2010) administered an online survey which mostly (95%) focused on public research laboratories or universities. The researchers emailed 2,300 invitations and received 240 responses, yielding a response rate of 10.4%. The survey was solicited internationally, and the sample frame was selected by targeting researchers through the ISI Web of Science search engine. The survey was specifically oriented towards ENM details, processing methods, safety measures, waste disposal procedures, and knowledge of nanomaterial handling legislation. Some key findings of the Balas *et al*. (2010) study included: lack of knowledge of local or national level regulation for nanomaterials, inorganic materials were the largest group of nanomaterials worked with, the most frequent method of synthesis was wet synthesis, and almost one quarter (24%) of respondents reported using no type of protection. The study also found that almost half of the respondents failed to use any type of personal protective equipment, and 85% of respondents did not use any special disposal procedure. The Balas *et al*. (2010) study is important not only because it had many nanomaterial specific EHS findings, but also because it focused on public research laboratories or universities rather than private industry.

Plitzko and Gierke (2007) administered a written questionnaire to a total of 656 member companies of The Association of the Chemical Industry in Germany. Of those contacted, 217 responded. This exploratory survey was divided into two sections, one asking questions about general EHS practices and another asking questions about specific types of nanomaterials and the EHS practices associated with them. Only 21% of companies performed activities involving nanomaterials. Of those companies that used nanomaterials, 40% of them used only small volumes of nanomaterials, typically between 10 and 100 kg. Additionally, 71% had only one to nine workers actively involved with nanomaterials, and 70% of companies handled two nanomaterial products at most.

Blando *et al*. (2007) submitted a mail questionnaire to industries located in New Jersey that had been identified as using lead in their processes. While this survey was not directly related directly to nanomaterials, it was designed to determine information about chemical and lead use, handling, and employee protection. Out of 104 potential respondents that were solicited, 45 returned a complete survey yielding a 43% response rate. The Blando *et al*. (2007) survey found that companies were generally non-compliant with OSHA standards, and that there was a lack of OSHA inspections and citations. This survey was particularly relevant because it further demonstrated a general lack of EHS regulation, even in areas where exposure and monitoring are better understood.

9.4.2 Surveys of Perception and Risk

From December 2005 to February 2006, Helland *et al*. (2008) collected responses to a written questionnaire submitted to 135 German and Swiss companies. A total of 40 companies completed the survey, resulting in a response rate of 29%. The subject of the survey was both risk assessment practices and risk perceptions associated with ENMs. Helland *et al*. (2008) targeted individuals in charge of risk assessment procedures.

The first portion of the survey focused on perceptions and consisted of 8 questions, all on risk and how risk perception affects procedures and performance. Helland *et al*. found that most companies believe they are only responsible for potential impacts to human health and the environment in the research, development and production stages (2008). However, in later stages of ENM life they believe that other stakeholders are responsible for this impact. The second part of the survey focused on regulation and found that there was little agreement on whether regulations should be established, and if so, whether government or industry should have regulatory authority. This survey is one of the only other studies regarding engineered nanomaterials that looked specifically at the issue of risk perception. Unlike this research study however, Helland *et al*. (2008) heavily favored open-ended, qualitative questions. The study also focused more on the issue of responsibility, and less on specific risks and risk perception within the industry.

In another study, Helland *et al*. (2009) researched the risk assessments performed by ENM producing companies. The questionnaire was divided into three main sections: material properties, exposure assessment, and risk assessment. In their findings, Helland *et al*. (2009) reported no relationship between nanoparticulate material characteristics, risk assessment procedures, and precautionary measures. The participants did not prioritize nanoparticulate material risk assessment. The study also found ENM companies did not have any sort of framework for evaluating risk. Furthermore, the survey revealed a lack of correlations between material characteristics and treatment of exposure and risk, which is an issue addressed in this research.

Besley *et al*. (2007) surveyed 177 nanotechnology researchers. The survey was developed through open-ended interviews of nanotechnology researchers and involved questions on important areas in research, potential benefits of nanotechnology, risks in nanotechnology, and perceptions on regulation. The researchers then used the ISI Web of Science database to find individuals who had recently published articles related to nanotechnology, and found 462 legitimate individuals. As part of their solicitation protocol, researchers first sent participants a letter asking them to fill out an online survey. Besley *et al*. (2007) then followed up with a series of email reminders both one and two weeks following the letter. In total, 177 usable surveys were completed. The Besley *et al*. (2007) study used a solicitation protocol very similar to the one utilized by this study. Their system of sending a preliminary mailed invitation followed by a series of emails proved very successful and ultimately resulted in a 32% response rate. Also similar to this study, the questions in the survey were designed to test for a predetermined set of variables with the intention that linear relationships between different variables might emerge from the responses. In their results, the Besley *et al*. (2007) study found that in the area of risk perception, experts felt that the benefits of nanotechnology outweighed the risks. Despite this perception of net benefits, the survey respondents generally indicated that current regulations are inadequate.

9.4.3 Other Nanomaterial Surveys

Palmberg (2007) conducted a survey that used a nanotechnology keyword search algorithm to select a population of Finnish researchers and inventors by looking at publications and patents. The survey was web-based and solicited 1002 individuals, of which 603 responded, yielding a 60% response rate. The study asked the sample population questions about challenges, interactions, and outcomes of technology transfer between universities and private companies. The study revealed differences in perceptions of researchers across a variety of organizations. It also highlighted many of the challenges of examining risk perceptions within the industry.

Also, Su *et al*. (2007) of the Science and Technology Policy Research and Information Center in Taiwan surveyed 150 companies in order to map the progress of nanotechnology development in Taiwan. The study focused on how the Taiwanese nanotechnology industry compared with other countries in terms of funding, program structure, and other characteristics. More than half of the companies surveyed were performing research and development (R&D), a proportion significantly larger than what is commonly found in other fields. The large amount of R&D taking place in the nanomaterials sector illustrated the rapidly evolving knowledge in the field of nanotechnology.

9.4.4 Evaluating Risk and Trust in Industry Related to Emerging Technologies

The perceived risks and the level of trust of industry involved in emerging technologies, like nanotechnology, are important to address if one wishes to increase risk communication between industry and informational/regulatory government agencies. As a consequence of our compliance-dependent culture in environmental safety and risk management, trust may have great implications for emerging technologies such as government imposing strict regulations or the inability of industry to effectively manage risk (Jeffcott *et al*., 2006). The necessity of trust in larger social structures is required of others to complete specialized tasks (Poortinga & Pidgeon, 2005). With this division of labor in society, the public generally holds government institutions responsible for mediating risks involved in industry and emerging technologies (Jeffcott *et al*., 2006). An individual's ability to trust in governmental institutions is regarded as an important component in effective regulation and the individual's acceptance of the risks of new technologies.

Government trust is especially important when possible views imposed from outside the industry are negative. Changes in perception of science and innovation have shifted negatively from the 20th century to now (Frewer, 1999). During the 1950's, a shift occurred mainly from a series of negative events linked to new technologies. Some of these incidences included the consequences of pesticides such as DDT and organophosphates, pharmacological mistakes like thalidomide, the nuclear Chernobyl accident, BSE (bovine spongiform encephalopathy, or "mad cow disease"), and the uncertain implications of genetically modified foods. This evaluation of handling and EHS practices of nanomaterials is a direct way to reveal the key structural drivers in industry that may influence trust and management of risks. These may ultimately indicate a government and public response to nanotechnology. Currently, government agencies, such as NIOSH, are trusting industry to manage these risks. If lines of trust and communication are weak to effectively and collaboratively address new risks as they are uncovered, then a more direct enforcement of industries by government involved in nanotechology may result. Additionally, if the industry improperly manages risks resulting in a negative incident, the public are likely to look to government for regulation to control the risk of nanomaterials (Weyman *et al*., 2006).

Trust is an important concern in safety performance as well. Jeffcott *et al*. (2006) propose that a "safe" organizational model functions well for ambiguous and uncertain circumstances in industry. When an organization contains a flexible hierarchy of procedures, has a high commitment to management, and possesses an open and communicative environment which fosters learning, then industry will be likely to quickly manage emerging risks. Analyzing company safe-handling practices, beliefs of worker's safety responsibility, and the level of trust that industry has in itself is key to unearthing industries' overall adherence to the "safe" organizational model explained by Jeffcott *et al*. (2006). Although, Power (2004) suggests that if industry attempts to address all possible risks, then this effort may hinder intelligent decision-making about hazards. Identifying the balance of a companies' risk management appears to be the most effective result for identifying a safe organization.

Trust in government agencies can be related to the historical nature of agencies, and in many ways, the relationship between industry and government has been historically regulatory (Weyman *et al*., 2006). This belief is perpetuated by public perception. The public generally believes that, without government, industry would impose unreasonable risks on others and the environment. As a consequence of this relationship, evaluating industries beliefs and trust in public involvement is beneficial. Additionally, in the realm of possible regulation, public perception of risks may be more important than actual risks if negative events are encountered (Frewer, 1999). These data will likely advance knowledge in the evolution of industries' level of opposition to government regulation in nanotechnologies.

Trust is dependent upon a variety of factors. Two main components that Frewer (1999) describe are an individual's evaluation of competency and honesty. Poortinga and Pidgeon (2003) describe a similar two factor structure by combining results from Frewer (1999) and Metlay (1996), and argue that trust is derived from factors of general trust and an evaluation of accountability. They define general trust as competence, care, fairness, and openness. Additionally, an entity is likely to distrust a source when they believe there is distortion of the information they are provided, perceive any bias, or remember the organization being proven wrong. Rather, the entity is more likely to trust the source when their personal beliefs clearly align, or the trust may be based on the level of agreement or sympathy the respondent feels towards the organization (Frewer 1999; Poortinga & Pidgeon 2003). One may then conclude that an increase in industries' trust in government and academia would further develop the risk management process and be effective for establishing useful policy about risk management in the EHS, waste management, and product stewardship of nanomaterials.

Within industry, individuals must perceive adequate benefits to a behavior involving risk in order to continue or accept that behavior (Frewer, 1999). Pidgeon *et al*. (2005) created a comparative matrix of perceived benefits and trusts in the British public's perception of genetically modified (GM) foods. These ratings were created by evaluating questions' factor loading and the internal consistency of survey questions, and then averaged questions related to perceived risks and averaged questions related to perceived benefits of GM foods. This modeling approach was an effective tool for revealing that perceptions of high benefits and high risks existed in the public, and that the British public mitigated many of their perceptions of risks by seeing the benefits to GM foods. Pidgeon *et al*. (2005) qualified this belief as being ambivalent rather than being pro- or anti-GM foods. Classifying ambivalence would also hold true for perceiving low benefits and low risks.

Individuals in particular industries may have more established positions on how they manage wastes as well (Poortinga & Pidgeon, 2003). As a consequence, their established beliefs are likely to be more solid than the public's and will likely require innovative and exploratory methods for establishing improved risk communication for waste management between academia, government, and the public. Furthermore, when asked their level of trust in a specific government agency, evidence suggests that respondents may make a general assessment of government and use this as a judgment (Poortinga & Pidgeon, 2003). This wider political judgment has been classified as risk governance. As noted above, established positions in industry and a greater understanding of the regulatory agencies may preclude industry participants from making a general risk governance judgment.

In comparison to practices and beliefs, risk and trust are important variables to measure independently, but also interact themselves. Current models for the interaction of trust and risk propose two possible causal relationships: 1) trust forms perceptions of risk and, 2) risk and trust are a result of a mediating factor, possibly from an individual's level of acceptability of risks. Recent comparative researches by Poortinga & Pidgeon (2005) indicate that the latter relationship is more likely. The specific risk judgments investigated here on nanotechnology are thought to be based on a generalized risk judgment. In public surveys, general risk judgments are strongly influenced by an affect heuristic. An affect heuristic is a predisposition to refer to a similar judgment for certain assessments. Poortinga & Pidgeon (2005) propose that the concept of an affect heuristic may be translatable to trust in risk-regulation. As previously stated, in the case of individuals in industry handling or manufacturing nanomaterials, views of risk and trust may be more specific, relating directly to the product.

9.5 2010 Bren Group Project

Motivated by the tremendous growth of the ENMs industry, the safety of nanotechnologies is garnering significant attention worldwide. Various governmental agencies, industries, and nonprofit groups are in the process of determining the EHS practices that will best protect worker, consumer, and environmental health. Without sufficient information or regulation, ENM industries may act independently to avoid risk, creating inconsistent methods for protecting worker safety and environmental health.

Our research project contributes to knowledge about the environmental risk and risk perception data on nanomaterials by documenting reported current, national and international engineered nanomaterial industry practices in workplace and environmental health, safety, product stewardship, and views on the potential risks of nanomaterials. Industry practices are important factors in studying the environmental release of nanomaterials. Nanomaterial manufacturing practices internal to the manufacturing process could directly affect the environment in two ways. First, nanomaterials manufacturers may dispose of their wastes in improper ways, such as uncontrolled emissions of untreated wastes into the surrounding environment (Krishna *et al*., 2009). Second, even where emissions are relatively controlled, long term chemical manufacturing can result in chronic and cumulative environmental contamination near manufacturing sites (Nadal *et al*., 2007). This suggests that emissions controls can be ineffective. Both waste management systems and emissions controls originate within the manufacturing operation, suggesting that the practices and equipment used in waste management and emissions control can be responsible for environmental contamination near chemical manufacturing sites.

Chemical manufacturing can pose risks to the environment as well as to workers. Chronic and sometimes acute, or catastrophic, cases of worker safety infringements within the chemical manufacturing industry have been discussed generally in health and safety literature, as well as through the public media. Indirectly, practices implemented internal to the firm to protect worker safety and health could predispose a nanomaterial manufacturing company to improve its environmental performance with regards to emissions controls, and waste disposal.

In 2006, a Group Project from the Bren School of Environmental Science and Management, with support from the International Council on Nanotechnology (ICON) at Rice University, conducted the first publicly available, worldwide survey of nanomaterials industries regarding their reported practices in worker safety and product stewardship. The survey resulted in an international webcast, presentation at an international ICON meeting, an ongoing ICON web-presence, and a peer-reviewed publication. The project suggested that industry leaders' perceived risk regarding ENMs may be a strong indicator of their choices in health, safety and environmental stewardship (Conti *et al*., 2007). The project also suggested that industries wished to implement best practices in worker safety and product stewardship, but they were lacking guidance for making informed decisions. In response to the latter finding, ICON developed a best practices Wiki project which launched in June 2009 (Kristin Kulinowski, personal communication, November 13, 2009).

Revisiting the issue of industries' practices three years later, this research sought to determine changes in industries' safe-handling practices of nanomaterials in light of recent toxicological research and publicly available guidance documents. This survey also included questions regarding views on risks and benefits. Participants were asked their personal views on the risk to human health and the environment of specific nanomaterials, and risk and benefit questions including perceptions of worker safety, government regulation, and public involvement. From these data, the primary risk drivers will be established by evaluating risk and benefit perceptions and workplace and product disposal safety practices. Additionally, the project evaluated the interaction of variables, such as risk perception and industry characteristics, which influence industries' adherence to publicly available guidance documents. Conclusions drawn from this study will publically inform industry and government agencies of industries' current practices, the source of guidance for these practices, and the practices that address human health and environmental exposure. Significant contributions will be made to the knowledge of effectively controlling human health and environmental risks of nanomaterials in the workplace by understanding industries' practices and response to risk.

10 Phase II: Survey of Industry

The overall approach of this project was to survey nanomaterial companies globally on their reported practices and views on risk associated with nanomaterials. The survey instrument was revised from a previous study administered by Conti *et al.* (2008). The questionnaire was intended to evaluate consistency of reported practices with guidance documents, evaluate risk perception, and test questions and hypotheses related to sets of dependent and independent variables. The questionnaire was critically evaluated by outside experts.

The sample frame was developed through a systematic identification of nanomaterial companies through review of internet sites, networking, the previous survey and ICON. A database was populated with contact information and refined to eliminate any academic or national laboratories. In accordance with federal regulations a confidentiality protocol, including a consent form (Appendix F), was created and approval for the use of Human Subjects was obtained by the Institutional Review Board at UCSB.

Solicitation of participants began September 2009 and continued until January 2010. A rigorous solicitation protocol was followed. Initial invitation packages, consisting of personalized interview invitations and a survey fact sheet, were sent through US postal mail and e-mail. Follow-up emails, spaced one week apart, were sent repeatedly for at least four weeks. Nonresponsive companies received phone calls and voicemails soliciting participation in a telephone interview. As a last resort, nonresponsive companies received a second round of e-mail invitations, spaced one week apart, which included an option to participate in an online version of the survey. Both telephone interviews and a self-guided, online questionnaire were used to collect data. However, the conversational interviewing technique used during telephone interviews encouraged elaboration of answers that was not obtained through the self-guided, online questionnaire.

After data from telephone interviews and online questionnaires was compiled, all answers to the survey were coded to enable rigorous data analysis. Pearson's chi-square test was used to determine significant relationships between dependent and independent variables. On significant findings, Fischer's exact chi-square test was performed to determine the directionality of relationships between dependent and independent variables. Finally, risk and benefit perception responses on nanotechnology were each averaged to form composite variables when related and internal consistency was verified by Cronbach's alpha.

10.1 The Survey Instrument

The survey instrument was revised from a previous study administered by Conti *et al.* (2008). In revising the survey instrument, new questions were introduced, existing questions were edited, and questions that were redundant were removed. The revisions drew from a variety of sources including the literature review, relevant components from the Conti *et al.* (2008) study, and recommendations from internal and external advisors. Also, questions were edited to be more close-ended than the Conti *et al.* (2008) study. Additionally, a new section was added that covered industry's risk perceptions. The revision process systematically used advisory recommendations through review and discussion periods and included oversight by project advisors and stakeholders.

The questionnaire (Appendix B) included a total of 65 primarily close-ended questions which were written to measure one or more independent or dependent variables. These variables were created in order to guide question creation, and to enable further data analysis following data collection (Appendix C).

The questionnaire was critically evaluated by outside experts for its ability to clearly address the concerns of industry, and to be understood by the target audience. Also, the technical aspects of the questionnaire's treatment of nanotechnology were closely critiqued and evaluated. Various academics with survey design experience were consulted during the creation of the survey instrument to ensure an appropriate questionnaire length and scope. Finally, various individuals who were involved with the Conti *et al.* (2008) study were also consulted when using the Conti *et al.* (2008) survey questionnaire as a framework.

In addition to the topics covered in the Conti *et al.* (2008) study, the questionnaire included a section regarding industry's perception of the risks associated with nanomaterials. These questions addressed personal views regarding factors that could constrain scientific innovation, as well as the potential risks of nanomaterials, and the best methods to limit those risks. These questions on risk were developed in conjunction with the assistance of risk perception experts.

It was anticipated that potential respondents would be concerned with sharing trade secrets or proprietary information associated with the nanomaterials they handled and that confidentiality should be assured. A formal confidentiality protocol was established in order to preempt concerns over confidentiality, as well as satisfy the requirements set forth by the UCSB Institutional Review Board. All academic research involving human subjects must be approved by the university-based Institutional Review Boards that protect respondents and non-respondents from potential negative impacts in connection to academic research. Because participants' responses regarding their industry practices could have had a potential negative impact on their companies or the individual respondent, the research design adopted a confidentiality protocol to protect the identity of participants. All confidentiality concerns were addressed in pre-survey documents. Respondents were offered the option to be assigned a pseudonym for reference purposes. All survey data was kept on secure severs within at UCSB. Finally, respondents were guaranteed that only aggregated results would be published in the final report.

Traditionally, the primary modes for implementing industry surveys are mail, web, and telephone. A 45-minute telephone survey was selected as the primary mode of implementation due to the increased richness in answers. The last step in developing the questionnaire involved practicing with the instrument and developing personal interviewing techniques. The survey process was tested on a wide variety of audiences, and mock telephone surveys were conducted and critiques were provided.

10.2 The Sample Frame

International contacts for the survey were gathered from a variety of sources including databases compiled by other academic researchers, internet searches, industrial databases, industry participants, and industry interest groups. The sample included company databases compiled by other academic researchers and web databases such as A-to-Z Nano, VDI Nanomap, and Nanowerk, and Lux Research's 2006 and 2007 Lux Reports. Similarly, "Nanotechnology & MEMS Industry Almanac 2008," by Plunkett Research Ltd., was consulted to find additional nanotechnology companies. Additional contacts and information was acquired directly through personal networking at nanotechnology related industry events. Other sources of contact information were acquired through individuals or industry groups that volunteered to help the team solicit the survey in Japan and Singapore. In the survey, industry participants were asked to recommend other companies they thought would be qualified to participate. The intent of this question was to obtain participant information directly from industry respondents. The selection of the 500 participants was based on their participation in a previous industry survey, references from other contacts, and the completeness of their contact information. The sample frame omitted all government, academic, or otherwise public research and production facilities and focused exclusively on private nanomaterial handling companies.

10.3 Solicitation Protocol

After the survey design was completed and internally tested and practiced, the survey was solicited to companies in the sample frame. Solicitation of participants began September 2009 and continued until January 2010. These potential participants were mailed an invitation package containing a personalized formal interview invitation (Appendix D) and a survey fact sheet (Appendix E). Within approximately one to three weeks after the initial mailing, a follow-up email was sent containing another copy of the personal invitation and background information regarding the study. A minimum of three follow-up emails were sent within the six weeks of initial contact. Companies that did not respond to emails received phone calls soliciting participation. Phone messages were left whenever potential respondents could not be reached. In the final stage of solicitation, potential respondents were again emailed an invitation to participate in the self-guided online version of the survey instead of the phone interview. These final invitations were repeatedly sent twice a week for two weeks.

Other industry surveys achieved response rates ranging from 10% to 43% (Balas, 2010; Blando, 2007). The response rate goal for this survey was 20% from 500 invited participants for a total sample size of 100. The selection of potential participants from North America, Europe, and Asia was based a both a goal to oversample North America and these regions' relative investment in nanotechnology (Lux Research Inc., 2007). Therefore, the survey population was designed to over sample North American responses and 57.5% of invitations were sent to firms in North America, 31% to Asian companies and 19% to European companies. However, due to lack of Asian companies in the database, only 15.1% of invited participants were from Asia. As a result, Europe made up 23.4% of the sample. Additionally, 2.4% of the sample population was from countries outside these continents.

10.4 Data Collection Method

Each potential survey respondent was assigned an anonymous 4 digit identification number. The collected data and the contact database were stored on secured servers. Additionally, email solicitation responses were stored on a single secure email client.

Upon agreeing to participate in the survey, a respondent was emailed a consent form to read and sign. The consent form included the confidentiality agreement (Appendix F), as well as an option to be assigned a pseudonym for data storage. An online consent form for phone interviews was also used. Another version of the consent form was included electronically at the beginning of the online version of the survey. After agreeing to participate and completing the consent form, the respondent participated in a telephone survey. In order to accurately capture responses, the phone conference service ReadyTalk was used to conduct and record interviews. The recording of the phone call was initiated once consent was confirmed. If the respondent did not agree to be recorded, the phone interview proceeded without being recorded.

Survey Monkey, an online survey service, was used for online survey implementation, data collection, and organization of phone interviews. The recorded respondent’s answers were inputted into Survey Monkey for archival purposes following the 45 minute telephone interview. Online survey respondents entered their responses into the Survey Monkey interface directly. Responses stored on Survey Monkey were exported into Microsoft Excel and then to SPSS.

10.5 Data Analysis Method

Data were coded with responses to unstructured or semi-structured questions grouped into categories based on dominant themes (Appendix G). For questions with scaled responses, answers were grouped into two categories. For questions regarding impediments and risk, or trust, responses were divided into “agree or disagree” and “less trust or more trust”, respectively. “Don’t know” responses were removed before analysis. The frequency response data for each individual question of the survey was reviewed and analyzed. Variables were chosen from set of previously formulated hypotheses (Appendix C). Response categories were treated as either independent or dependent variables so relationships between responses and associated significances could be determined. Hypotheses were initially tested using Pearson’s chi-square testing. For findings of significance, a Fisher’s exact chi-square tests were performed. Due to the small number of respondents, answer categories were collapsed into binary variables. Risk and benefit perception responses on nanotechnology were averaged to form composite variables and internal consistency was verified by Cronbach’s alpha. Pearson’s was performed in Microsoft Excel and Fisher’s exact and Cronbach’s alpha were performed in SPSS 12.0.1 (SPSS Inc.).

10.6 Risk and Trust Analysis Method

A combined approach of using quantitative and qualitative questioning is most effective for a greater understanding of risk in uncertain and emerging industries (Weyman *et al*. 2006). Direct ranking elicits less bias and personal opinion, so using both approaches pair well together. Additionally, ordinal ranking is beneficial for small sets of entities (Thurstone 1959). Also, it is important to look at both international and national differences of perceptions of risk and trust. For example, in a recent study by Poortinga & Pidgeon (2003), differences in responses of trust may exist between British and American samples (Frewer 1999).

This project measures a unique perspective of trust by asking a particular entity—in this case, industry—rather than asking the general public their level of trust as other studies have done (Poortinga & Pidgeon 2003). Specifically, industry was asked their level of trust in government to protect against risks of nanotechnology and their level of trust in industry, government, and academia to convey the benefits of nanotechnology.

11 Results

Twenty-six respondents participated in telephone interviews and 34 respondents participated through the online version of the survey.

11.1 Sample Characteristics

A total of 487 potential participant companies were identified and invited. After the initial invitations to participate were mailed, the research team learned that eight of these companies no longer existed and thirty of these companies reported that they did not work with nanomaterials. These thirty-eight companies were removed from the sample for a new sample size of 449. Of the 449 companies contacted, sixty companies completed the survey for an overall response rate of 13.4% (Table 1). Companies from North America exhibited the highest response rate of 17%, while European companies followed with 10.5%. The overall response rate of Asia was 8.8%. However, the only respondents from Asia were from Japan and China. No companies outside these regions completed the survey.

Table 1. Response rates by continent and country.

Continent (number contacted)	Response Rate	Country	Companies interviewed
North America (257)	***17%***	**United States**	**43**
		Canada	**1**
Europe (105)	***10.5%***	**Germany**	**3**
		Italy	**2**
		United Kingdom	**2**
		Finland	**2**
		Denmark	**1**
		Belgium	**1**
Asia (68)	***7.4%***	**Japan**	**4**
		China	**1**

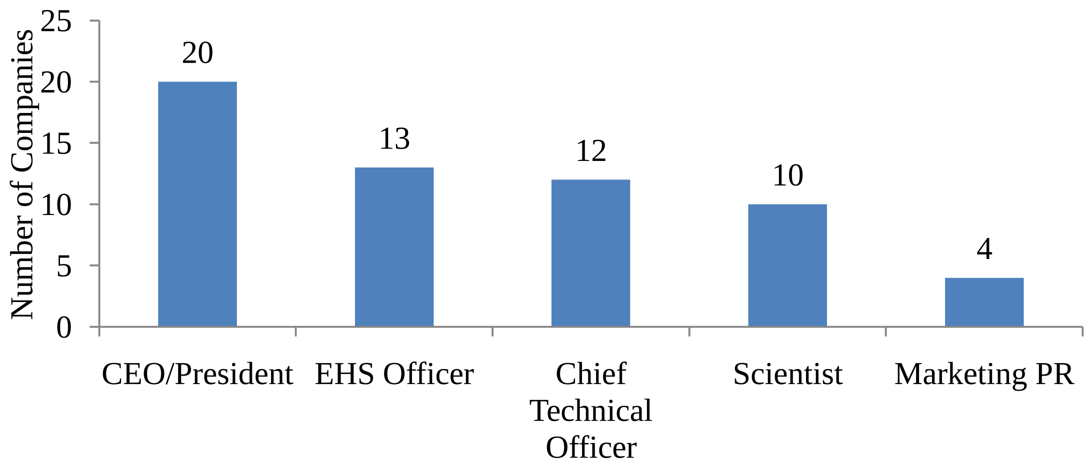


Figure 1. Distribution of job titles as a function of the number of respondents (n=59).

Most respondents were CEOs or Presidents (34%) (Figure 1). EHS Officers represented 22% of respondents, Chief Technical Officers (CTOs) represented 20%, Scientists represented 17%, and 7% of the sample engaged in marketing and public relations (PR). The average length of time a respondent had been in their position was 7.2 years (n=60). Overall, respondents reported a range of 0.25 to 45 years. The median tenure was five years, and the mode was three years. The average length of employment of respondents who reported working as CEO/President, EHS officer, and CTO was 6 years. The average length of employment of respondents who reported working as scientists was 9 years. Respondents that work in marketing or PR reported on average 2.5 years of employment in this position.

11.2 Company Information

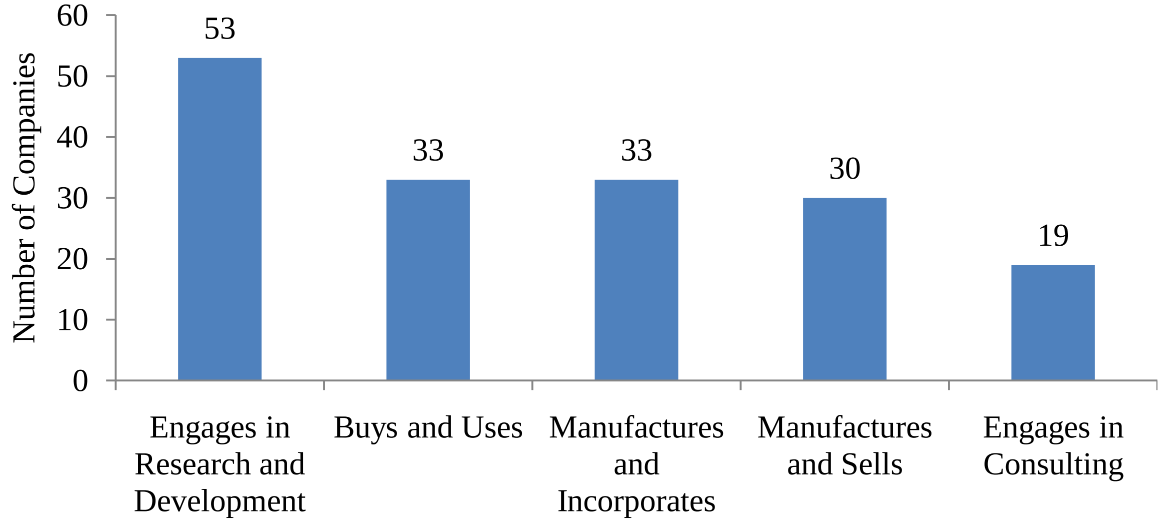


Figure 2. Types of activities companies engage in with regards to nanomaterials (n=60).

When participants were asked the types of activities their company engages in with regards to nanomaterials, they could select multiple categories. Most companies (88%) engaged in research and development (Figure 2). Companies that buy and use (55%), or manufactured and incorporate (55%) nanomaterials also comprise a large portion of the sample. Similarly, 50% of respondents represented companies that manufacture and sell nanomaterials. Finally, 32% of companies engage in consulting.

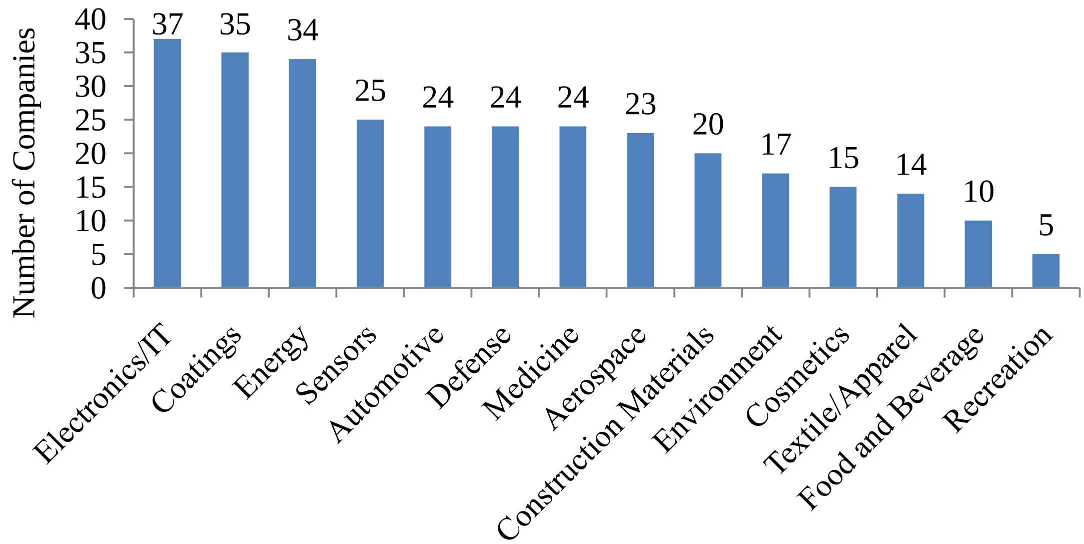


Figure 3. Company nanomaterial applications (n=60).

When participants were asked the sectors in which their company's nanomaterials activities are oriented, they could select multiple sectors. Most companies (62%) engaged in the development of electronics and information technology (Figure 3). A similar number of companies were involved in coatings (58%) and energy sectors (57%). Approximately 40% of companies were involved in automotive, defense, medicine, aerospace, and sensors. The construction materials sector included 33% of respondents. About a quarter of the companies were involved in the sectors of the environment (28%) and cosmetics (25%). Less than 25% of companies were involved in sectors of textile and apparel, food and beverage, and recreation.

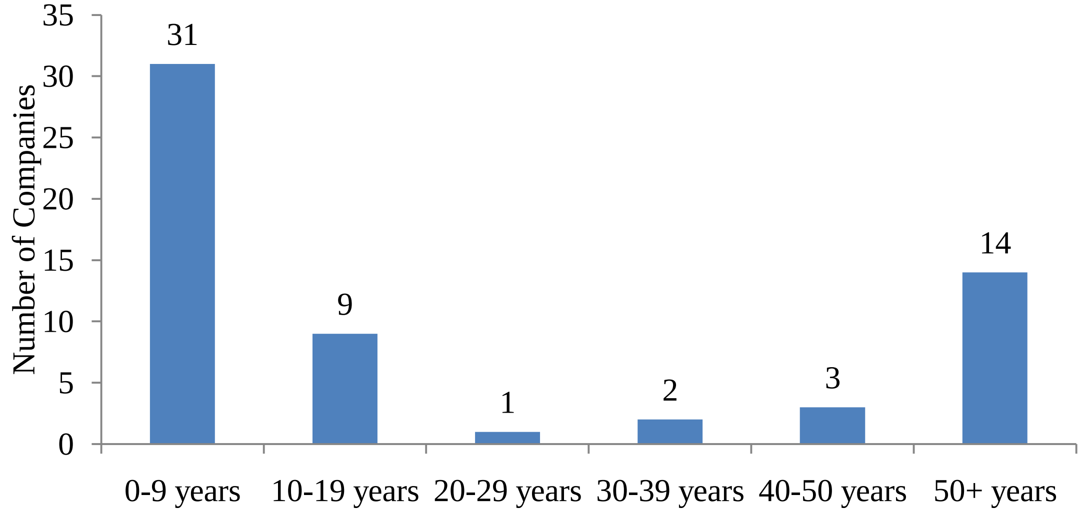


Figure 4. Distribution of companies by age (n=60).

Most companies (52%) were formed within the last ten years (Figure 4). The average age of a company was approximately 34 years, with a median of 9 years and a mode of 6 years. The least represented categories were companies formed between 20-50 years ago (10%). Almost a quarter of the sample was companies formed greater than 50 years ago (23%).

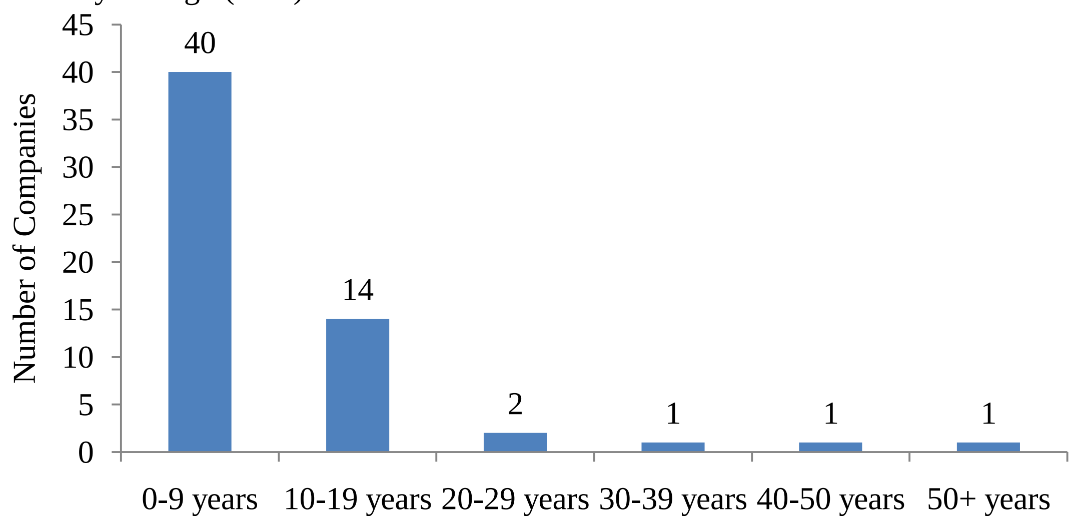


Figure 5. Number of years handling nanomaterials (n=59).

The average time a company reported handling nanomaterials was approximately 10 years, with a median of 6 years and a mode of 5 years. The majority of companies (68%) began handling nanomaterials within the last ten years (Figure 5). Only five of the companies (8%) handled nanomaterials for more than twenty years.

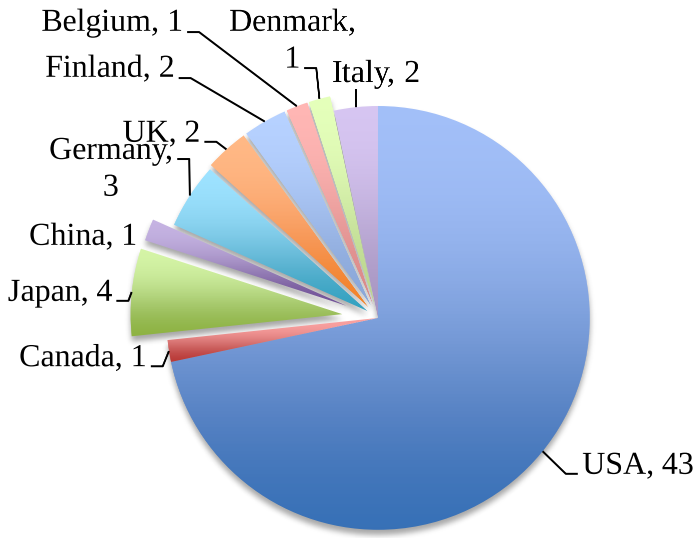


Figure 6. Geographical distribution of headquarters (n=60).

The majority of companies (72%) were from North America, with 43 from the United States and 1 from Canada (Figure 6). Of the remainder, 7% were from Japan and 18% of respondents were from countries in Europe including Germany, the UK, Finland, Belgium, Denmark, and Italy.

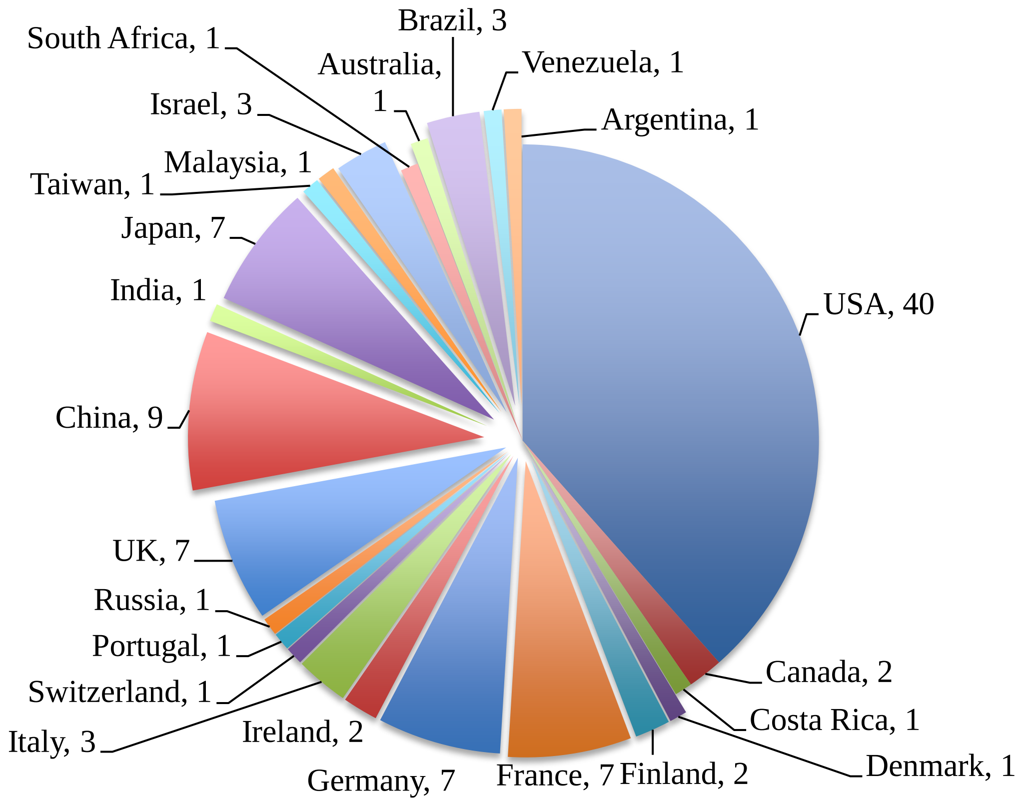


Figure 7. Geographical distribution of countries in which nanomaterials are handled (n=60).

Companies had the option of reporting multiple countries in which nanomaterials were handled (Figure 7). Respondents reported using and/or manufacturing nanomaterials in North America, Europe, Asia, Australia, South America, and Africa. Most companies (41%) used and/or manufactured nanomaterials in North America, with 38% in the United States and 2% in Canada and Costa Rica. Approximately 31% used and/or manufactured in Europe, and 5% in South America. Less than 1% of companies used and/or manufactured nanomaterials in Africa and Australia.

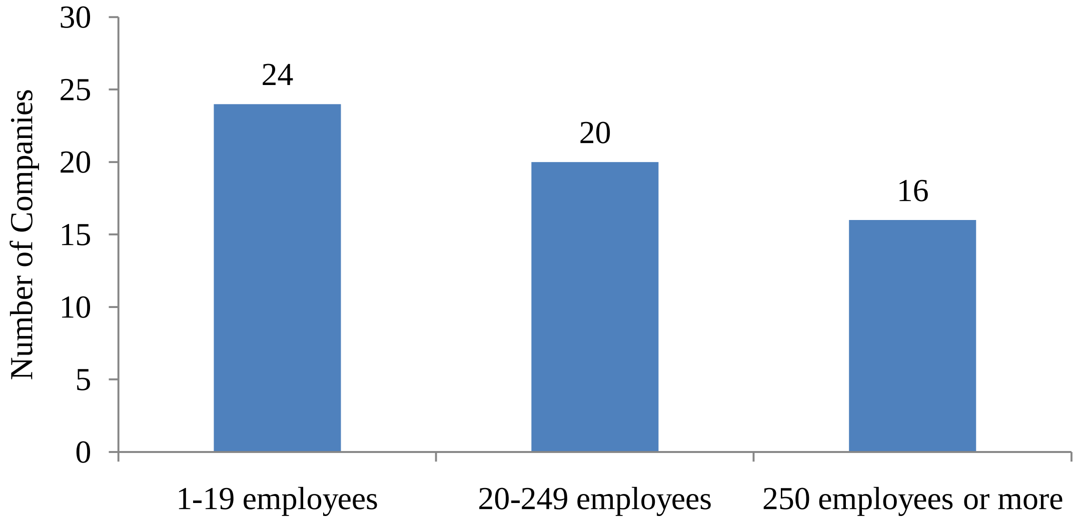


Figure 8. Number of employees in company (n=60).

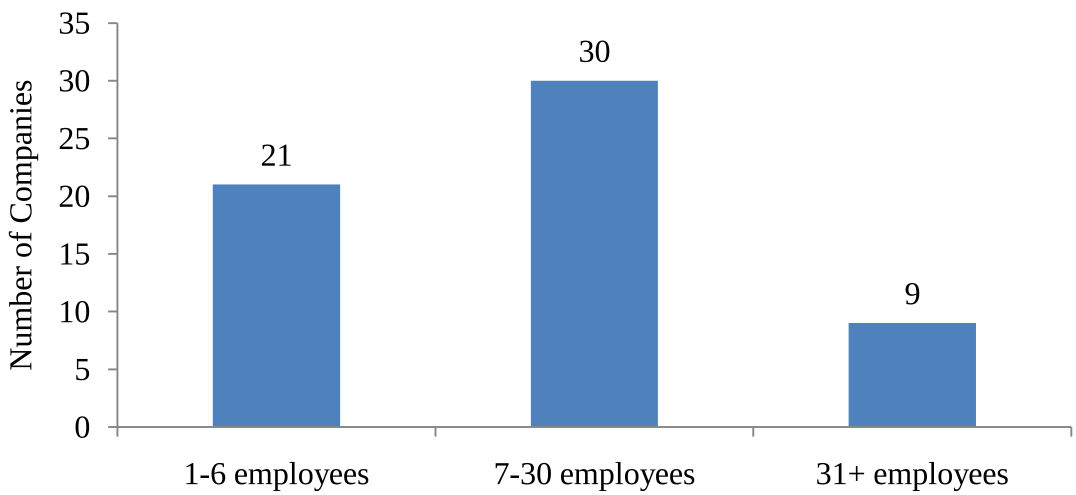


Figure 9. Number of employees that work directly with nanomaterials (n=60).

Reported company sizes were grouped into evenly distributed categories of start-up (1-19 employees), small (20-249 employees), or medium-large (250+ employees) (Figure 8). Most companies (40%) have 1-19 employees, with 33% having 20-249 and 27% having 250 or more employees. The average number of employees in each company is approximately 14,357 individuals, with a median of 24 individuals, and a mode of 3 individuals.

The reported numbers of employees working directly with nanomaterials were grouped into evenly distributed categories of operation type: start-up with regard to nanotech (1-6 employees), small operation (7-30 employees), and large operation (more than 30 employees) (Figure 9). Most companies (50%) have 7-30 employees that work directly with nanomaterials. A smaller percentage (35%) of companies has

1-6 employees and 15% have 31 or more employees that work directly with nanomaterials. The average number of employees that work directly with nanomaterials in each company was approximately 45 individuals, with a median of 11 individuals, and a mode of 10 individuals.

11.3 Nanoparticle-Specific Information

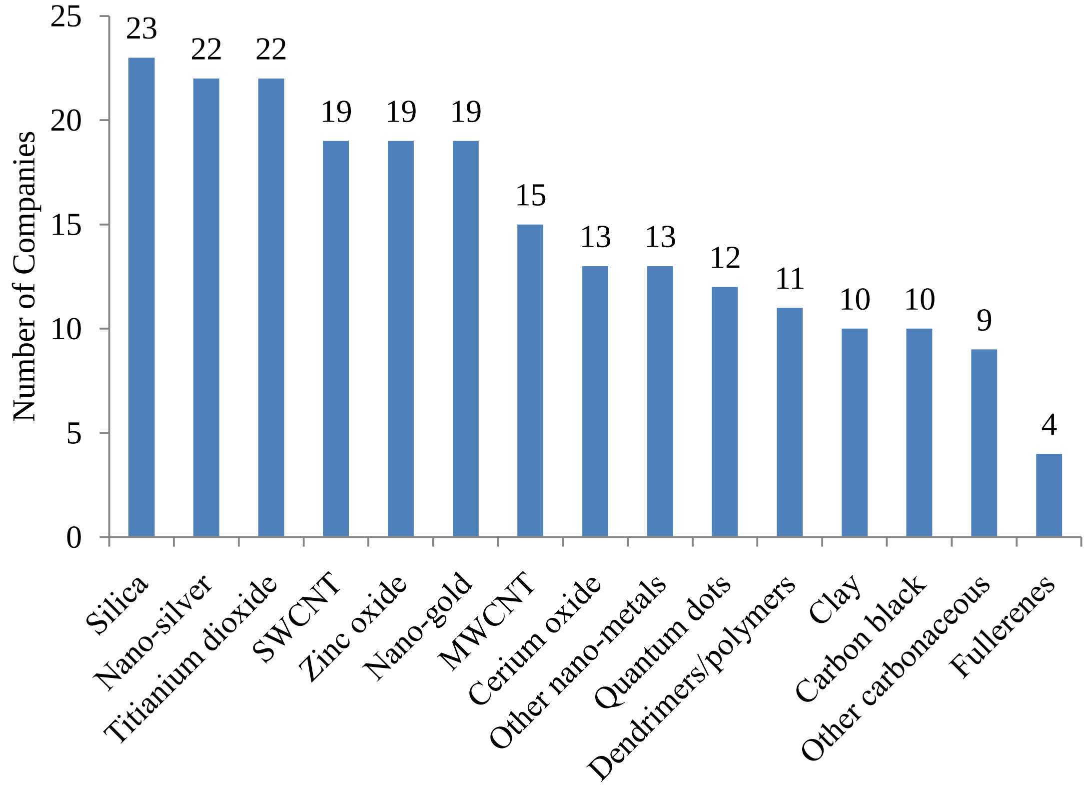


Figure 10. Types of nanomaterials handled (n=60).

Participants indicated handling as many nanomaterial types as applied to their company. The variety of responses is well distributed across the number of nanoparticle types described (Figure 10). Most respondents reported handling silica (38%), nano-silver (37%), and titanium dioxide (37%). SWCNTs, zinc oxide, and nano-gold, are each handled by 32% of companies. MWCNT were worked with by 25% of companies, and cerium oxide and other nano-metals were worked with by 22% of companies. Quantum dots were handled by 20% of companies. Additionally, dendrimers/polymers, clay, carbon black, and other carbonaceous materials were handled by 15-18% of companies. The smallest percent of companies handled fullerenes (7%). Some participants indicated handling nanoparticles in general. These seven responses included composite nanoparticles, all the above, all nanomaterials, and that they work with so many nanomaterials that they were generally lumped into one category. Participants also specified nanoparticle-specific information such as: size of nanoparticle, form of nanoparticle, whether or not the nanoparticle agglomerated, to what size the nanoparticle agglomerated, and scale of nanoparticle production (Figures 11-26).

11.3.1 Single-walled carbon nanotubes

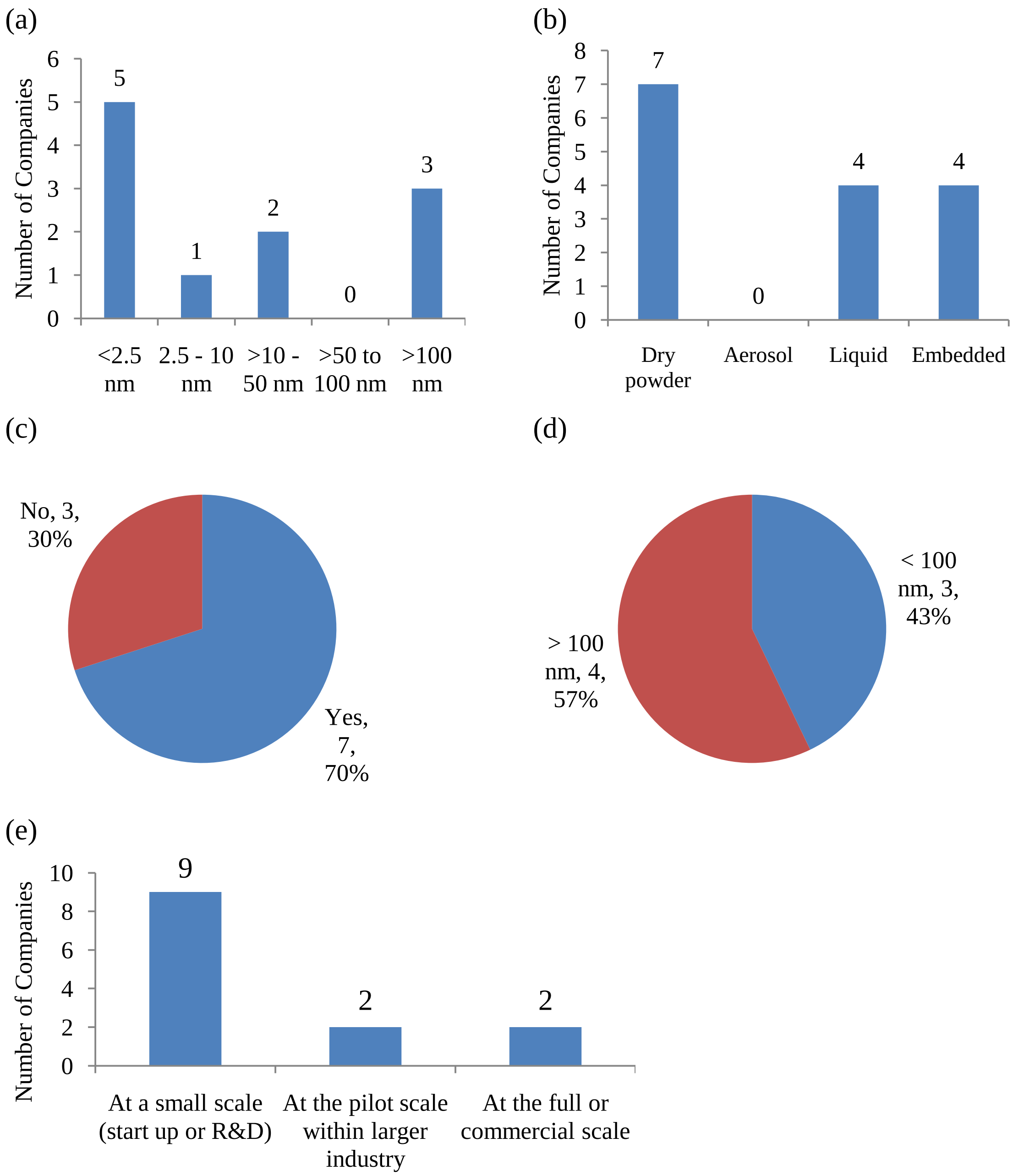
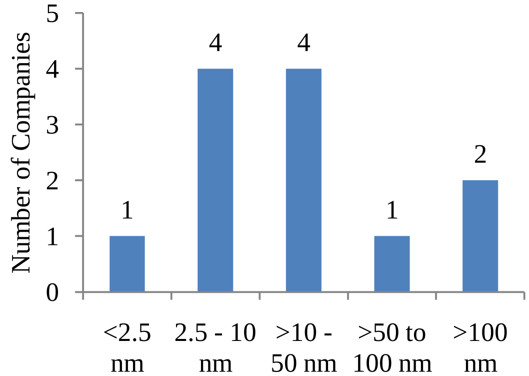


Figure 11. Single-walled carbon nanotubes: (a) size of nanoparticle, (b) form of nanoparticles handled, (c) number of companies whose nanoparticles agglomerate, (d) to what size the nanoparticles agglomerate, and (e) scale of nanoparticle production.

11.3.2 Multi-walled carbon nanotubes

(a)



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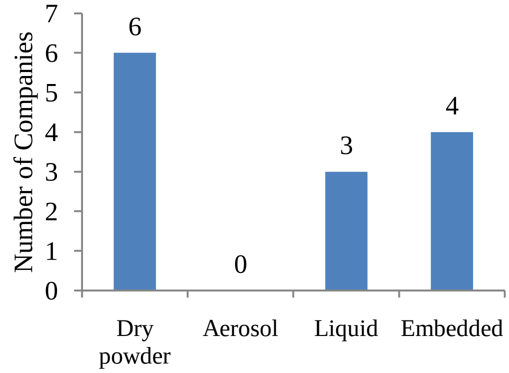

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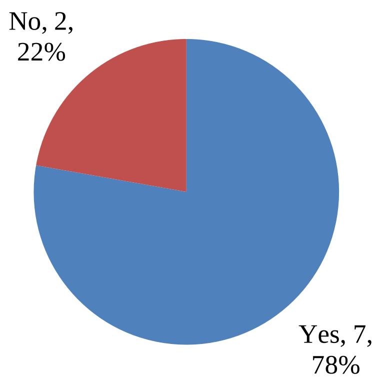

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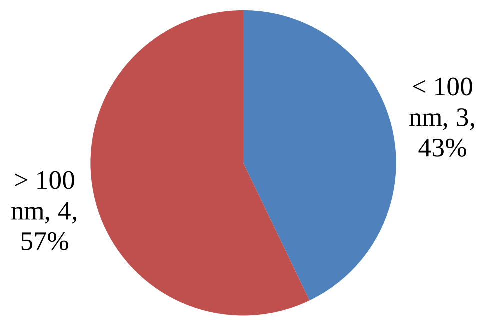


(e)

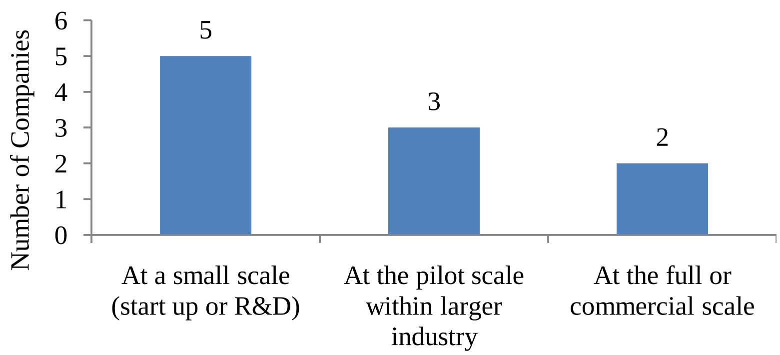


Figure 12. Multi-walled carbon nanotubes: (a) size of nanoparticle, (b) form of nanoparticles handled, (c) number of companies whose nanoparticles agglomerate, (d) to what size the nanoparticles agglomerate, and (e) scale of nanoparticle production.

11.3.3 Carbon black

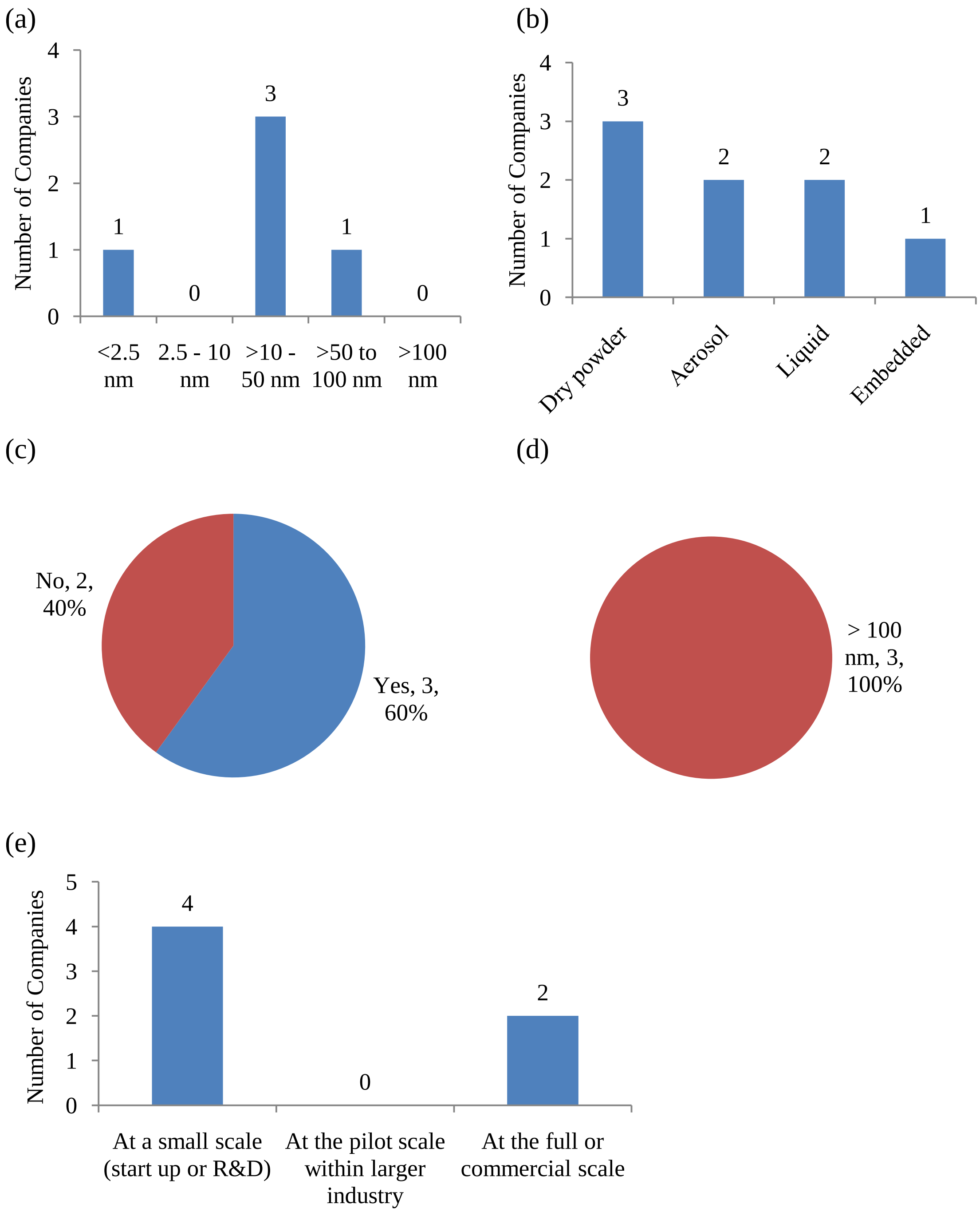


Figure 13. Carbon black: (a) size of nanoparticle, (b) form of nanoparticles handled, (c) number of companies whose nanoparticles agglomerate, (d) to what size the nanoparticles agglomerate, and (e) scale of nanoparticle production.

11.3.4 Fullerenes

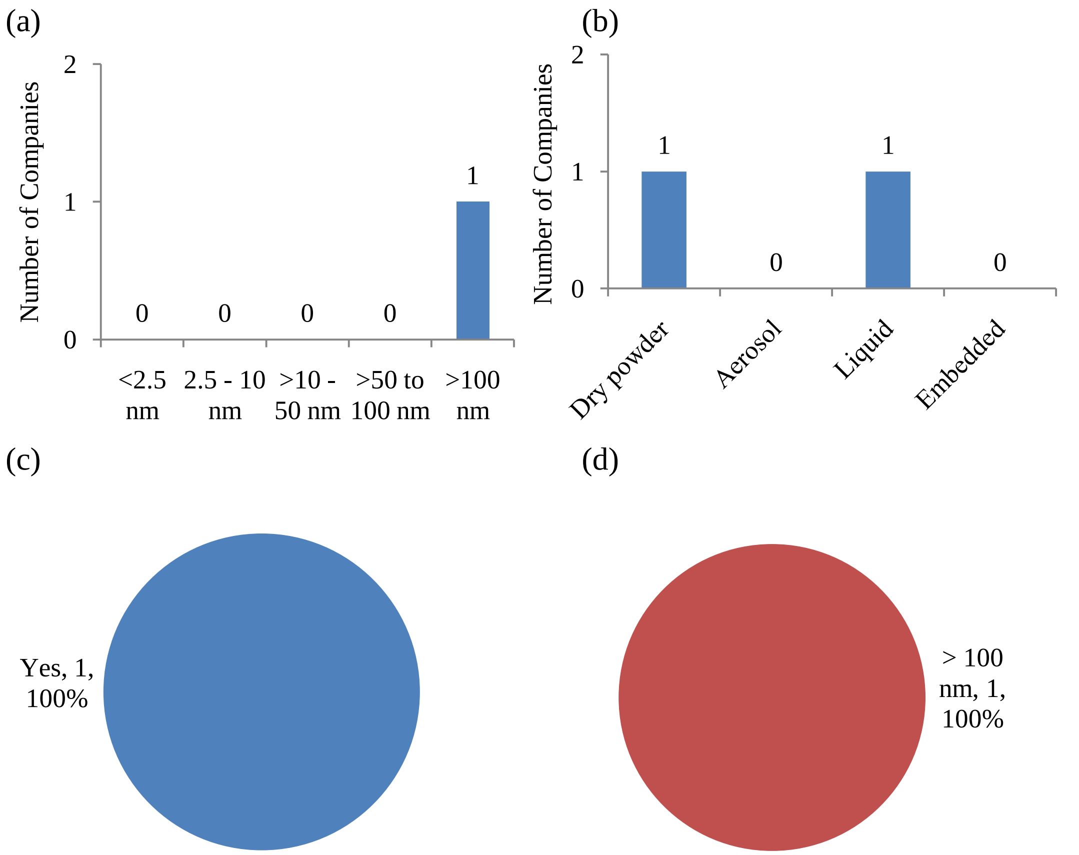


Figure 14. Fullerenes: (a) size of nanoparticle, (b) form of nanoparticles handled, (c) number of companies whose nanoparticles agglomerate, (d) to what size the nanoparticles agglomerate. The one company that reported handling fullerenes did not report (e) the scale of nanoparticle production.

11.3.5 Nano-silver

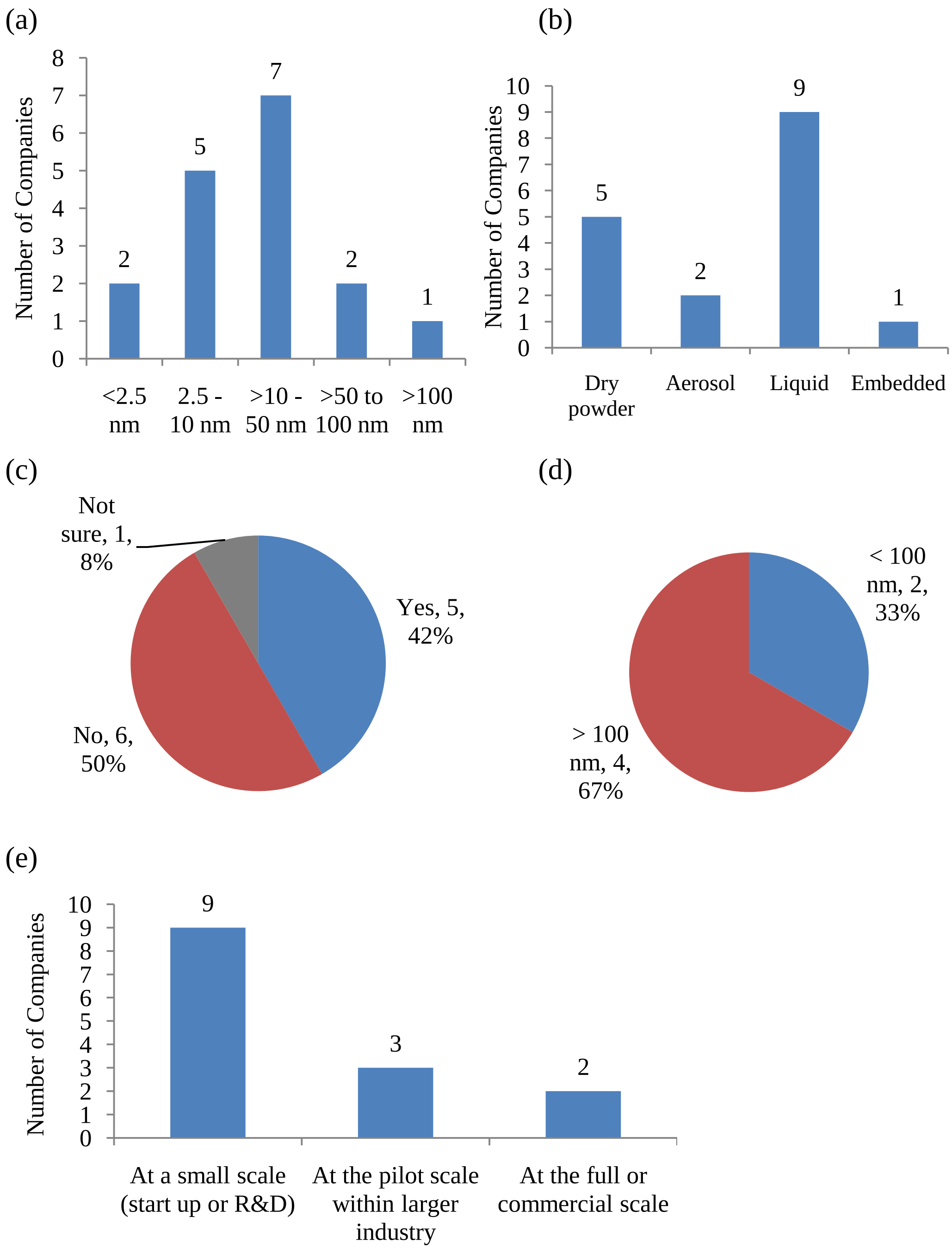


Figure 15. Nano-silver: (a) size of nanoparticle, (b) form of nanoparticles handled, (c) number of companies whose nanoparticles agglomerate, (d) to what size the nanoparticles agglomerate, and (e) scale of nanoparticle production.

11.3.6 Nano-gold

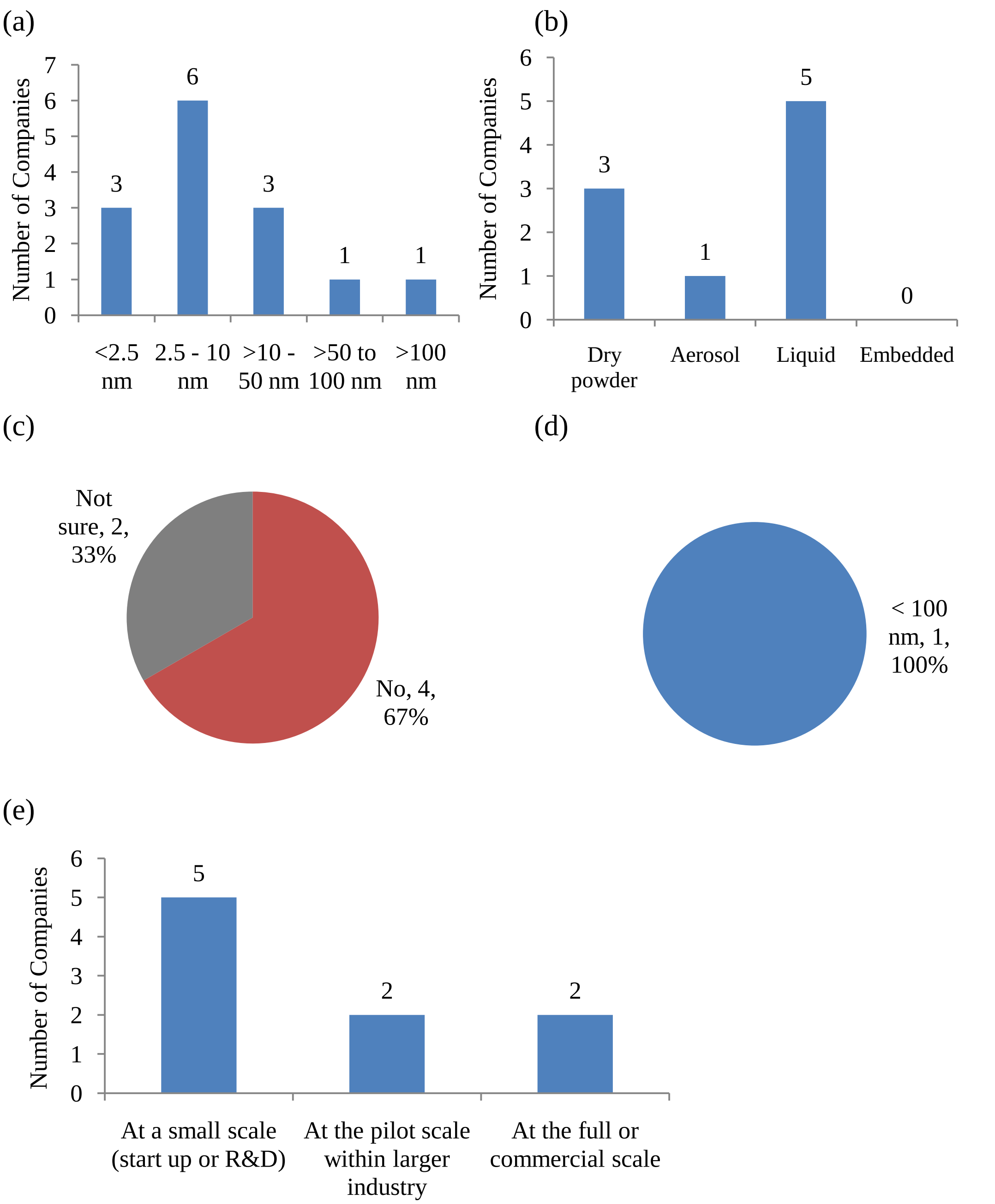


Figure 16. Nano-gold: (a) size of nanoparticle, (b) form of nanoparticles handled, (c) number of companies whose nanoparticles agglomerate, (d) to what size the nanoparticles agglomerate, and (e) scale of nanoparticle production.

11.3.7 Titanium dioxide

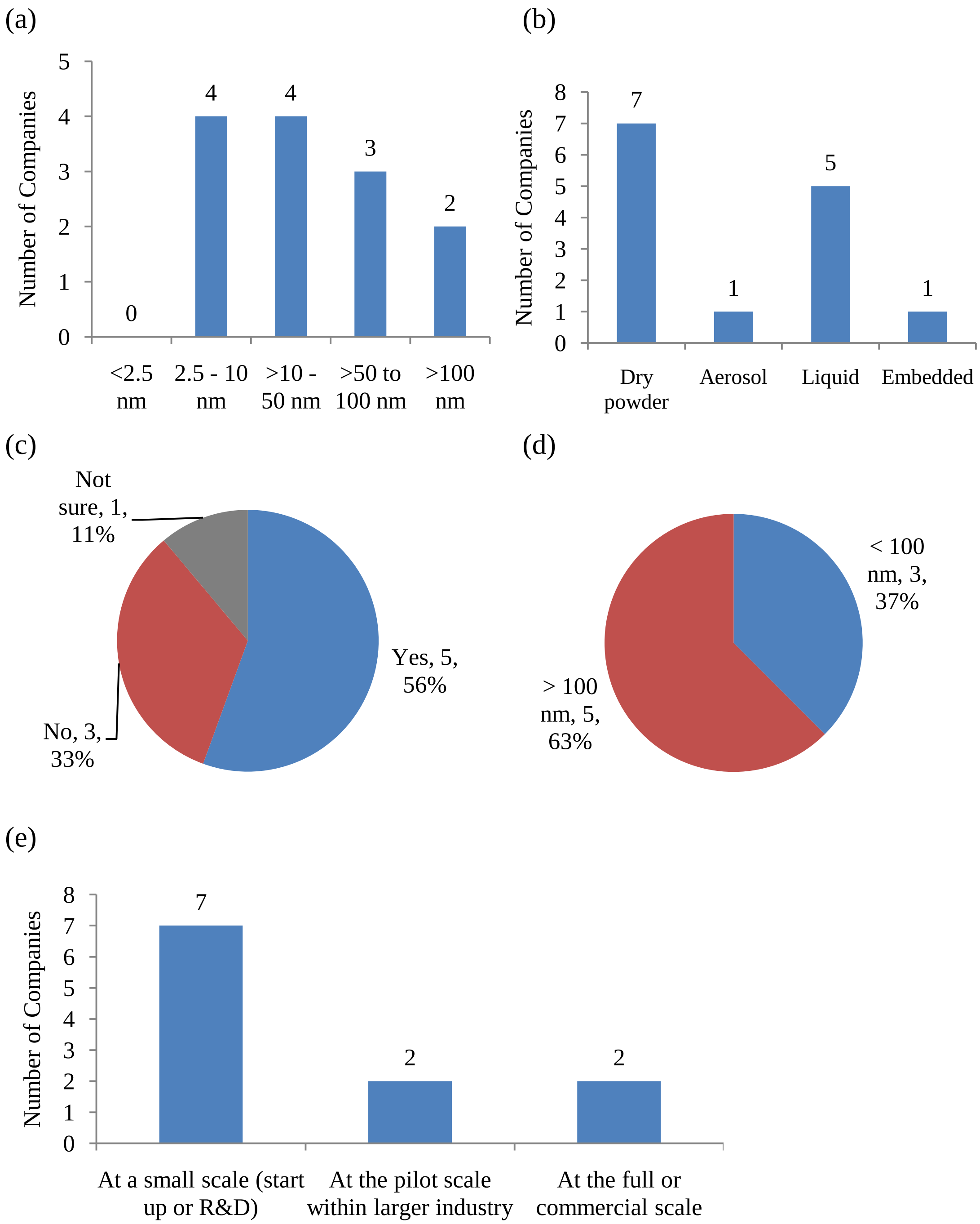


Figure 17. Titanium dioxide: (a) size of nanoparticle, (b) form of nanoparticles handled, (c) number of companies whose nanoparticles agglomerate, (d) to what size the nanoparticles agglomerate, and (e) scale of nanoparticle production.

11.3.8 Zinc oxide

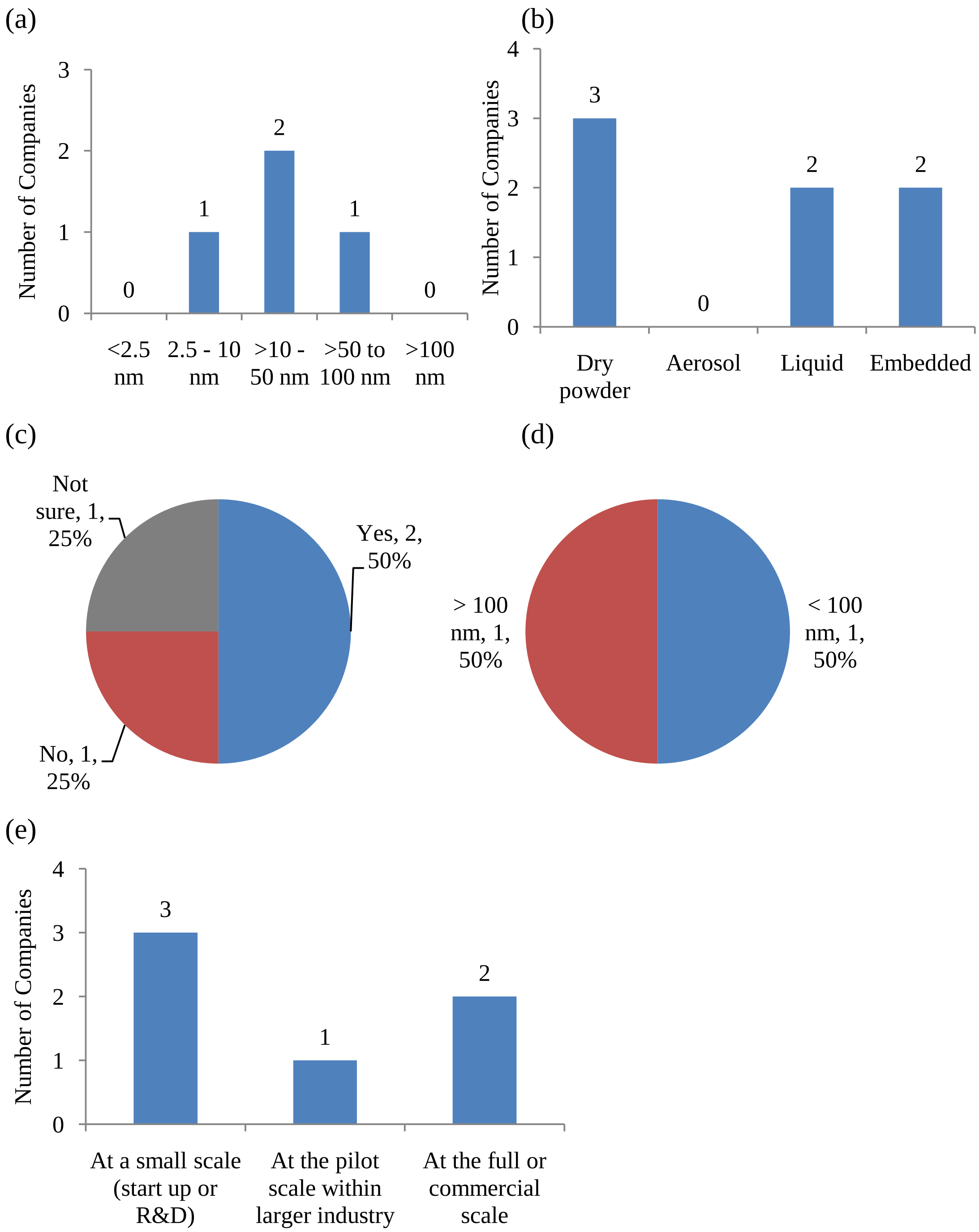


Figure 18. Zinc oxide: (a) size of nanoparticle, (b) form of nanoparticles handled, (c) number of companies whose nanoparticles agglomerate, (d) to what size the nanoparticles agglomerate, and (e) scale of nanoparticle production.

11.3.9 Cerium oxide

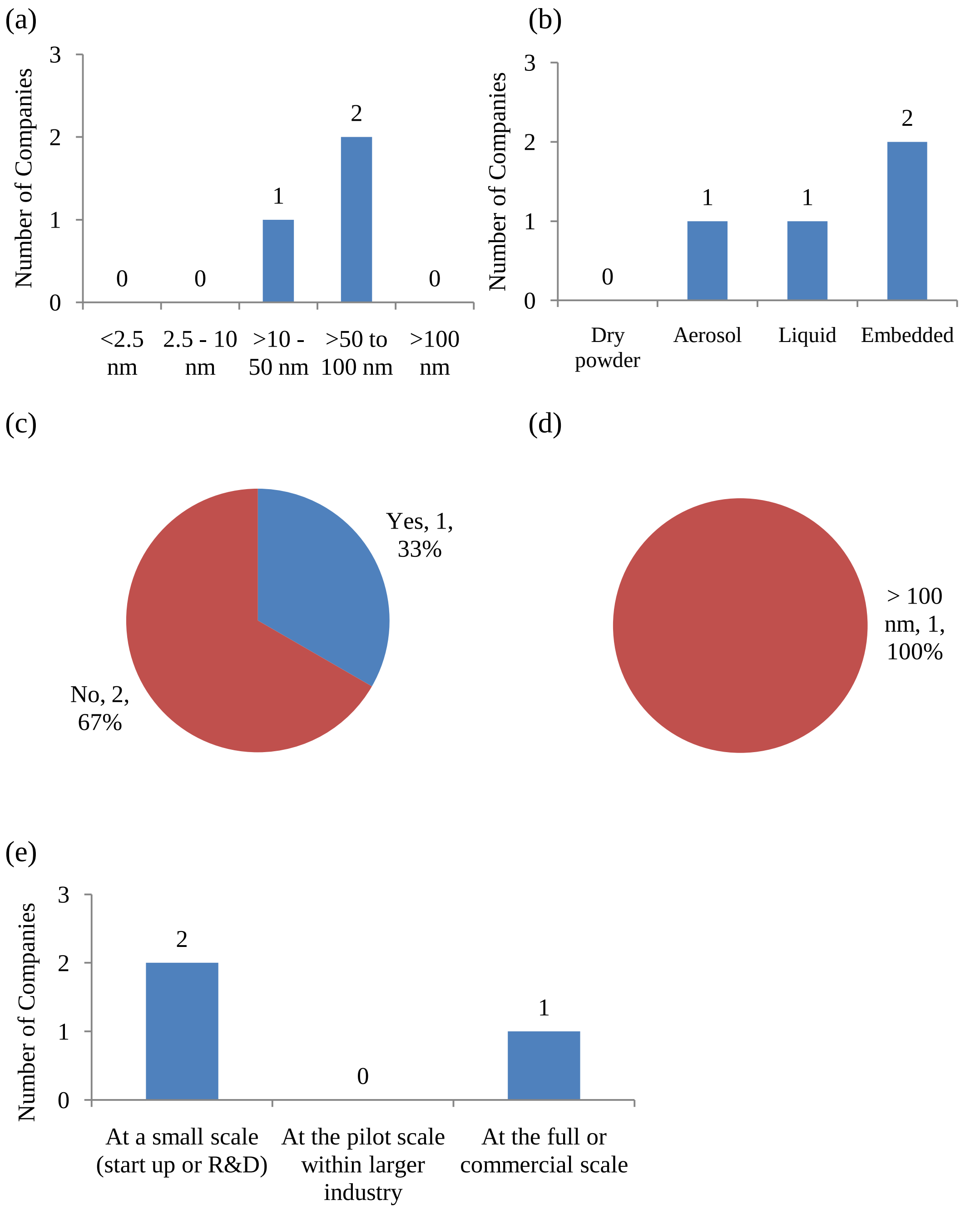
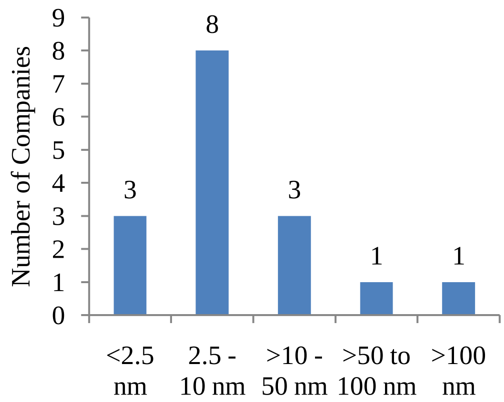


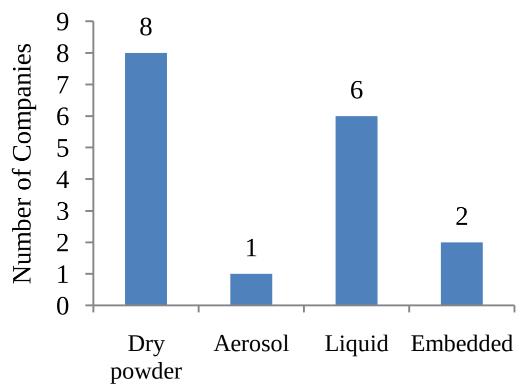
Figure 19. Cerium oxide: (a) size of nanoparticle, (b) form of nanoparticles handled, (c) number of companies whose nanoparticles agglomerate, (d) to what size the nanoparticles agglomerate, and (e) scale of nanoparticle production.

11.3.10 Silica

(a)



(b)



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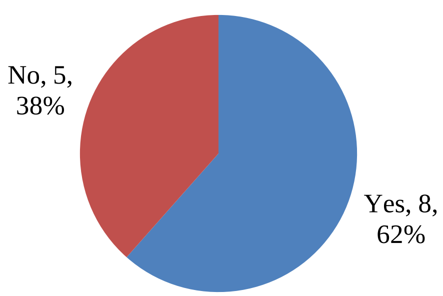

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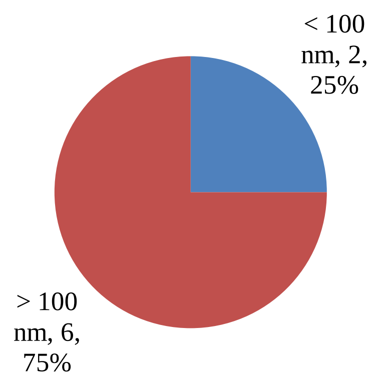

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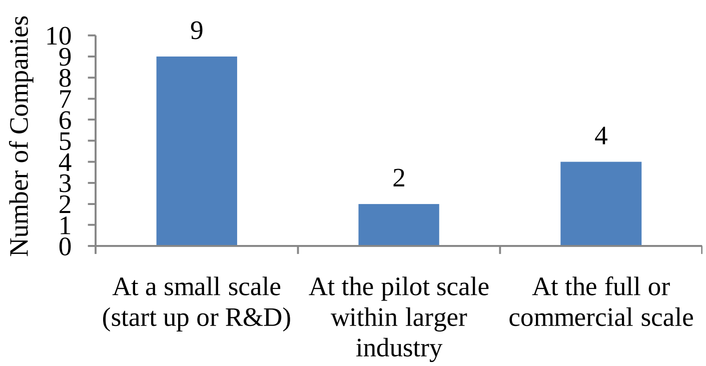

Figure 20. Silica: (a) size of nanoparticle, (b) form of nanoparticles handled, (c) number of companies whose nanoparticles agglomerate, (d) to what size the nanoparticles agglomerate, and (e) scale of nanoparticle production.

11.3.11 Clay

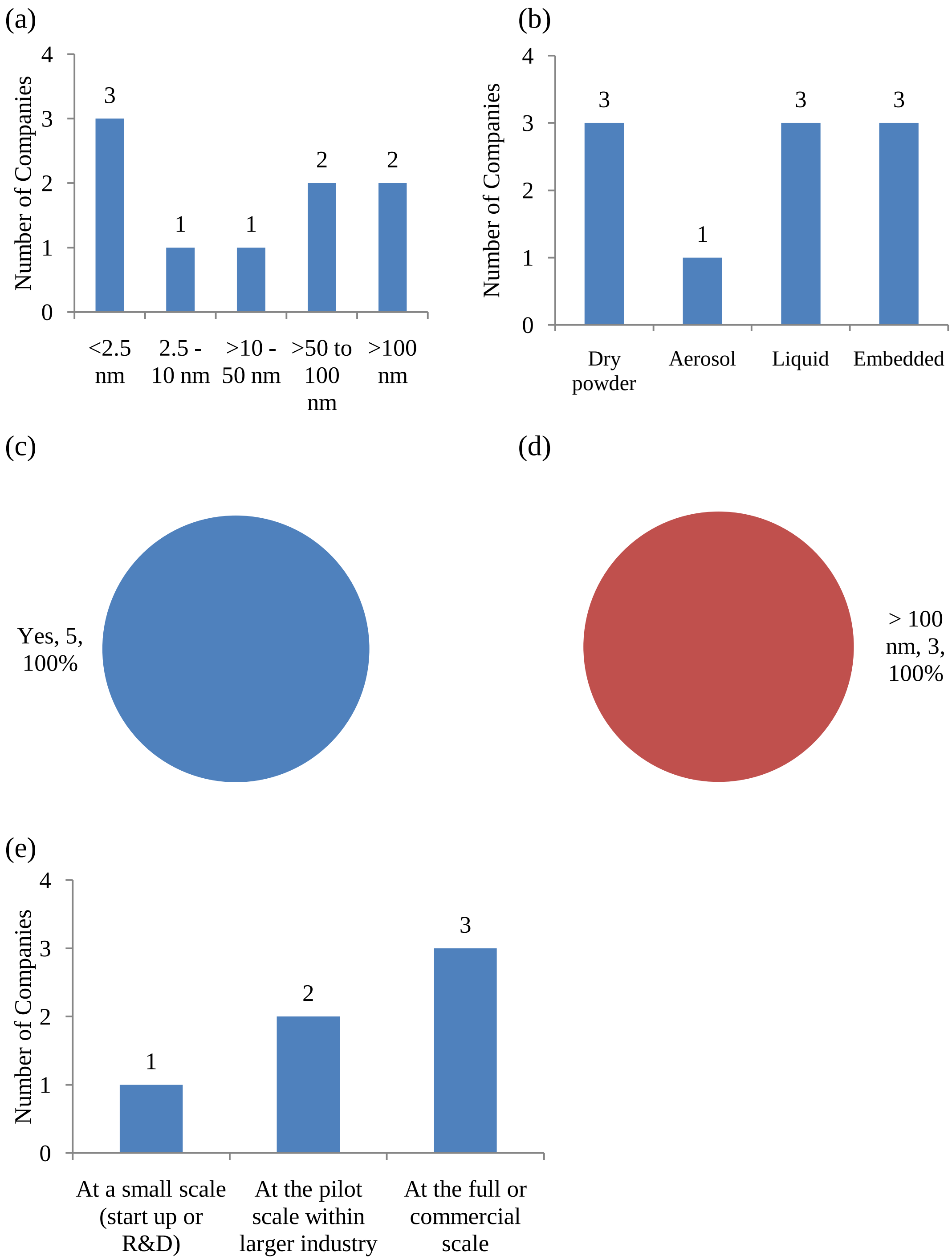

Figure 21. Clay: (a) size of nanoparticle, (b) form of nanoparticles handled, (c) number of companies whose nanoparticles agglomerate, (d) to what size the nanoparticles agglomerate, and (e) scale of nanoparticle production.

11.3.12 Quantum dots

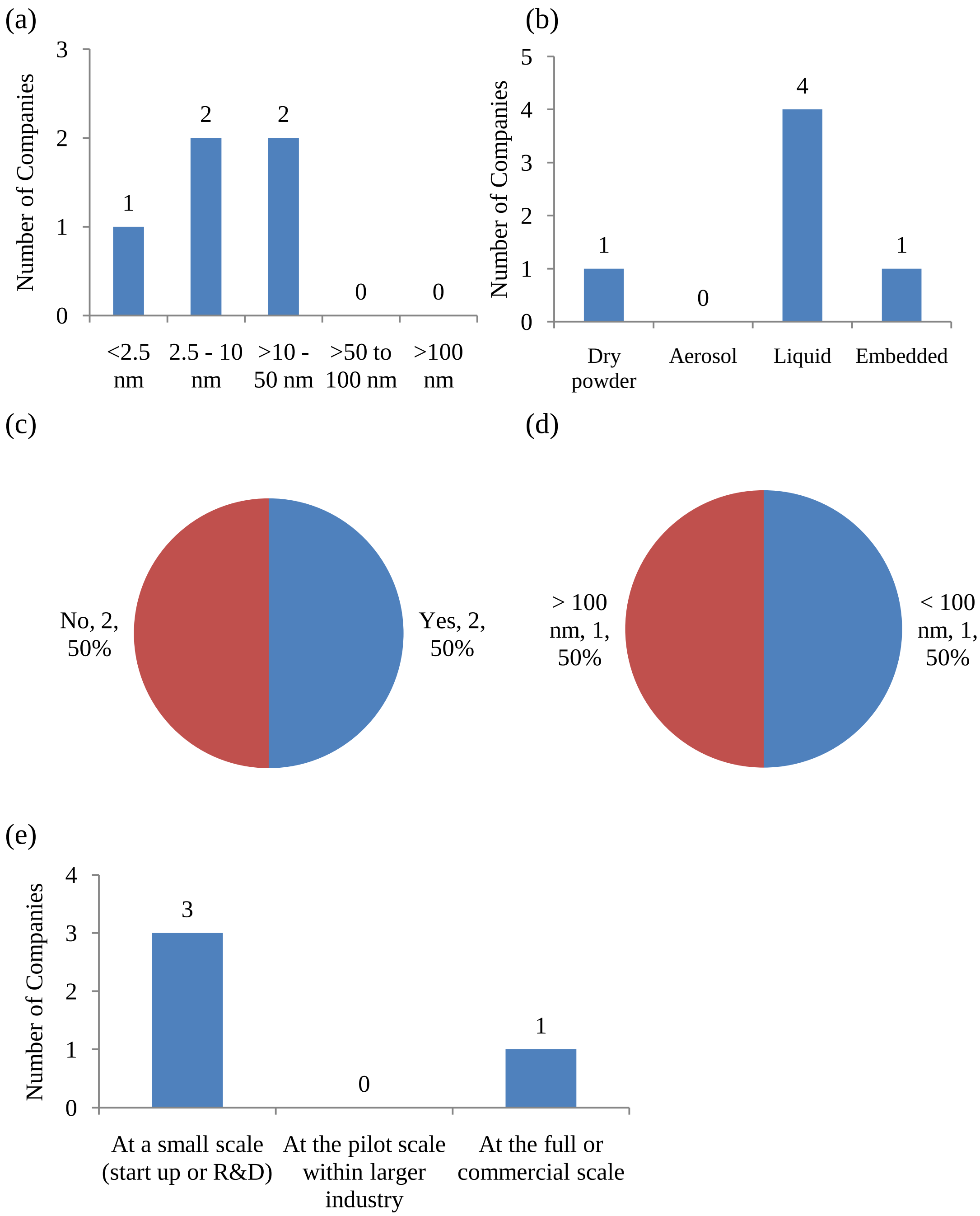

Figure 22. Quantum dots: (a) size of nanoparticle, (b) form of nanoparticles handled, (c) number of companies whose nanoparticles agglomerate, (d) to what size the nanoparticles agglomerate, and (e) scale of nanoparticle production.

11.3.13 Dendrimers / polymers

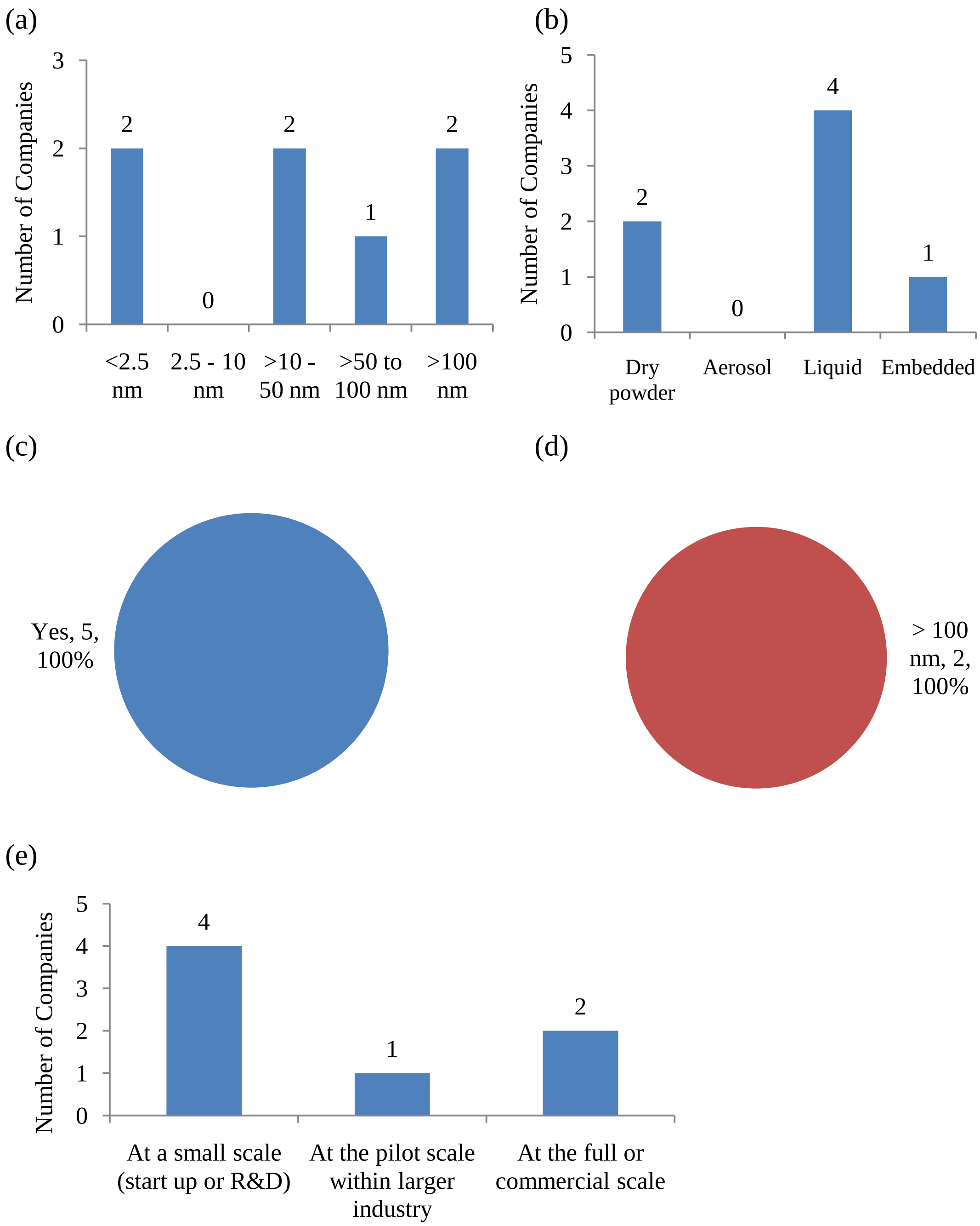

Figure 23. Dendrimers/polymers: (a) size of nanoparticle, (b) form of nanoparticles handled, (c) number of companies whose nanoparticles agglomerate, (d) to what size the nanoparticles agglomerate, and (e) scale of nanoparticle production.

11.3.14 Other carbonaceous material

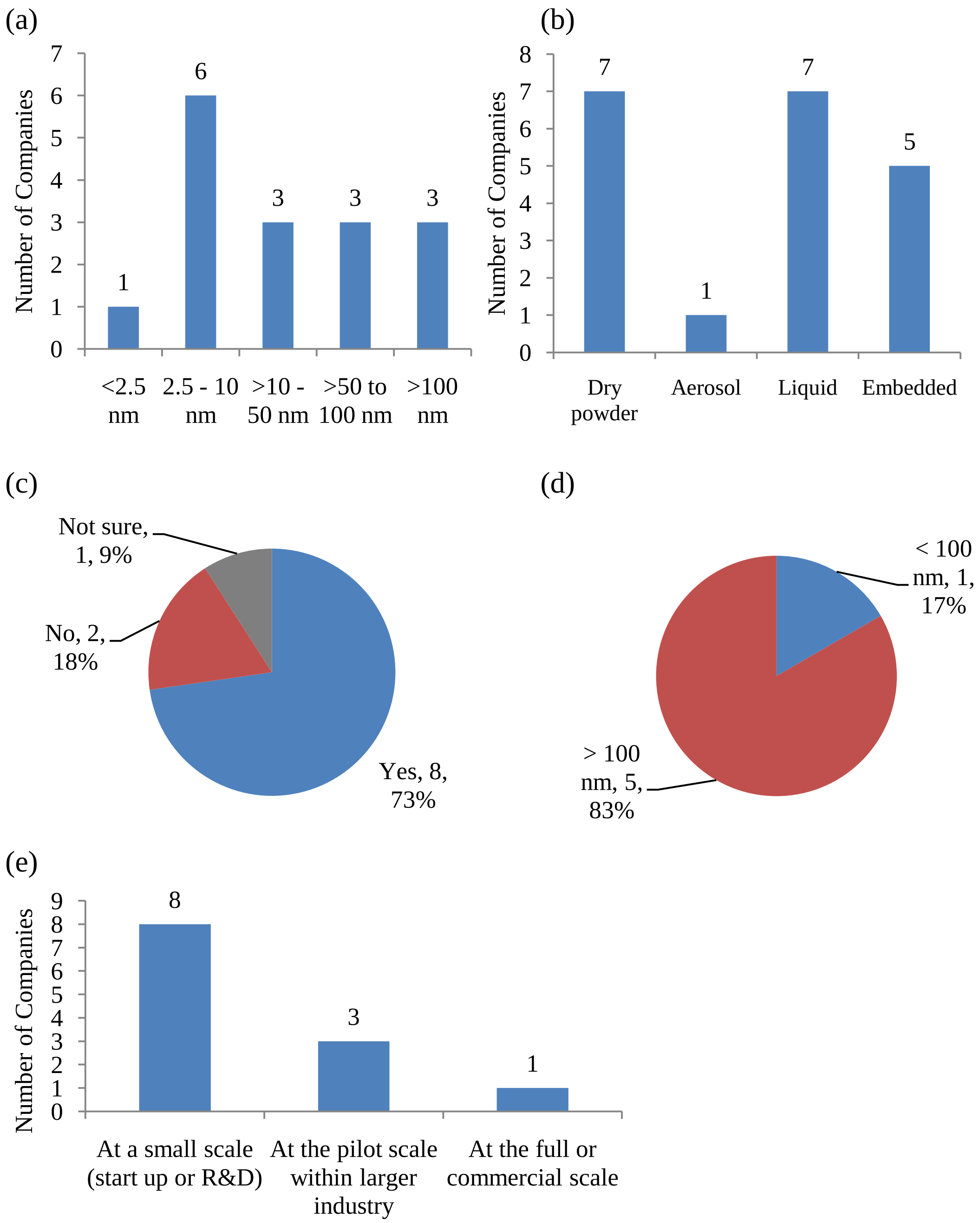

Figure 24. Other carbonaceous material: (a) size of nanoparticle, (b) form of nanoparticles handled, (c) number of companies whose nanoparticles agglomerate, (d) to what size the nanoparticles agglomerate, and (e) scale of nanoparticle production.

11.3.15 Other nano-metals

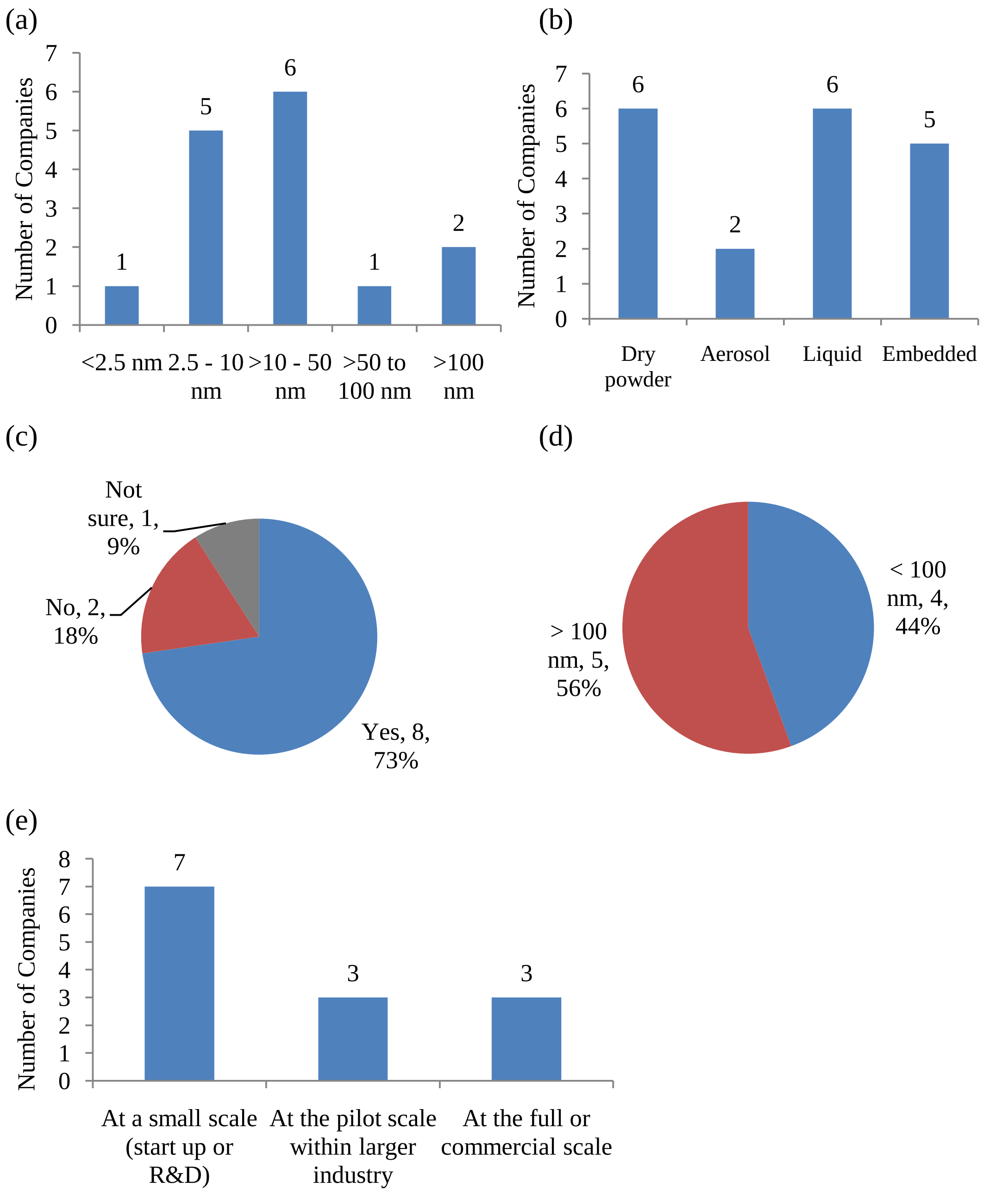

Figure 25. Other nano-metals: (a) size of nanoparticle, (b) form of nanoparticles handled, (c) number of companies whose nanoparticles agglomerate, (d) to what size the nanoparticles agglomerate, and (e) scale of nanoparticle production.

11.3.16 Other nanomaterials

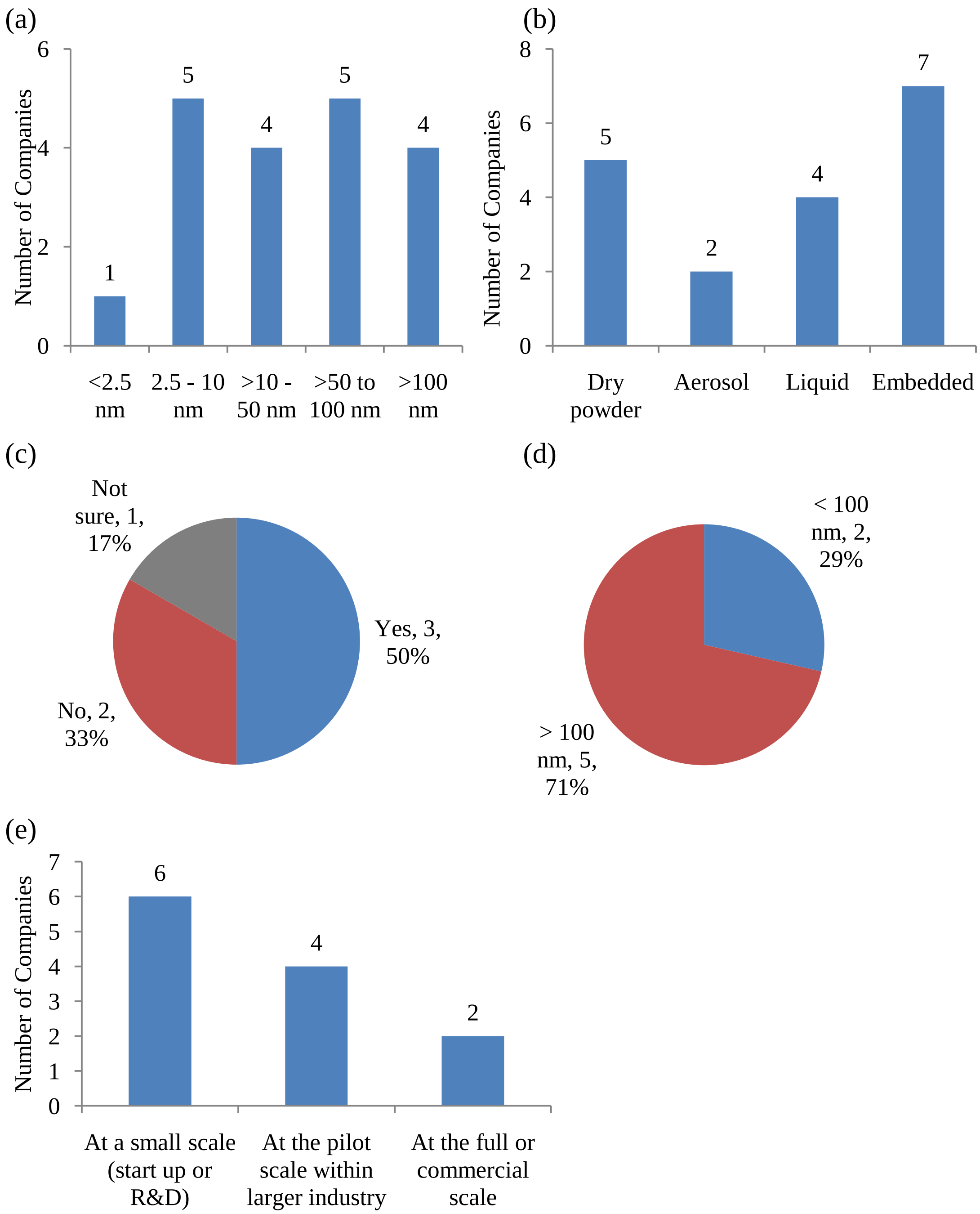

Figure 26. Other nanomaterials: (a) size of nanoparticle, (b) form of nanoparticles handled, (c) number of companies whose nanoparticles agglomerate, (d) to what size the nanoparticles agglomerate, and (e) scale of nanoparticle production.

11.4 Occupational and Environmental Health and Safety Programs

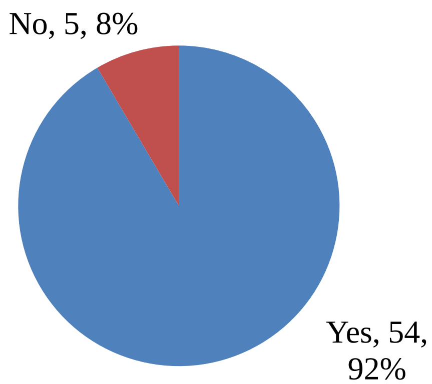

Figure 27. Percent of companies that implement a general EHS program (n=59).

Most companies implemented a general health and safety program (92%, Figure 27). The average number of full-time equivalent EHS employees was 33, with a median of 1 employee, and a mode of 1 (n=57). Of the participants that reported having a general environmental health and safety program, nine had no full time equivalent EHS staff. The range of full-time equivalent EHS employees was zero to 500.

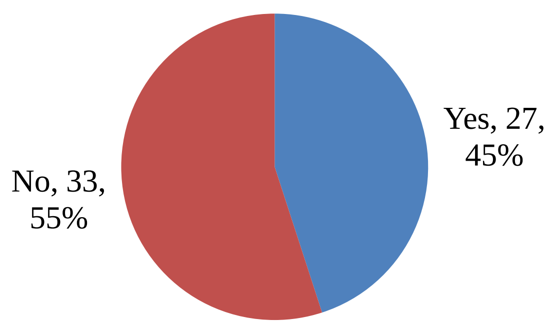

Figure 28. Percent of companies that implement a nano-specific EHS program (n=60).

Fewer companies (45%) reported implementing a nano-specific EHS program (Figure 28). Of the 27 companies that reported having a nano-specific EHS program, 23 companies indicated how many full-time equivalent nano-specific EHS staff are employed, and 4 did not answer. The average, median and mode of reported nano-specific EHS employees were one employee. Of the participants that reported having a nano-specific EHS program, eight had no full-time equivalent nano-specific EHS staff. The range of nano-EHS employees reported was zero and the maximum was 5 full-time employees.

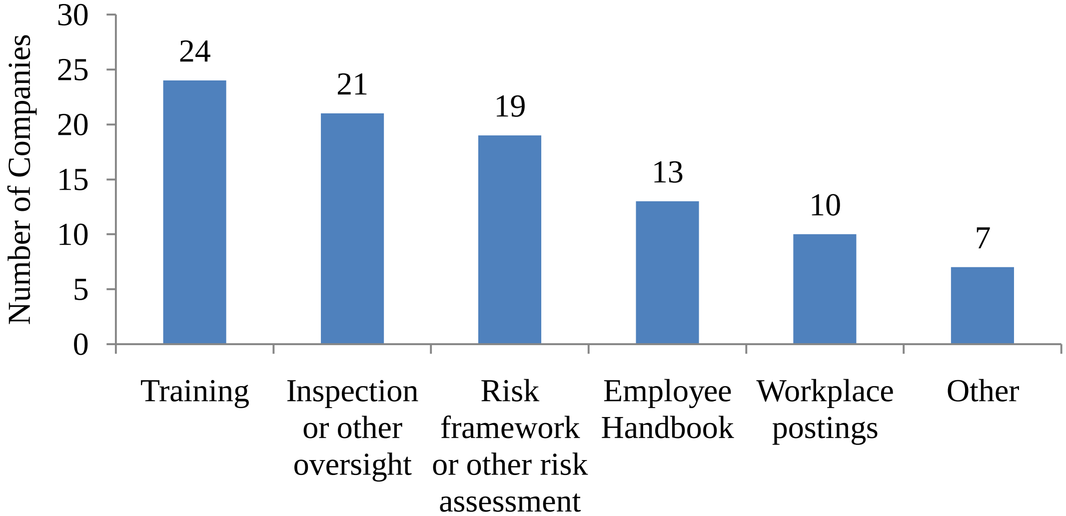

Figure 29. Components of a nano-specific EHS program (n=27).

All but three companies that reported having a nano-EHS program offered nano-specific training (89%, Figure 29). Most reported inspection or other oversight (78%) and a risk framework or other risk assessment (70%) as a component of their nano-specific EHS program. Less than half of the participants indicated providing an employee handbook (48%), displaying workplace postings (37%), and other nano-specific EHS components (26%). These other responses include a hazard review, websites, nanomaterials handling plan, process specific protocols, medical exam, and testing and characterization.

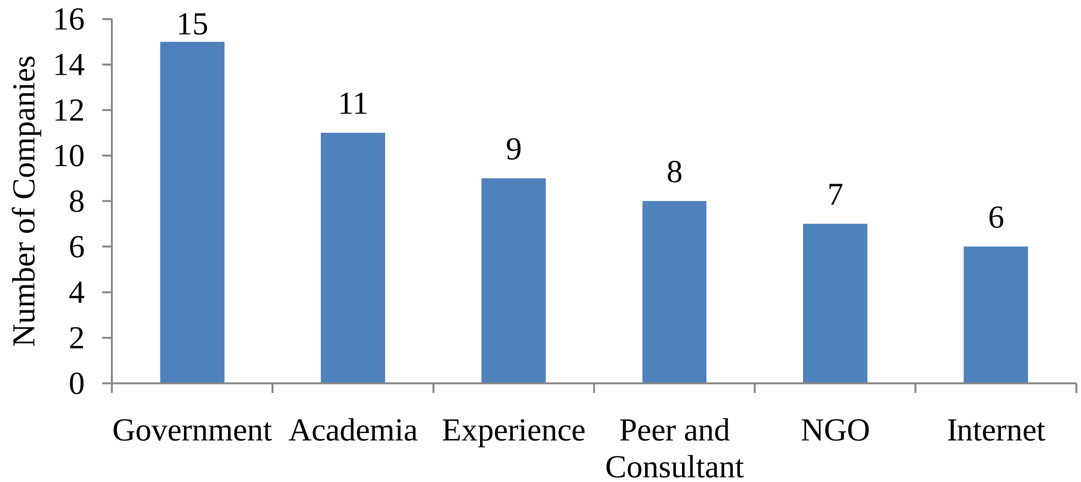

Figure 30. Sources of nano-specific guidance for development of EHS programs (n=27).

Most respondents (55%) reported using government guidance documents from organizations such as NIOSH, EPA, HSE, IRSST, and the Finnish Institute of Occupation Health (FIOH) (Figure 30). The next most common response (41%) was through academic research and literature. Other respondents reported using internal sources, such as 'company history' with the particles, internal research and toxicity testing.

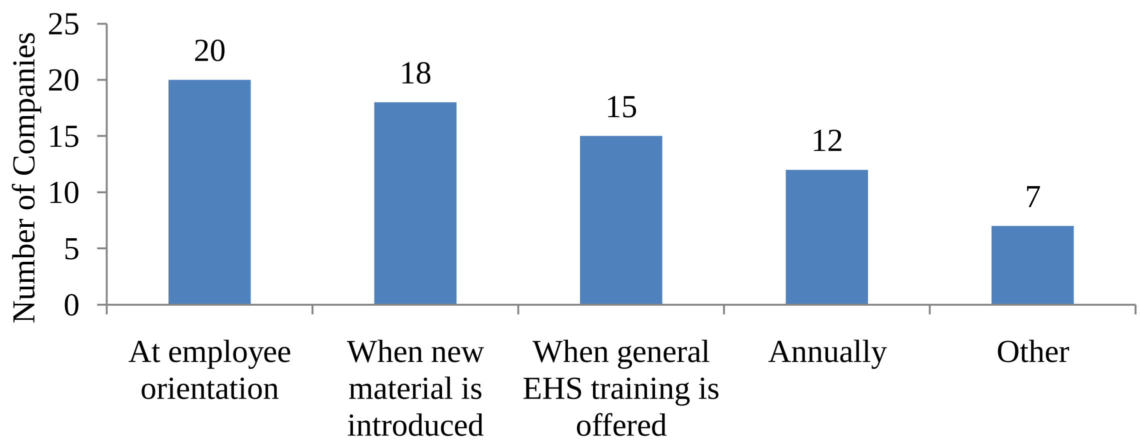

Figure 31. Frequency of offering nano-specific EHS training (n=27).

Most participants reported offering training during singular events, such as at employee orientation or when a new material is introduced, 74% and 67% respectively (Figure 31). Approximately half of the respondents offered nano-specific training on when general EHS training is offered (55.5%), and a smaller proportion (26%) reported some other time at which this training is offered. Other responses included training at monthly safety meetings, the beginning of a new process, and quarterly. One respondent reported offering training when needed and another stated that training was continuously improved and that all employees were empowered to shut down the production process if necessary. Another participant indicated there was no set schedule for training.

11.5 Employee and Area Exposure Monitoring

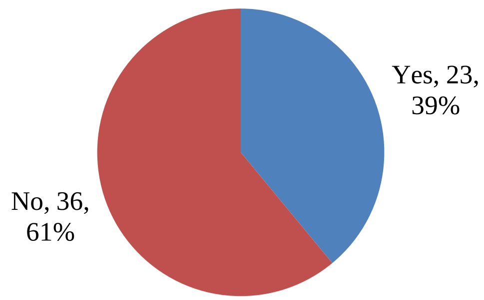

Figure 32. Workplace monitoring for nanoparticles (n=59).

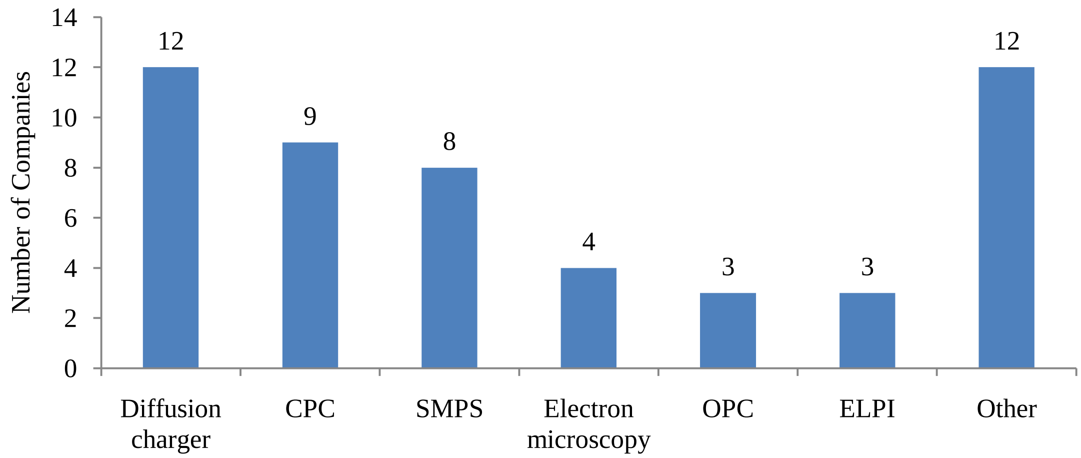

Figure 33. Types of monitoring equipment (n=23).

More than half of respondents (61%) reported monitoring the workplace for nanoparticles (Figure 32). Participants selected all applicable monitoring equipment (Figure 33). Of the companies that reported monitoring, most used some other method than the options provided. Other responses included ultraviolet visible spectroscopy, atomic absorption spectroscopy, pumps and cyclones for collection with x-ray diffraction analysis, similar methods for asbestos monitoring for carbon nanotubes by evaluating under a microscope, a tapered element oscillating microbalance, aspiration electron microscopy, surface testing to see deposition on work surface, NIOSH Manual of Analytic Methods, handheld particle counter, light scattering, NIOSH field team equipment, diffusion charger, wipe samples, filter devices attached to employees, ultraviolet light, and silicon dioxide. Out of the monitoring equipment choices provided, 48% participants selected diffusion charger, 39% chose condensation particle counter (CPC), 35% reported scanning mobility particle sizer (SMPS), 17% chose electron microscopy, and 13% of participants selected optical particle counter (OPC) and electrical low pressure impactor (ELPI), and. Twelve participants reported the measurements for the monitoring equipment which included: particle count, morphology, composition, particle diameter, surface area, and amount.

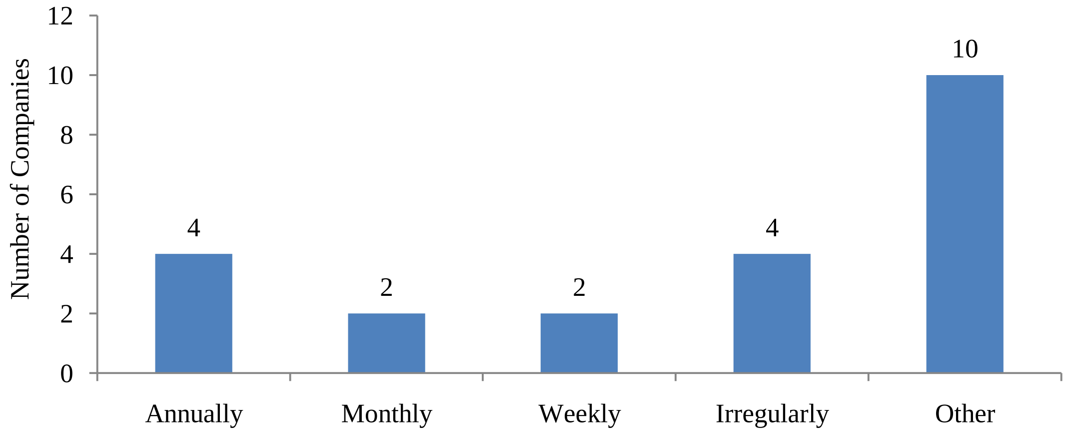

Figure 34. Nanoparticle monitoring frequency (n=22).

Few respondents (35%) reported monitoring the workplace at regular intervals (Figure 34). Most companies reported monitoring at some other time or irregularly. Other responses included: when a hazard assessment is performed, when requested, depends upon previous monitoring results, continuously, daily, four months, six months, a two to three year cycle, one time, and once for NIOSH participation.

11.6 Containment and Exposure Controls

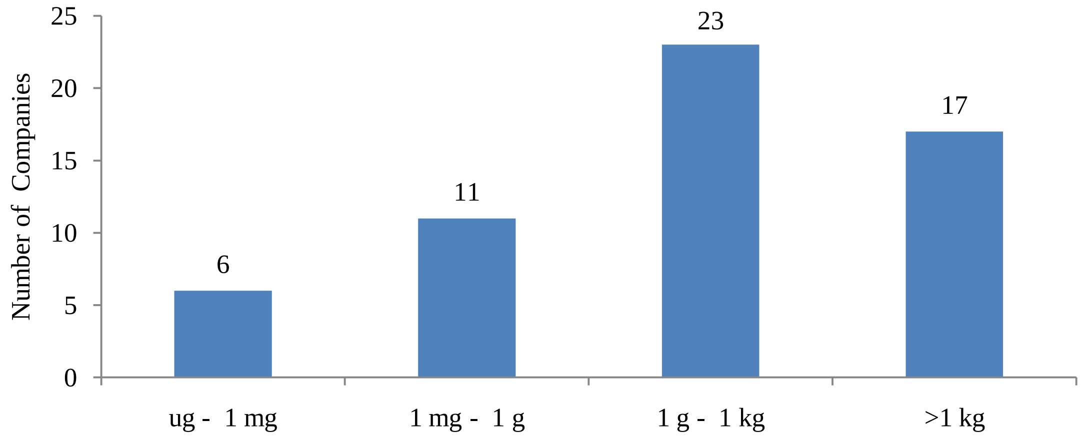

Figure 35. Maximum amount of nanomaterials handled at one time (n=60).

Most companies (38%) reported handling a maximum amount of 1 gram to less than 1 kilogram (Figure 35). Next were companies with employees that handle more than 1 kilogram of nanomaterials (28%). Fewer companies reported handling nanomaterial amounts 1 milligram to less than one gram (18%) and micrograms to less than one milligram (10%). Two companies reported maximum amounts outside of these categories, and these responses were interpreted for the approximate maximum amount handled.

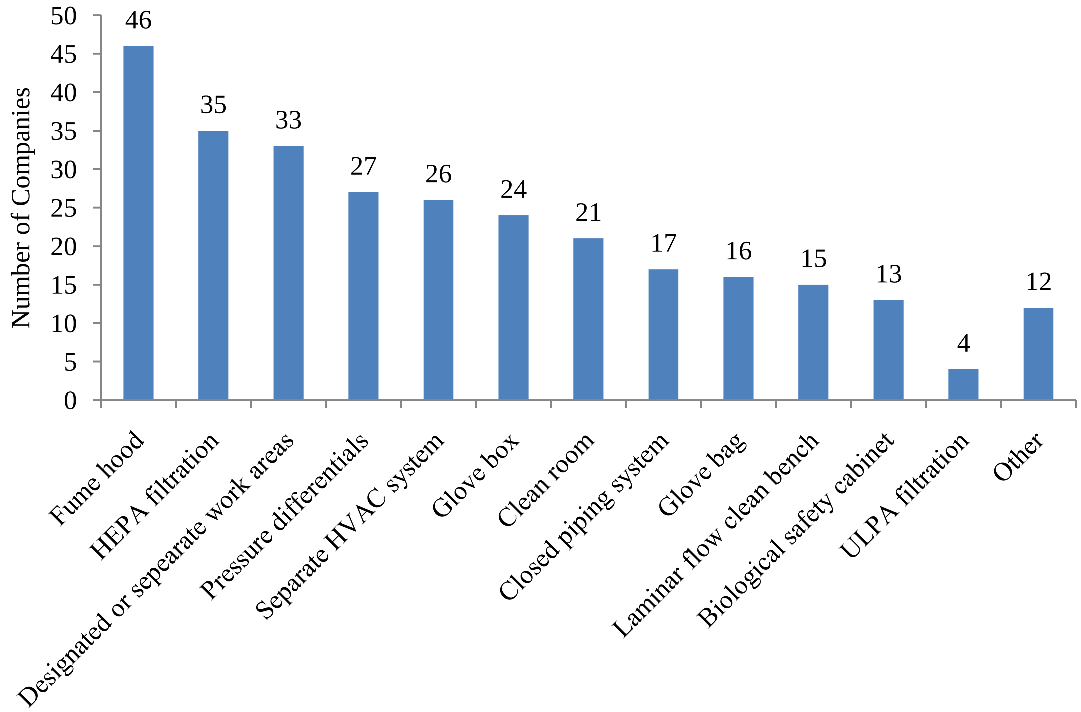

Figure 36. Facility and design controls used to manage employee exposure to nanomaterials (n=56).

Participants selected all applicable design and control features. One of the 56 participants indicated that none of these were used (Figure 36). Most participants (82%) reported using a fume hood for facility design and engineering controls. High efficient particulate absorbing (HEPA) filters (63%) and separate work areas (60%) are also among the most common exposure controls. Approximately half of the companies reported use of pressure differentials, glove box, and a separate heating, ventilating, and air condition (HVAC) system. Fewer companies indicated the use of a clean room, closed piping system, glove bag, laminar flow clean bench, and biological safety cabinet. Other facility and design controls reported included airline respirators, local area exhaust, enclosed reactor system for making carbon nanotubes, extensive air scrubbing, and secondary shields to protect product.

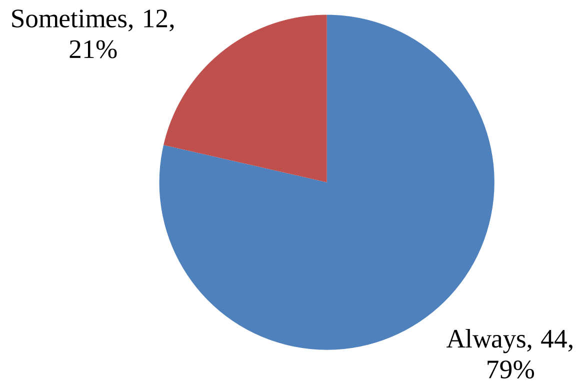

Figure 37. Reported engineering control use (n=56).

The majority of companies (79%) reported always using the engineering controls. Some companies (21%) indicated using controls sometimes (Figure 37). No respondents reported never using engineering controls.

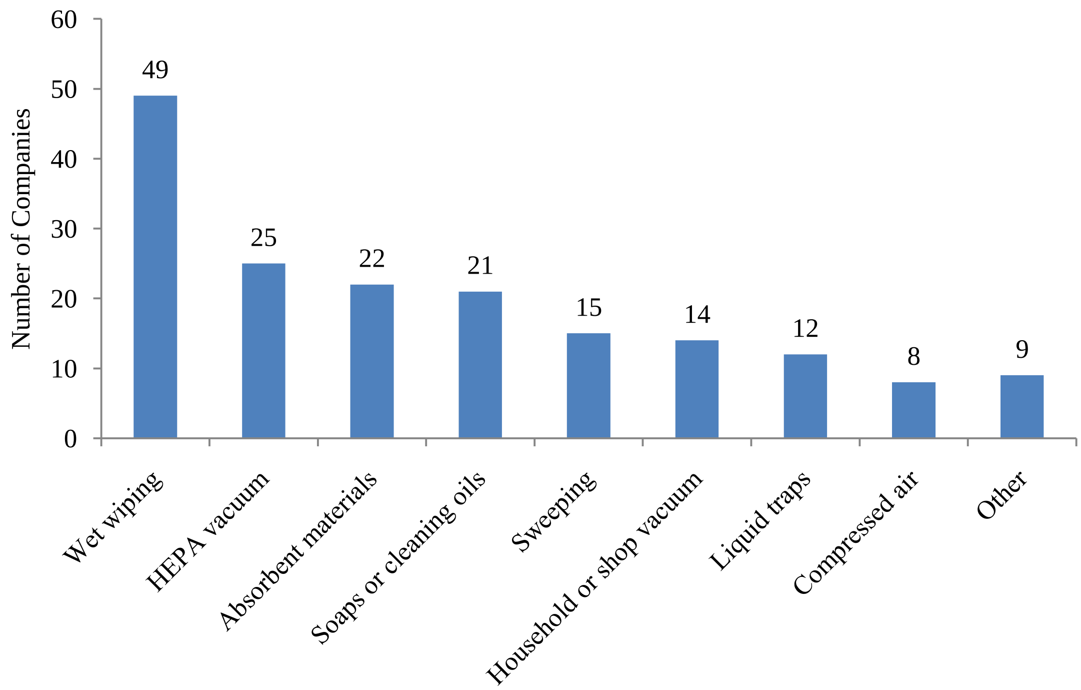

Figure 38. Cleaning methods for areas in which nanomaterials are handled (n=56).

Participants selected all applicable cleaning methods. Most participants reported using wet wiping (88%) for cleaning areas in which nanomaterials are handled (Figure 38). A number of respondents indicated the use of a HEPA vacuum (45%) absorbent materials (39%), and soaps or cleaning oils (38%). Fewer participants reported sweeping (27%), household or shop vacuum (25%), liquid traps (21%), and compressed air (14%). Other reported methods for cleaning included solvents, vacuuming that is vented to the outside of the building, and Fantastic brand cleaner.

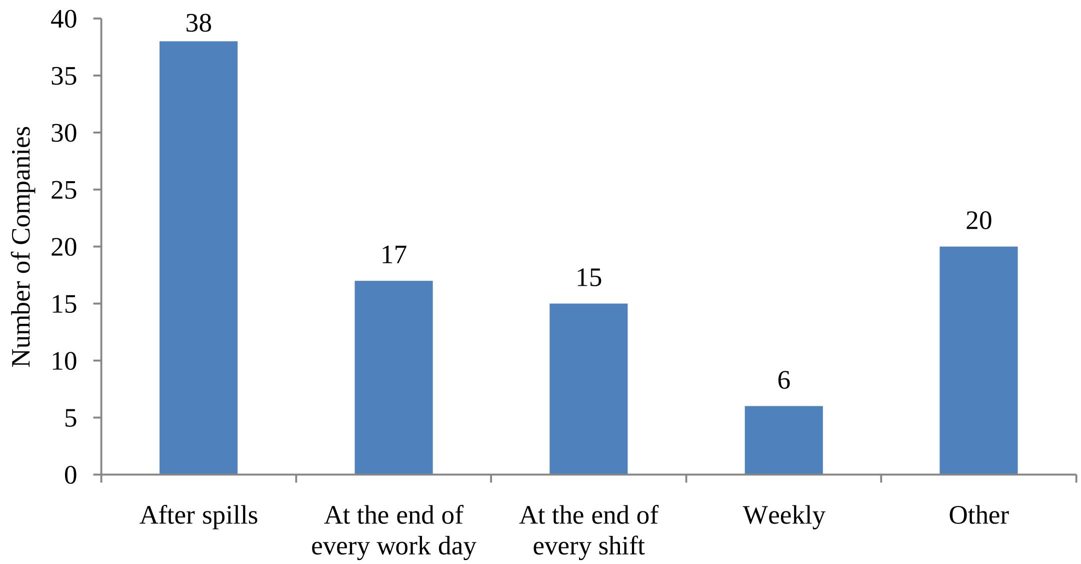

Figure 39. Cleaning frequency (n=57).

Respondents selected all applicable cleaning frequencies (Figure 39). One participant answered that they were not sure when cleaning was performed. Most participants (67%) reported cleaning after spills. Approximately one-third of the companies indicated that they cleaned at end of every work day (30%) or some other time (26%). About one quarter of respondents reported cleaning at the end of every shift. Some of other answers included after operations, after specific equipment is used, when necessary, a clean as you go policy, daily, two times a week, three times a week, and monthly.

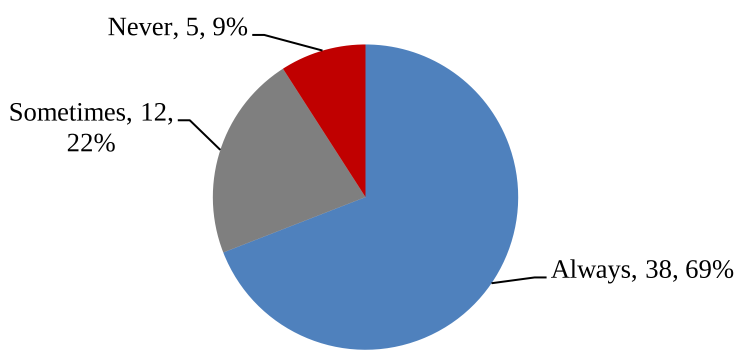

Figure 40. Reported frequency of closed-container transportation (n=55).

Most companies (69%) reported always transporting nanomaterials in closed containers (Figure 40). Nearly a quarter of participants reported sometimes transporting nanomaterials in closed containers (22%). Few companies (9%) indicated that they never transporting their nanomaterials in closed containers. Additional feedback from this question indicates that handling varies depending on the material, and that containers are mainly used to protect the product. A few participants mentioned the heavy costs associated with the loss of nanomaterial.

11.7 Personal Protective Equipment

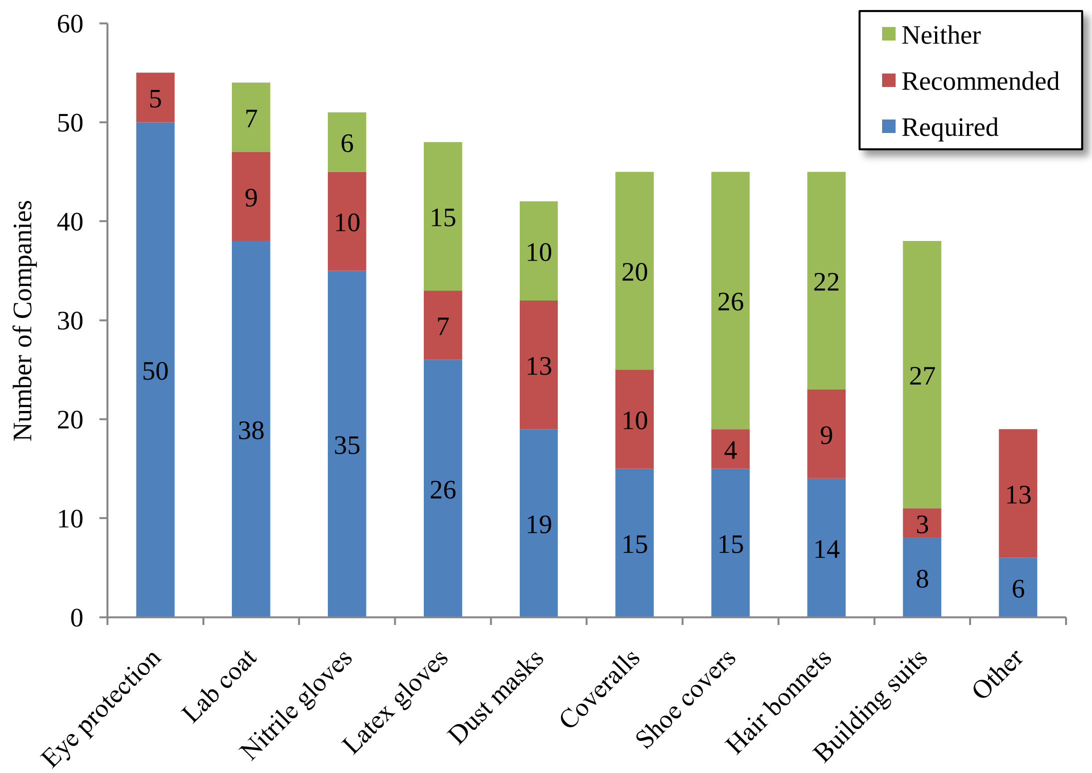

Figure 41. Company use of personal protective equipment by type indicating whether the equipment was recommended, required, or neither recommended or required (42-55).

Most participants (91%) reported eye protection as a required PPE (Figure 41). A majority of participants also reported requiring lab coats (70%) and nitrile gloves (69%). Latex gloves and dust masks were required by approximately half of the respondents. Fewer companies reported requiring coveralls (33%), shoe covers (33%), and hair bonnets (31%). Only 8 companies indicated that they require building suits. Participants could select all applicable PPE.

Around a quarter of companies reported recommending dust masks. Approximately 22% of companies indicated that they recommend coveralls, lab coats

(17%), and nitrile gloves (19%). Fewer companies recommended eye protection, hair bonnets, shoe covers, and building suits. Lastly, 13 companies indicated recommending other types of PPE. Some of the other responses included air line respirator for packaging, PPE dependent upon control banding, steel-capped shoes for the manufacturing line, positive face ventilation, and clean room attire. A few participants indicated that the use of PPE was dependent upon the type of situation and the type of nanoparticle handled. Another participant stated that dust masks are required when nuisance dust is present or nanoparticles are high in the ambient air. One respondent said that they rarely handle raw nanomaterials at their facility so PPE does not realistically apply to them. One company stated that PPE are only required in clean rooms. Finally, another company indicated that they handle all nanoparticles as hazardous materials.

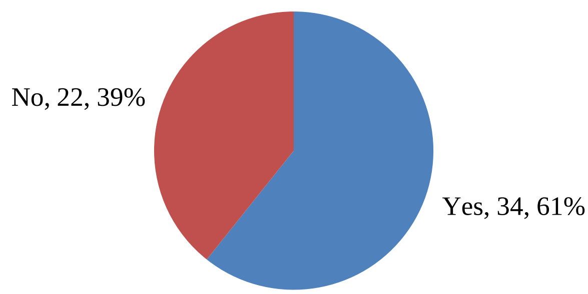

Figure 42. Respiratory protection use (n=56).

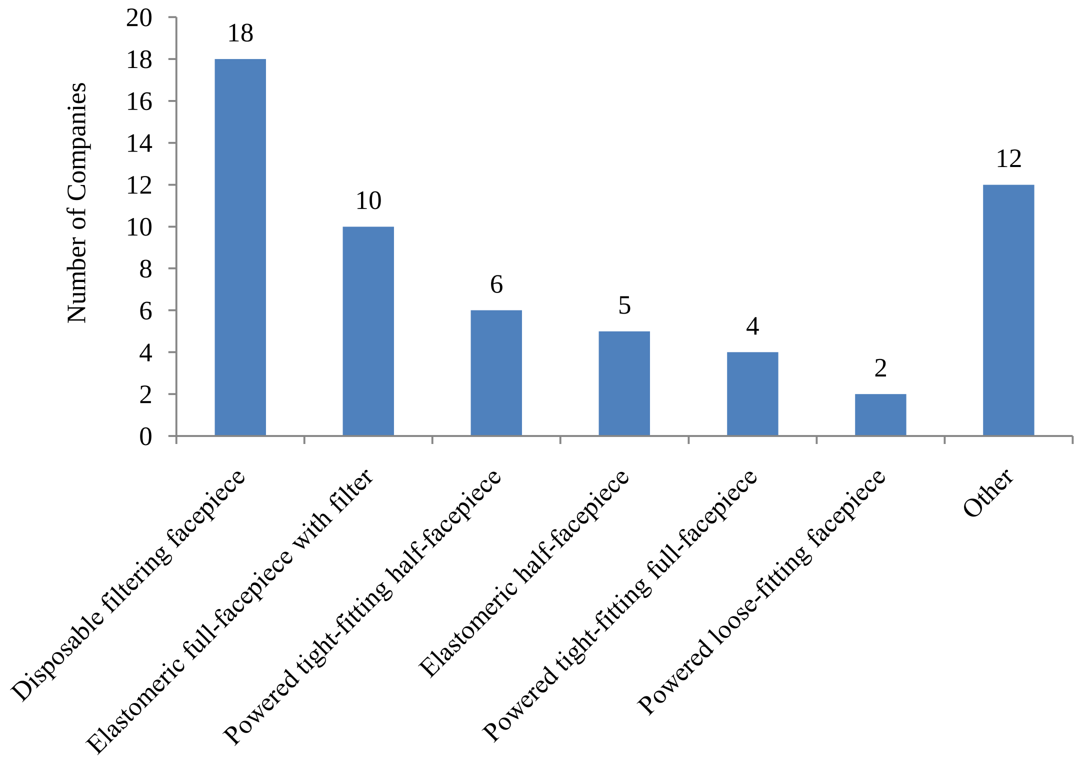

Figure 43. Respirator type (n=34).

Most participants (61%) reported using respiratory protection with nanomaterials (Figure 42). Participants selected all applicable respirator types (Figure 43). Most participants reported a disposable filtering facepiece (53%). Nearly 30% of companies reported using elastomeric full-facepiece with a filter. Fewer respondents reported using a powered tight-fitting half-facepiece (18%) or an elastomeric half-facepiece (15%). Nearly a third of companies reported using some other form of respiratory protection: additional use of a N-95 filter, non-powered full-facepiece and unsure of filter, N-100 filter, cartridges designed to handle organic solvents, N-95 or P-95 depending upon whether the filter is disposable, industrial style respirator, and a full-face positive airflow helmet mask. Some companies provided the following comments on respiratory protection: face mask used occasionally for clinical protection, the company tried to engineer the respiratory risks out, the size of the facepiece is not important rather only that it is required, the elastomeric half-facepiece is required only when handling powders or when solutions may become aerosolized through sonication, respiratory protection is required when incorrect airflows are present, and respiratory protection depends on the stage of the process or the chemical hazards present.

11.8 Barriers to Implementing Nano-Specific Health and Safety Practices

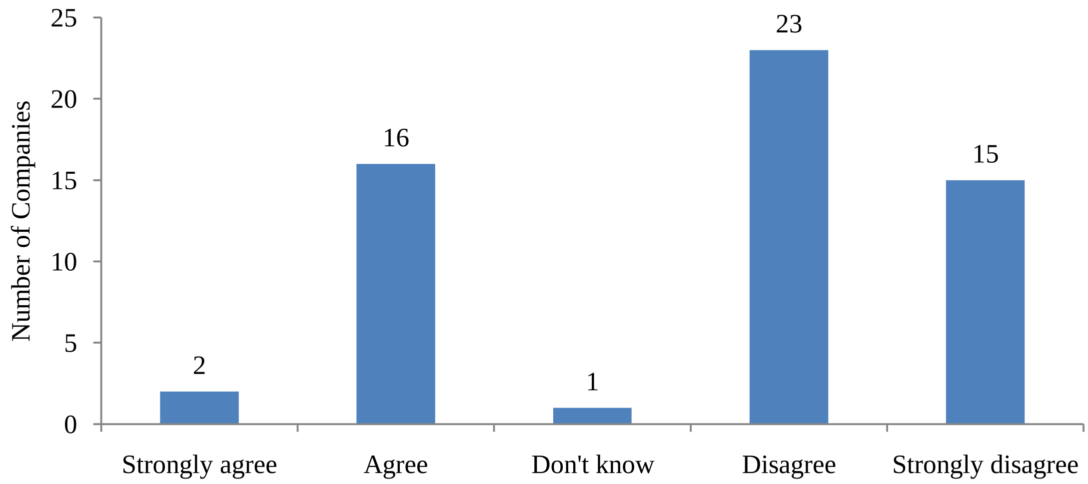

Figure 44. Level of agreement with the statement "Budget constraints are an impediment in implementing nano-specific health and safety practices" (n=60).

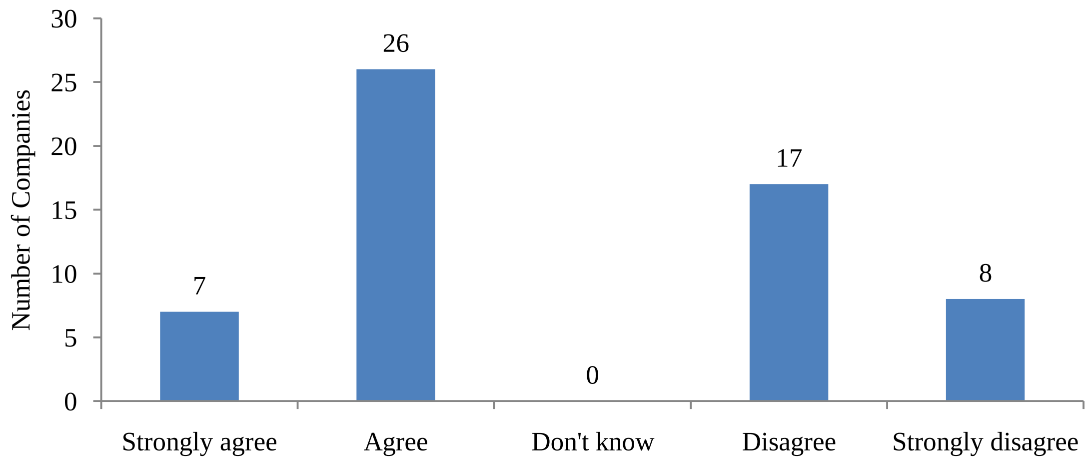

Figure 45. Level of agreement with the statement "Lack of information is an impediment in implementing nano-specific health and safety practices" (n=60).

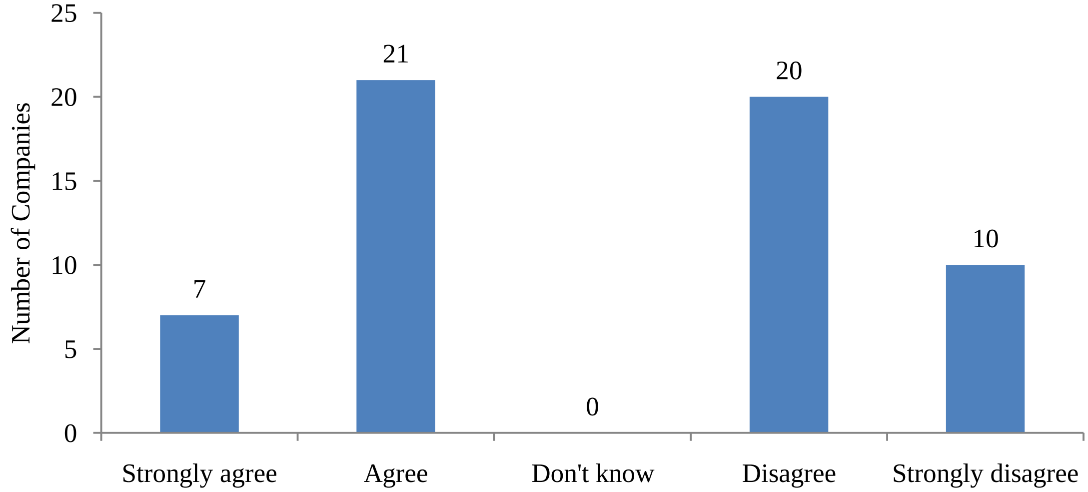

Figure 46. Level of agreement with the statement “Lack of health and safety guidance or regulations is an impediment in implementing nano-specific health and safety practices” (n=60).

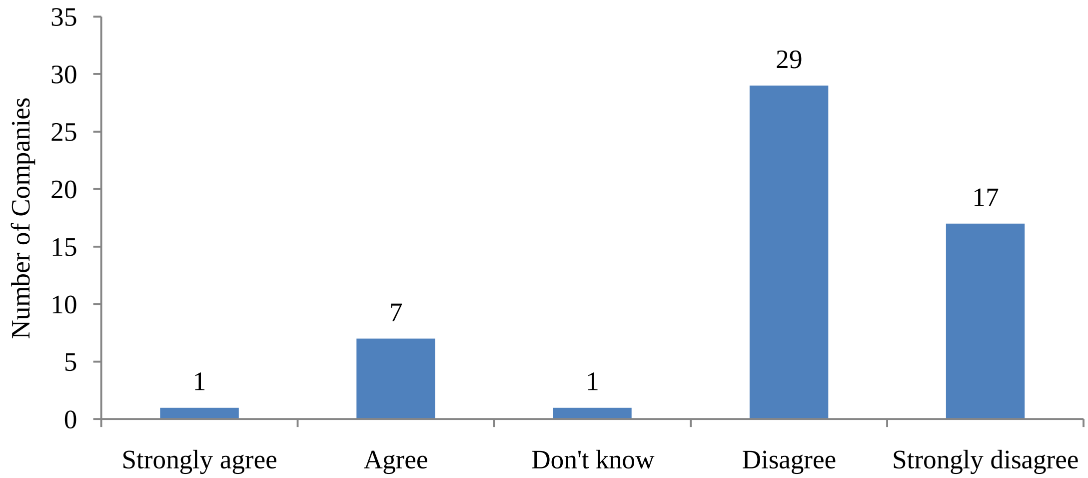

Figure 47. Level of agreement with the statement “Internal enforcement is an impediment in implementing nano-specific health and safety practices” (n=60).

Respondents were asked to state their level of agreement with four statements describing possible impediments to nano-specific EHS practices: budget constraints, lack of information, lack of guidance or regulations, and internal enforcement. Most respondents (63%) reported that they either disagreed or strongly disagreed with the statement regarding budget constraints (Figure 44). Companies were fairly evenly divided between agreement and disagreement with impediments due to lack of information (Figure 45) and lack of regulation or guidance (Figure 46). Slightly more companies (55%) agreed or strongly agreed that lack of information was a barrier, while fewer (47%) agreed or strongly agreed that lack of regulation was a barrier. Most companies (77%) disagreed or strongly disagreed that internal enforcement to nano-specific EHS practices (Figure 47). No companies reported any other barriers in implementing a nano-specific EHS practices.

11.9 Waste Management and Product Stewardship

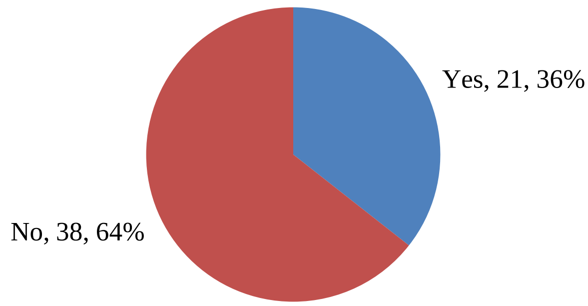

Figure 48. Presence of a nano-specific waste program (n=59).

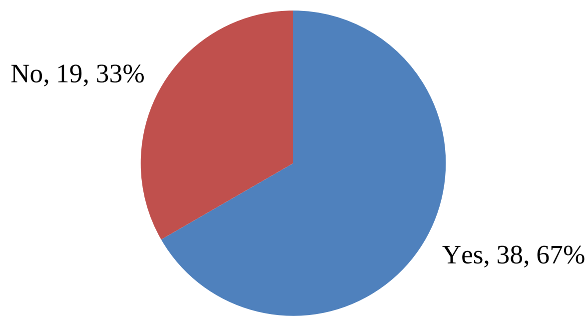

Figure 49. Hazardous waste disposal of nanomaterials (n=57).

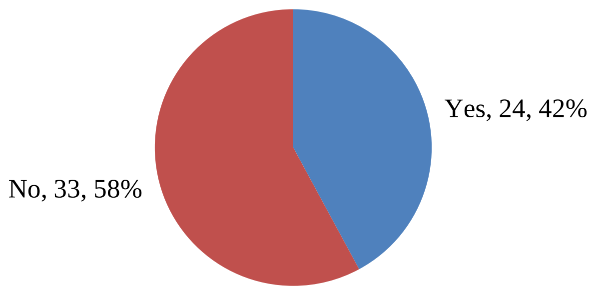

Figure 50. Separate waste containers for nanomaterials (n=57).

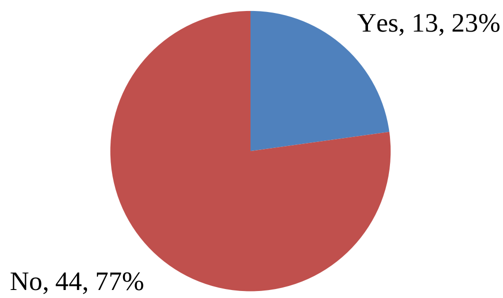

Figure 51. Listing nanomaterials as “nanomaterials” on waste manifests (n=57).

Respondents reported their waste management practice in regards to nanomaterials. Most companies (64%) indicated that there was no nano-specific waste program within their company (Figure 48). One respondent said that the company they worked sent all their waste materials away to be incinerated. A majority of the respondents (67%) indicated that their company disposed of nanomaterials as hazardous waste (Figure 49). Many companies said that their decision to dispose of materials as hazardous was determined by the substance itself, not the size or structure. Most companies (58%) reported that they did not use separate disposal containers either in the lab or in waste storage areas for nanomaterials (Figure 50). Some respondents indicated that disposal varied based on material type. The majority of companies (77%) do not list nanomaterials separately as “nanomaterials” (Figure 51).

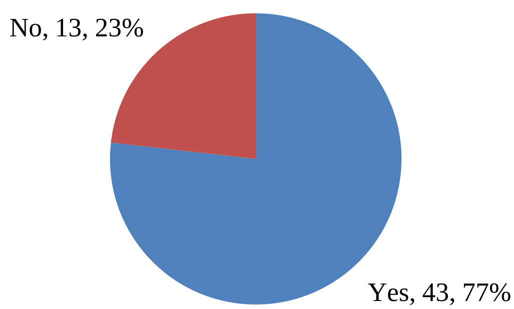

Figure 52. Disclosure of nanomaterials in products (n=57).

Companies reported whether they advertised or otherwise disclosed that their products contained nanomaterials. Most respondents (77%) indicated that their company advertises or discloses that their products contain nanomaterials. Some respondents stated that they used the disclosure of nanomaterials within the product as a marketing tool.

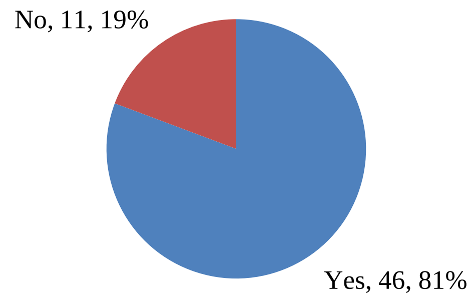

Figure 53. Provision of nano-specific guidance to customers (n=57).

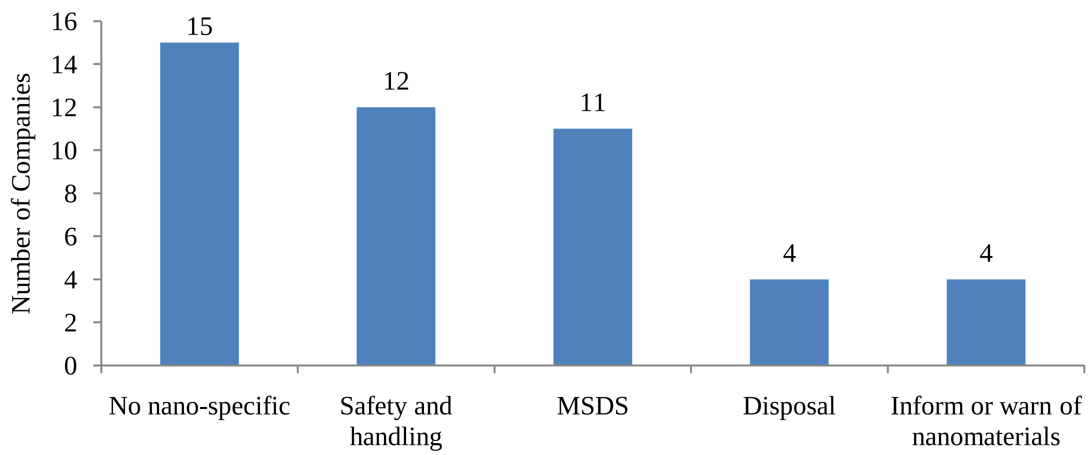

Figure 54. Type of nano-specific guidance companies provide to their customers (n=45).

A majority of the respondents (81%) indicated that their company provides some level of guidance to customers about safe use and/or disposal of their products (Figure 53). Figure 54 shows types of information that companies reported providing as nano-specific guidance to customers. Most companies that supply guidance to customers reported providing non-nano-specific guidance (33%). Some companies (24%) reported providing material safety data sheets (MSDS) as nano-specific guidance. However, MSDS are not nano-specific.

11.10 Views on Risk and Trust

11.10.1 Views on Risk of Nanomaterials

Companies were asked to rate the level of risk they thought a particular type of nanomaterial poses to human health and/or the environment, and they provided a variety of responses. Three respondents answered "don't know" to one or all comparative items because they thought the category was "too broad" or "too generic". Two participants declined to answer this set of questions replying that the answers were too subjective to evaluate the individual or the environmental exposure risks. Figures 55 through 60 show the distribution of levels of risk as a percentage of the total number of answers recorded.

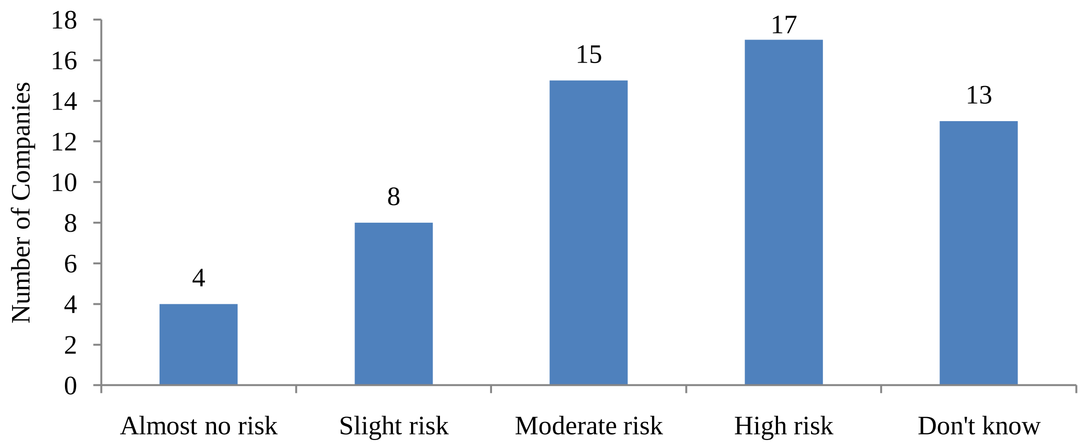

Figure 55. Level of risk for carbon nanotubes (n=57).

Most participants perceived moderate (26%) or high (30%) levels of risk associated with CNTs (Figure 55). Few respondents (7%) believed CNTs had almost no risk. Nearly a quarter of respondents indicated they did not know the risk posed to human health and/or the environment.

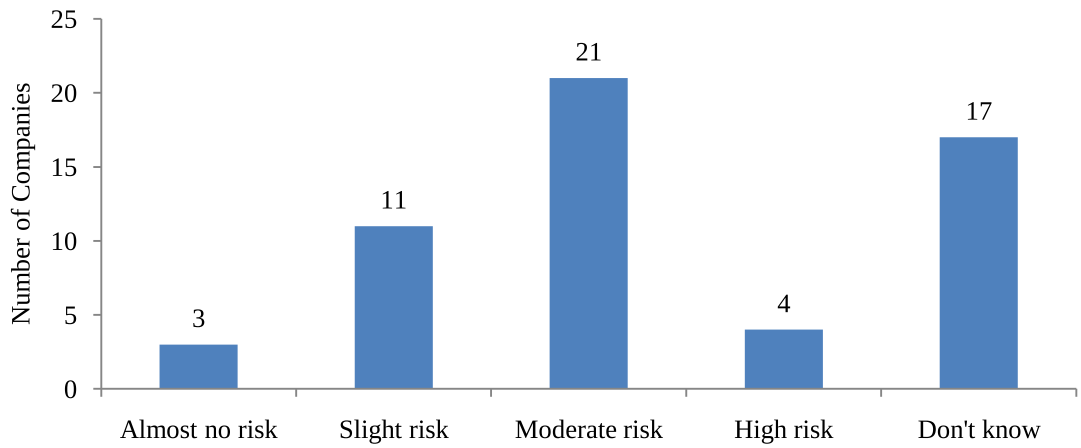

Figure 56. Level of risk for other carbonaceous material (excluding CNTs) (n=56).

Most participants (38%) perceived a moderate risk from other carbonaceous materials (Figure 56). Perceived risk increased from almost no risk, to slight risk, and moderate risk. Less than 10% of respondents thought that carbonaceous nanomaterials posed a high risk. Almost one third of participants indicated they did not know the risk posed to human health and/or the environment.

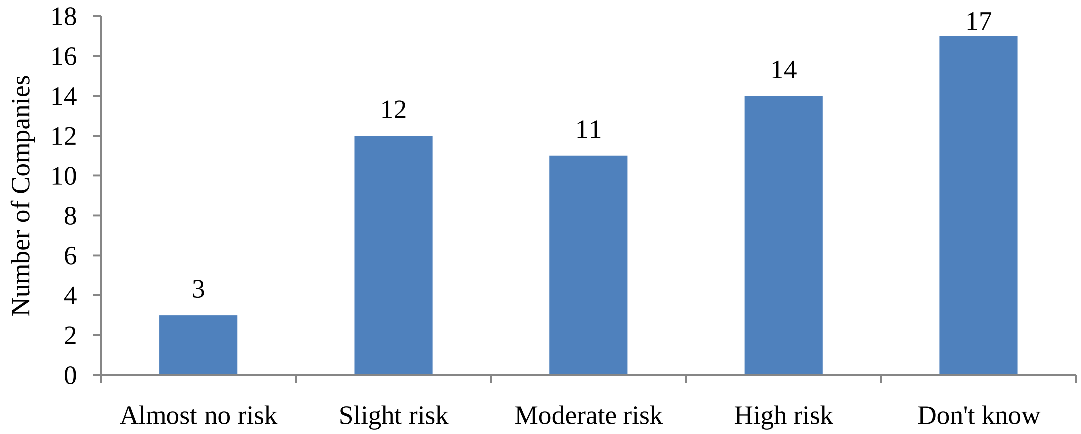

Figure 57. Level of risk for dry powders (n=57).

Approximately 20% of respondents perceived a slight, moderate, or high risk from dry powders (Figure 57). Most participants (30%) indicated they did not know the risk posed to human health and/or the environment.

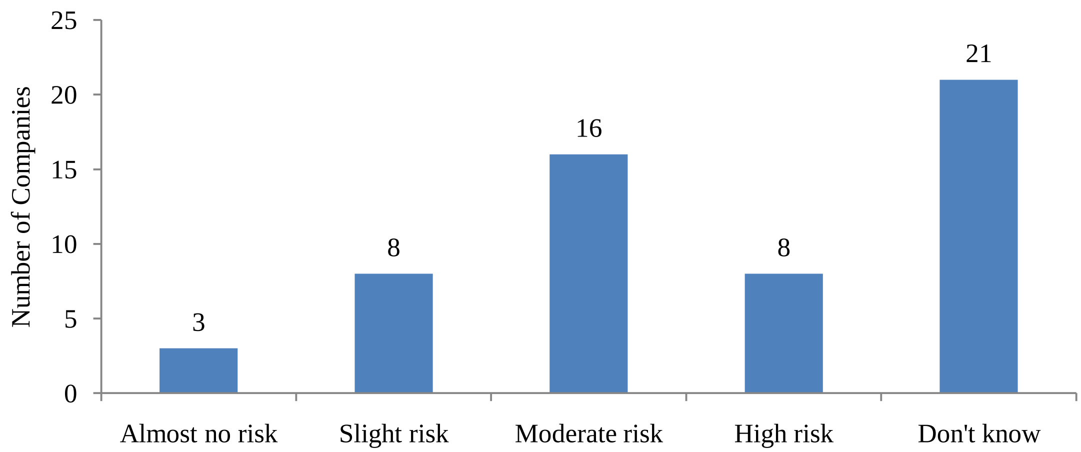

Figure 58. Level of risk for quantum dots (n=56).

Most participants (38%) indicated that they did not know the risk posed to human health and/or the environment to quantum dots (Figure 58). Next, 29% of respondents perceive a moderate risk for quantum dots.

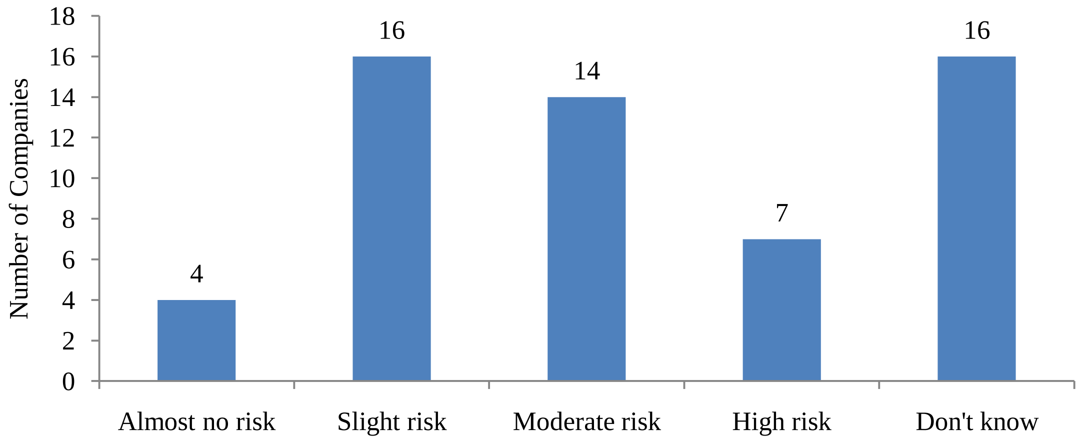

Figure 59. Level of risk for metal oxides (n=57).

More than one-fourth of respondents did not know the level of risk associated with metal oxides (Figure 59). Also, about 25% of respondents think that metal oxides pose a slight or moderate risk. Few (7%) considered metal oxides as almost no risk.

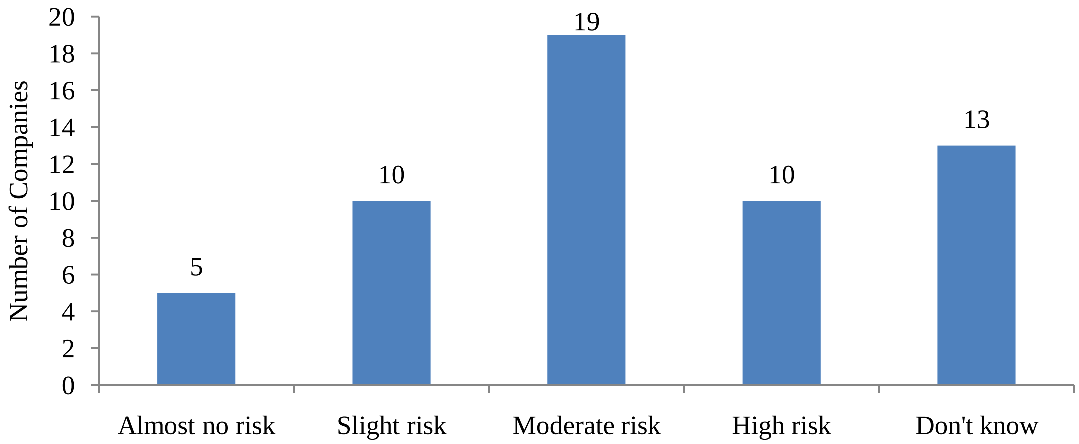

Figure 60. Level of risk for heavy metals (n=57).

Most participants (33%) perceive a moderate risk from heavy metals (Figure 60). Nearly one-fourth of participants indicated they did not know the risk posed to human health and/or the environment. Few respondents (9%) perceived almost no risk from heavy metals.

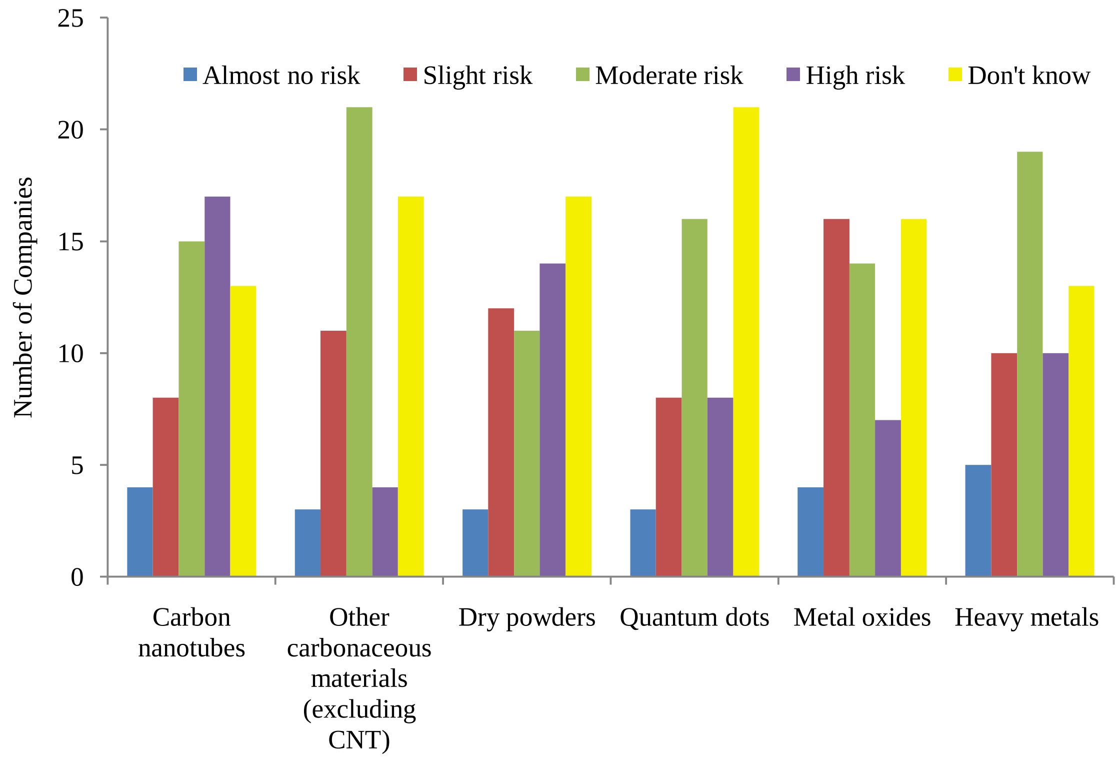

Figure 61. Reported levels of risk by nanomaterial type (n=56 to 57).

Reported perceived risks were compared by risk level across the six categories of nanomaterials. Figure 61 shows that a most participants perceived metal oxides as a slight risk to human health and/or the environment as compared to the other categories of nanomaterials. More participants answered that other carbonaceous materials pose a moderate risk to human health and/or the environment than other nanomaterial categories. More participants reported carbon nanotubes as a high risk to human health and/or the environment, as compared to other nanomaterial categories.

A significant number of respondents reported “don’t know” as their response to the risk of specific nanomaterials or characteristics. This response was used when a few participants were not familiar with the nanomaterial, while others indicated “don’t know” when they did not feel comfortable responding. In these cases, respondents had difficulty rationalizing the statements’ intent or were frustrated that the categories were not specific enough for their level of scientific expertise. Some stated that they required more information, and, therefore, would not participate. Responses were not specific to each nanomaterial category, but were a reflection of the set of questions. Some of the qualitative responses to this question include the following:

- "The material tends to be very specific depending on the material, particle, and size. For example, zinc oxide is part of a lot of cosmetics. But alumina, in certain particle size form, is an inhalation problem."
- "I don't think it's a good question to ask. Everything has a risk; it depends on how much you are taking. I will refuse to answer the question, because there is no correct answer to this question. I think it's a tricky question. I don't want to answer because it's not going to help anybody. The question is too generic. Not appropriate."
- "Other carbonaceous nanomaterials have been in industry for 100 years. For dry powders, it has to do with the composition of the material. If it's a toxic material, then the nanomaterial will be toxic. For quantum dots, the same principle applies as dry powders. For metal oxides, the same thing applies. Calcium oxide is good for you because you need calcium, but if it's mercury oxide you don't want it near you. For heavy metals: some are dangerous, some aren't. The nanomaterial has little impact on this differentiation. I can tell who ever made this doesn't understand nanomaterials."
- "This is a bad question, it really depends on exposure. But I'll give you my best guess."

11.10.2 Views on Risk

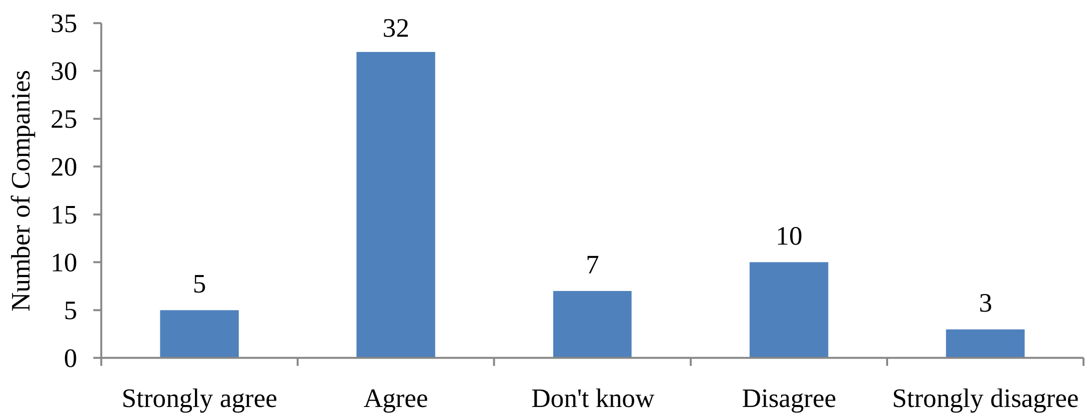

Figure 62. Level of agreement with the statement "Industries working with nanomaterials can be trusted to regulate the safe-handling of these materials" (n=57).

A majority of participants agreed with this statement (56%, Figure 62). One respondent that strongly disagreed with this statement qualified their answer by saying, "No one should referee their own game."

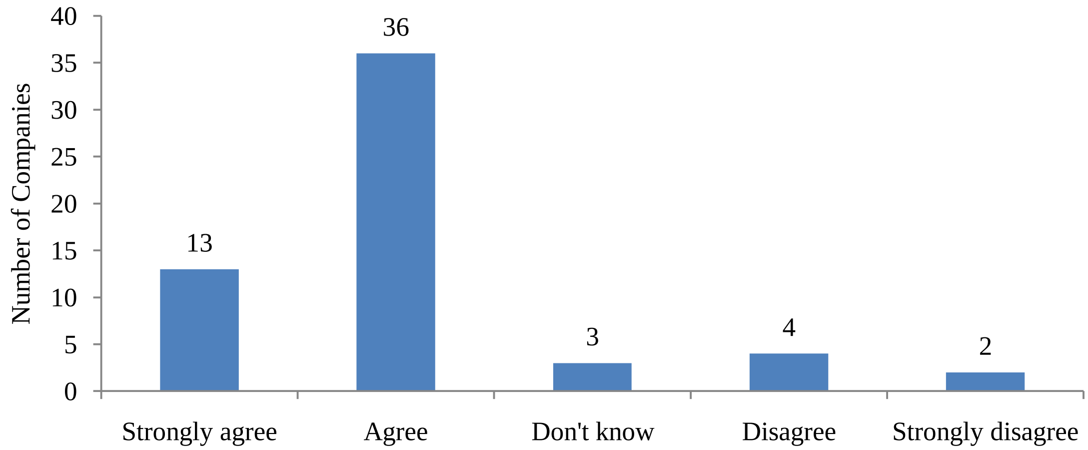

Figure 63. Level of agreement with the statement “It is reasonable to assume that industries working with nanomaterials will adapt or alter their safe-handling practices when new hazards are discovered” (n=58).

Most participants (62%) agreed that industries would adapt or alter their practices (Figure 63). One respondent that strongly agreed with this statement qualified their answer by saying, "Industries mitigate risk of suit.” Another respondent that disagreed with this statement added, “It depends on their financial situation; if they are against the wall, no they will not.”

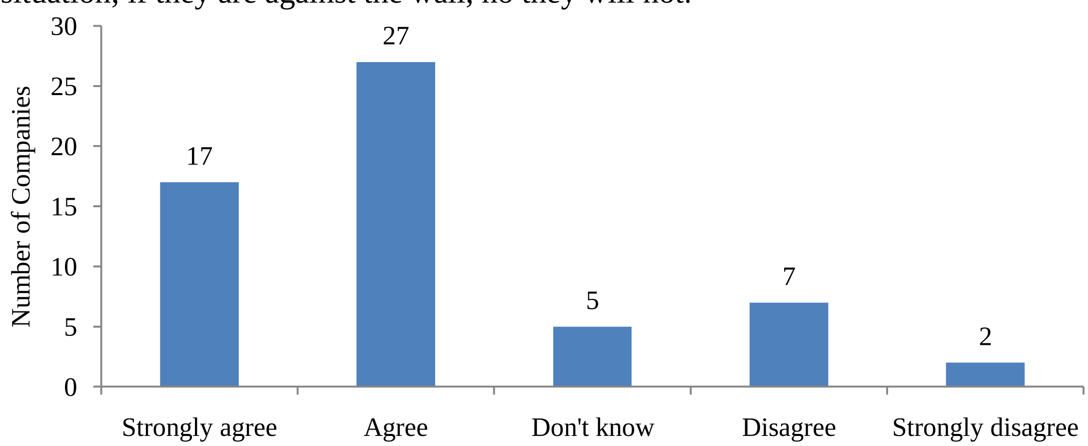

Figure 64. Level of agreement with the statement “In the case of nanotechnologies, the benefits of advancements in science and technology outweigh the risks involved in research, development, and production” (n=58).

A majority of participants (76%) reported some level of agreement, with most participants agreeing with this statement (47%, Figure 64). One respondent that disagreed with this statement added, “That is not an effective principle to follow.” One participant that responded “don’t know” qualified their answer by saying, “there are so many different levels to this tricky question; the safe answer is I don’t know.”

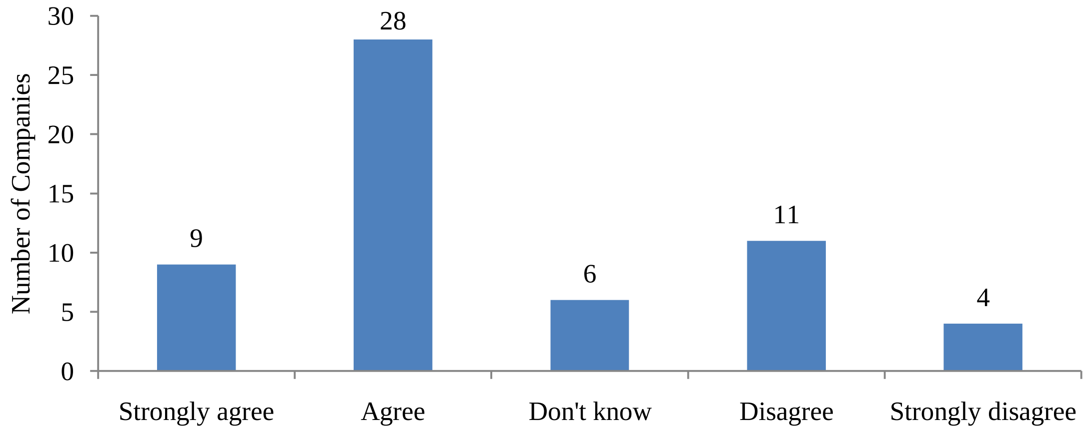

Figure 65. Level of agreement with the statement “Waiting until safety studies are complete to commercialize nanotechnology will deprive society of too many potential benefits” (n=58).

Most respondents (48%) agreed with that waiting until safety studies are complete would deprive society of too many benefits (Figure 65). Nearly 30% of participants had some level of disagreement with this statement while 10% answered “don’t know.”

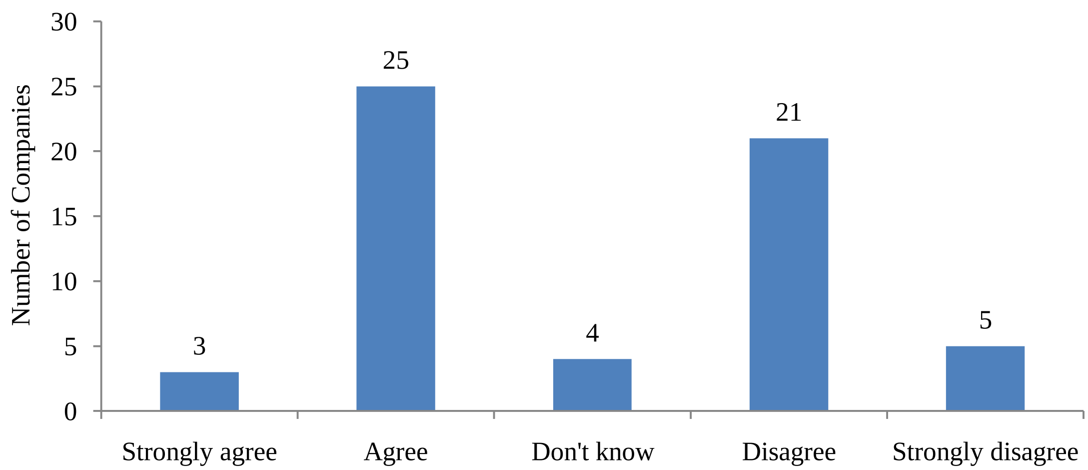

Figure 66. Levels of agreement with the statement “Voluntary reporting approaches for risk management are effective for protecting human health and the environment” (n=58).

Most participants agreed with this statement (43%, Figure 66). However, nearly the same proportion of participants (36%) disagreed with the statement. Two respondents that strongly disagreed with this statement added, “You need to stick it to me better than that; I need to follow the collectively established rules” and “most people don't do anything unless there is a big hammer over their head.”

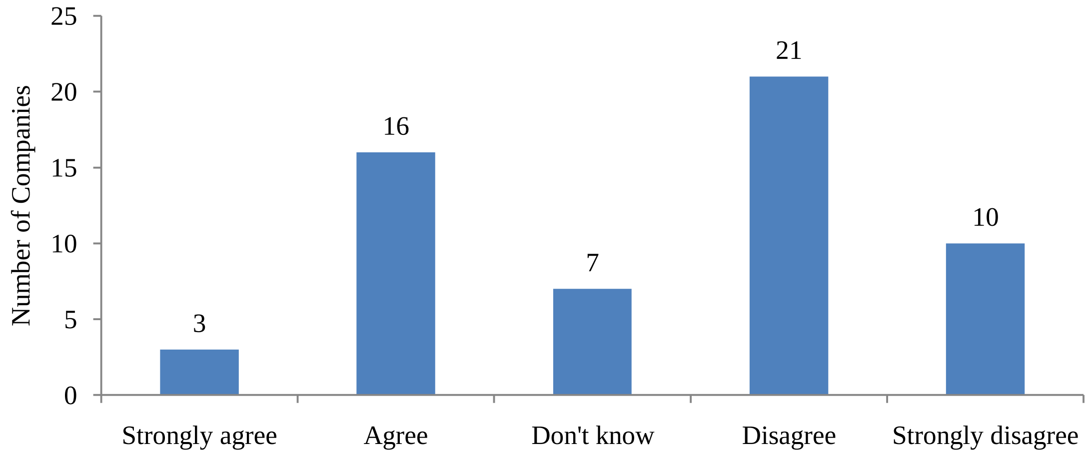

Figure 67. Level of agreement with the statement "Direct involvement of citizens in policy decisions about research and development of new technologies is beneficial" (n=57).

A majority of participants (54%) indicated some level of disagreement with this statement (Figure 67). However, 33% of participants either agreed or strongly agreed. Participants who did not know their level of agreement represented 12% of responses. Some respondents who answered "don't know" qualified their answer by commenting that the type of citizen (i.e., uninformed or paranoid) influenced their uncertainty when answering this question.

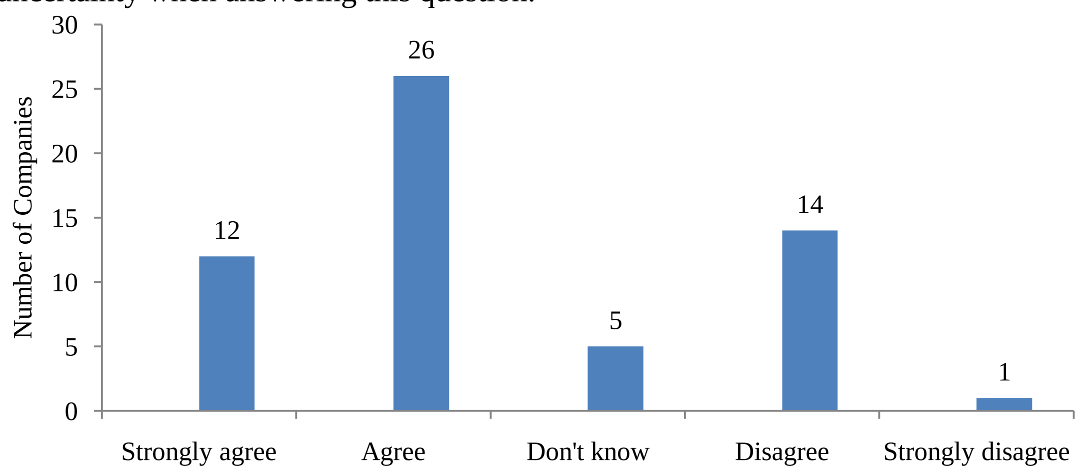

Figure 68. Level of agreement with the statement "In my company, we worry that nanotechnologies may encounter unwarranted public backlash such as that which accompanied genetically modified foods in Europe" (n=58).

Most respondents indicated some level of agreement with the statement, "In my company, we worry that nanotechnologies may encounter unwarranted public backlash such as that which accompanied genetically modified foods in Europe" (66%, Figure 68). A small number reported strongly disagreeing (2%) or not knowing their level of agreement (9%). One participant that strongly agreed with this statement also commented, “This is why the company spends so much time participating in surveys and collaboration with government and research.” Two respondents that disagreed with this statement added that they don’t worry about it but, “we are cautious” and “we do think about it”.

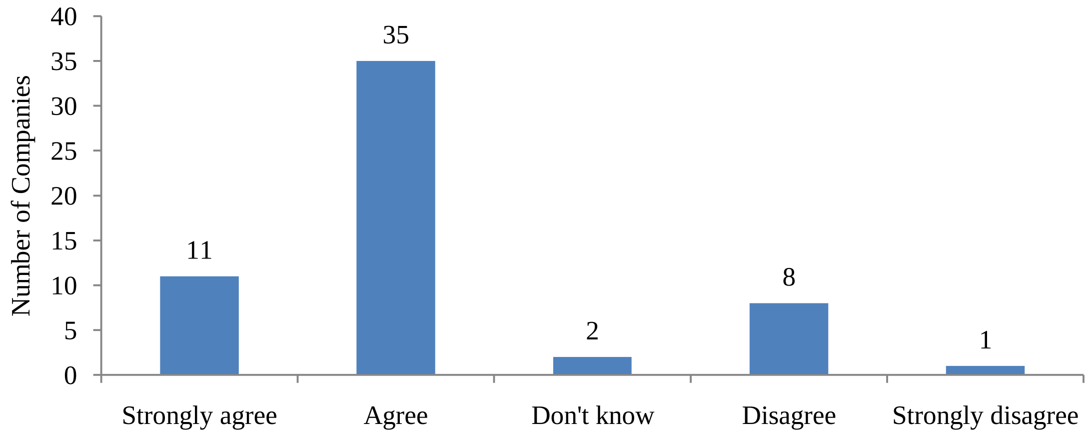

Figure 69. Level of agreement with the statement “Businesses are better informed about their own workplace safety needs than are government agencies” (n=57).

Many participants agreed or strongly agreed that businesses are better informed about their workplace safety needs (81%, Figure 69). Few respondents reported some level of disagreement with this statement (17%). Two respondents indicated they didn’t know their level of agreement (1%).

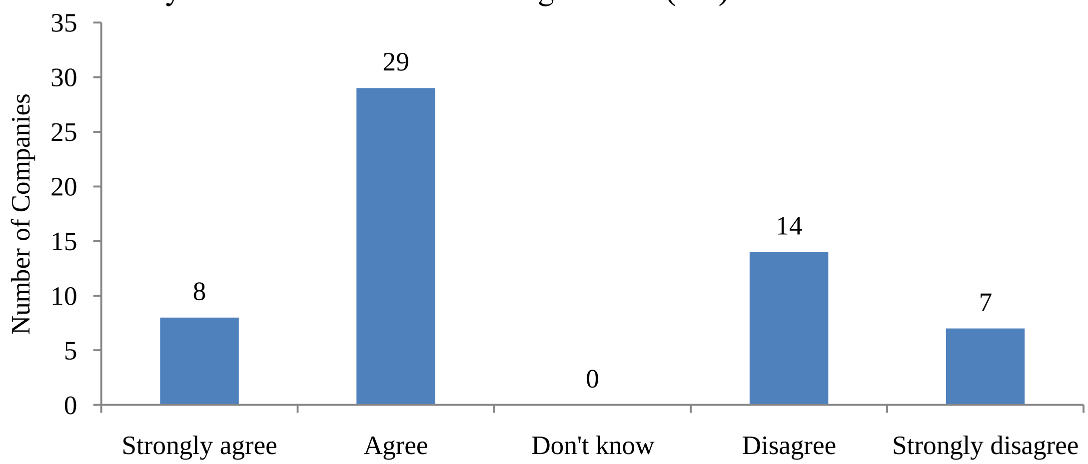

Figure 70. Level of agreement with the statement “Employees are ultimately responsible for their own safety at work” (n=58).

Half of respondents agreed that employees are ultimately responsible for their own workplace safety (Figure 70). More than one-third of participants indicated some level of disagreement with this statement. No participants answered “don’t know.”

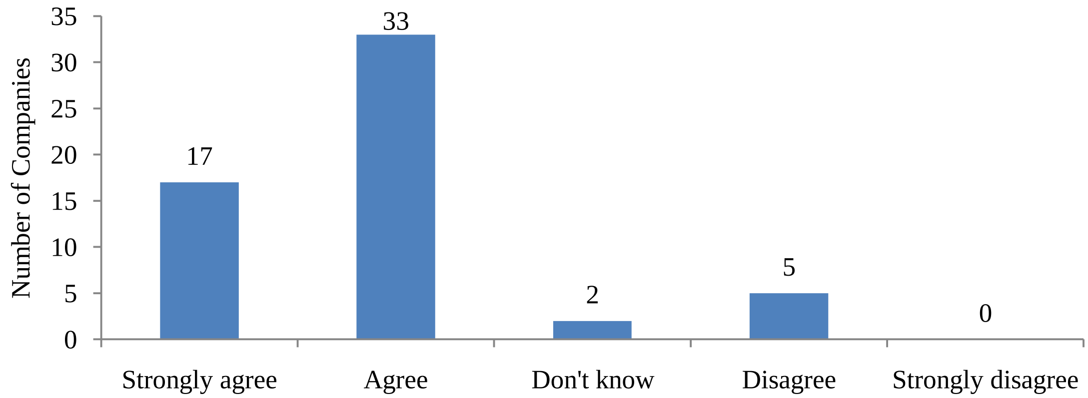

Figure 71. Level of agreement with the statement “Workplace safety should take priority over scientific and technological advancements” (n=57).

A majority of participants (88%) indicated some level of agreement with the statement, “Workplace safety should take priority over scientific and technological advancements” (Figure 71). No respondents strongly disagreed with this statement. Five participants who in responding to this question also commented on the unnecessary trade-off between workplace safety practices and scientific/technological advances saying, “there’s no reason why they shouldn’t be in parallel,” and “they go hand-in-hand.”

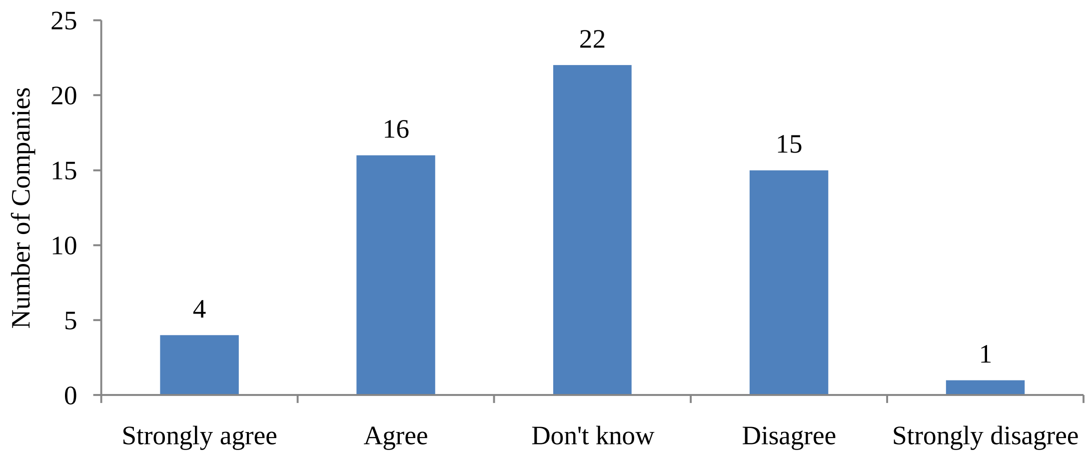

Figure 72. Level of agreement with the statement “Insurers in my industry are increasingly concerned about nano-specific risks” (n=58).

Most respondents (38%) answered “don’t know” when asked their level of agreement with the statement, “Insurers in my industry are increasingly concerned about nano-specific risks” (Figure 72). Nearly 35% of participants had some level of agreement, and 27% disagreed or strongly disagreed that insurers are increasingly concerned about nano-specific risks.

A factor analysis of the risk perception statements determined four main components, but only two variables significantly contributed to the variance of one component. These two evaluated statements were: “Industries working with nanomaterials can be trusted to regulate the safe-handling of these materials” and “It is reasonable to assume that industries working with nanomaterials will adapt or alter their safe-handling practices when new hazards are discovered.” Each statement accounted for 86.7% and 90.7% variance respectively of this component. These two questions were constructed by averaging into one variable, called perceived risk. A measure of internal consistency for a psychometric score was used to determine the reliability of the scores, and a significant Cronbach’s alpha of 0.792 resulted. The frequency of these was plotted three dimensionally against a variable measuring perceived benefit (Figure 73). The perceived benefit statement was, “In the case of nanotechnologies, the benefits of advancements in science and technology outweigh the risks involved in research, development, and production.” This method was similar to the analysis of GM foods in Britain by Pidgeon *et al*. (2005).

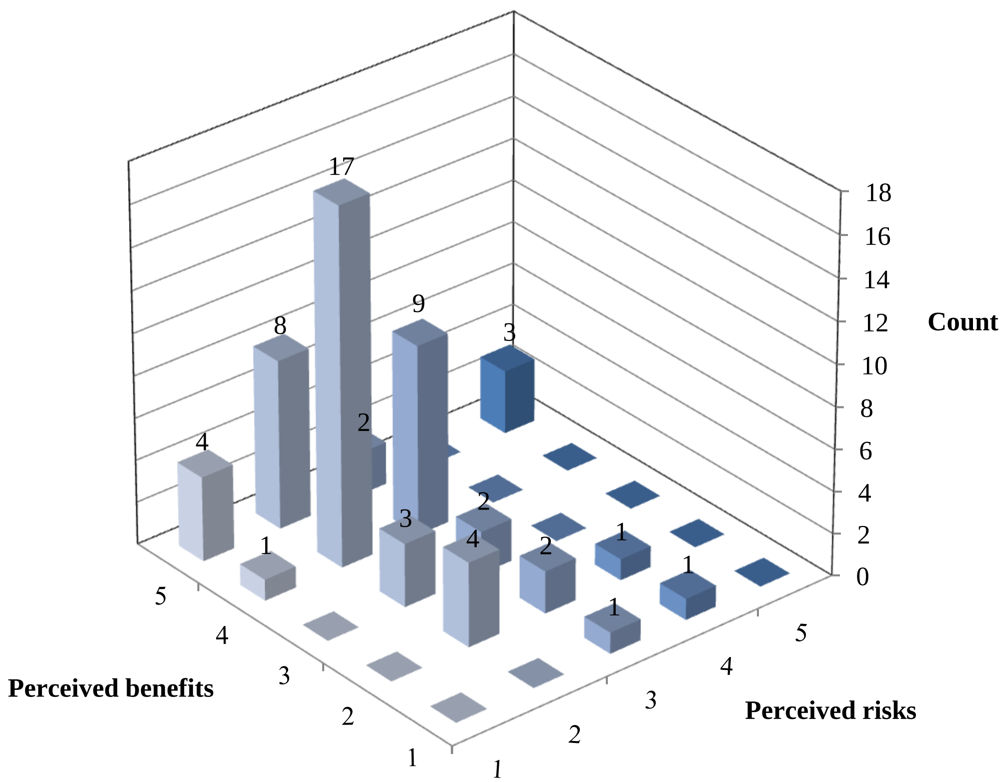

Figure 73. Perceived risks and benefits of nanotechnology. (n = 58)

The majority of respondents (29%) perceived high benefits to nanotechnology score of 4 of 5 and perceived a lower risk score of 2 of 5 (Figure 73). The next two highest numbers of respondents were in adjacent categories, with a perceived benefit score of 4 and risk score of 3 (16%), followed by a perceived benefits score of 5 and risk score of 2 (14%). A smaller number of respondents were in other adjacent categories (<7%). None of the respondents received both a benefit and risk score of 1, or a benefit of 1 and risk score of 5.

11.10.3 Views on Risk Management

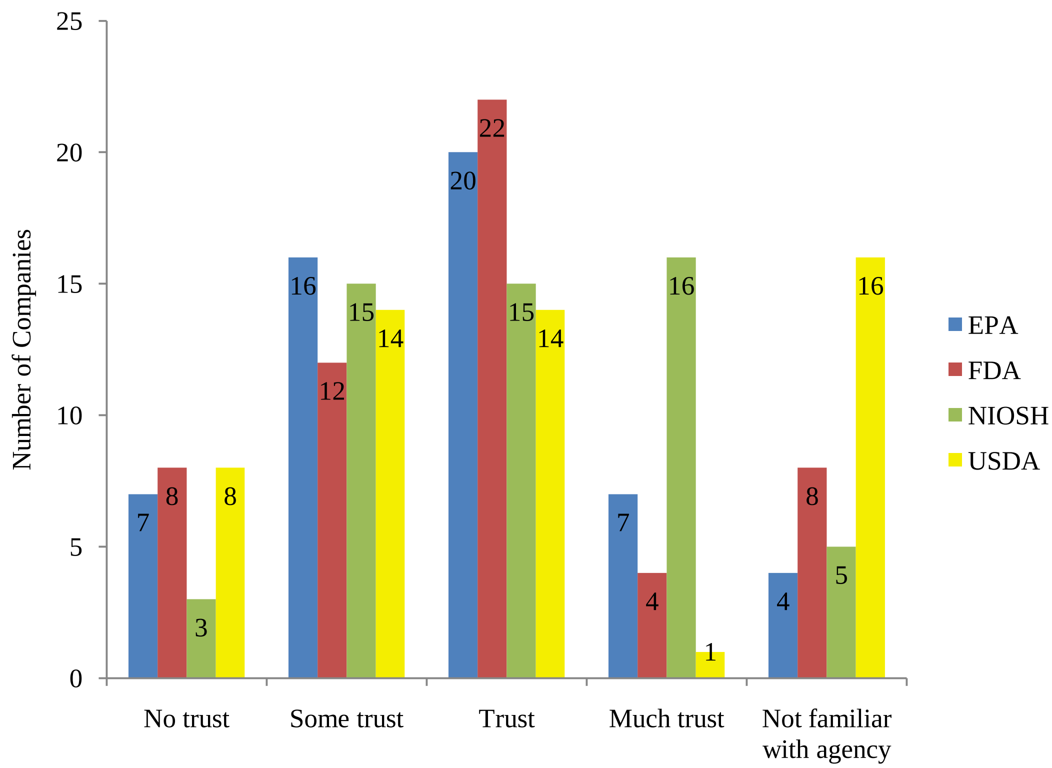

Figure 74. Reported level of trust in government agencies in the US to effectively assess and manage nano-specific EHS risks (n=54).

Reported levels of trust in US government agencies to effectively assess and manage nano-specific EHS risks were compared by levels of trust across four agencies (Figure 74). All but 1 of the 43 companies headquartered in the US rated their level of trust in US government agencies to effectively assess and manage nano-specific EHS risks. In addition, thirteen companies headquartered outside the US rated their level of trust in US government agencies. Six companies, one headquartered in the US and five headquartered outside the US, did not rate their level of trust in these government agencies.

Most participants (37% and 41%) reported having trust in EPA and the Food and Drug Administration (FDA) respectively. Most participants (30%) reported much trust in NIOSH; however a similar proportion of participants also reported trust (28%) and some trust (28%). Most participants (30%) were not familiar with the US Department of Agriculture (USDA); however, a similar proportion of participants also reported trust (26%) and some trust (26%) in USDA. Some of the participants that reported not being familiar with USDA qualified their answer by adding that USDA should not be responsible for assessing and managing nano-specific EHS risks.

Overall, more participants reported more trust in NIOSH than other government agencies to effectively assess and manage nano-specific EHS risks. A similar number of participants reported no trust in EPA, FDA and USDA, with few participants reporting no trust in NIOSH. More participants reported trust in FDA than EPA, NIOSH and USDA. A similar number of participants reported some trust in EPA, NIOSH and USDA, with the fewest participants reporting some trust in FDA.

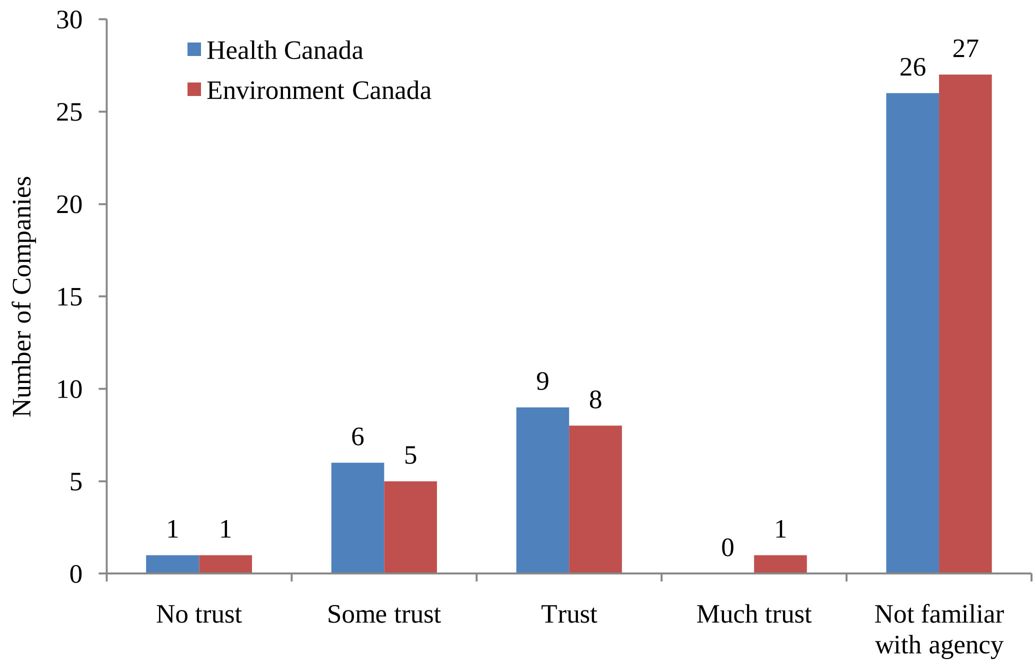

Figure 75. Reported level of trust in government agencies in Canada to effectively assess and manage nano-specific EHS risks (n=42).

Reported levels of trust in Canadian government agencies to effectively assess and manage nano-specific EHS risks were compared by levels of trust across two agencies (Figure 75). The one company headquartered in Canada rated its level of trust in Canadian government agencies to effectively assess and manage nano-specific EHS risks. In addition, 41 companies headquartered outside Canada rated their level of trust in Canadian government agencies. Eighteen companies headquartered outside Canada did not rate their level of trust in these government agencies.

The majority of participants reported not being familiar with Health Canada and Environment Canada (62% and 64% respectively). Next, many participants reported trust in both Health Canada and Environment Canada (21% and 19%

respectively). One participant reported no trust in Health Canada or Environment Canada. One participant reported much trust in Environment Canada, and no participants reported much trust in Health Canada to effectively assess and manage nano-specific EHS risks.

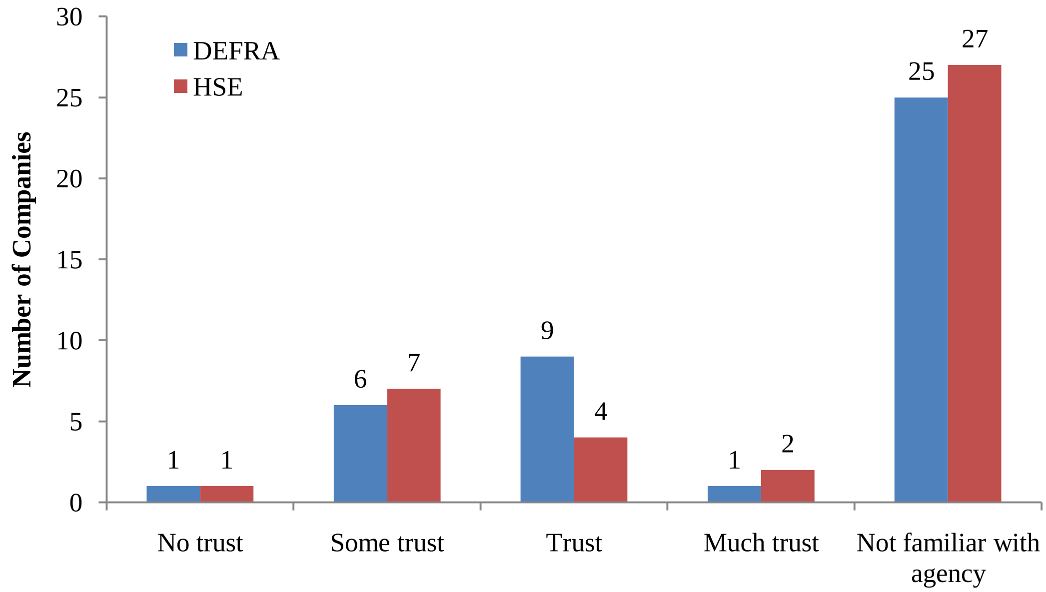

Figure 76. Reported level of trust in government agencies in the UK to effectively assess and manage nano-specific EHS risks (n=42).

Reported levels of trust in UK government agencies to effectively assess and manage nano-specific EHS risks were compared by levels of trust across two agencies (Figure 76). One company headquartered in the UK and five companies headquartered in other European countries reported their level of risk in UK government agencies to effectively assess and manage nano-specific EHS risks. In addition, 36 companies headquartered outside Europe rated their level of trust in UK government agencies. Eighteen companies, one of which was headquartered in the UK, did not rate their level of trust in these government agencies.

The majority of participants reported not being familiar with Department for Environment, Food and Rural Affairs (DEFRA) and HSE (60% and 66% respectively). More participants reported trust (21%) in DEFRA than other levels of trust. More participants reported some trust (17%) in HSE than other levels of trust. One participant reported no trust in DEFRA and HSE. Very few participants reported much trust in DEFRA and HSE.

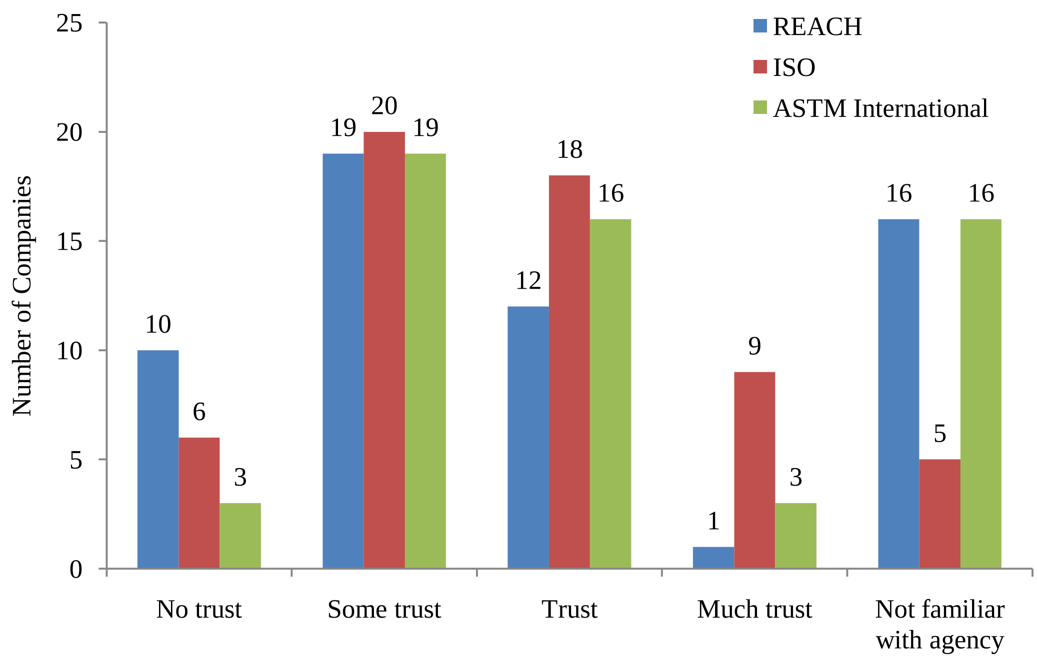

Figure 77. Reported level of trust in international organizations to effectively assess and manage nano-specific EHS risks (n=58).

Reported levels of trust in international organizations to effectively assess and manage nano-specific EHS risks were compared by levels of trust across three organizations (Figure 77). Most participants (33%, 34%, and 33% respectively) reported some trust in Registration, Evaluation, Authorization, and Restriction of Chemicals (REACH), ISO and ASTM International to effectively assess and manage nano-specific EHS risks. A similar number of participants (31% and 28% respectively) reported trust in ISO and ASTM International. More participants reported much trust in ISO than ASTM International and REACH. More participants reported no trust in REACH than ISO and ASTM International. More than one-quarter of participants reported not being familiar with REACH (28%) and ASTM International (28%) to effectively assess and manage nano-specific EHS risks. More participants reported no trust in REACH (17%) rather than much trust in REACH (2%). More participants reported much trust in ISO (16%) rather than no trust in ISO (10%). A similar number of participants compared to no trust (5%) as reported much trust (5%) in ASTM International.

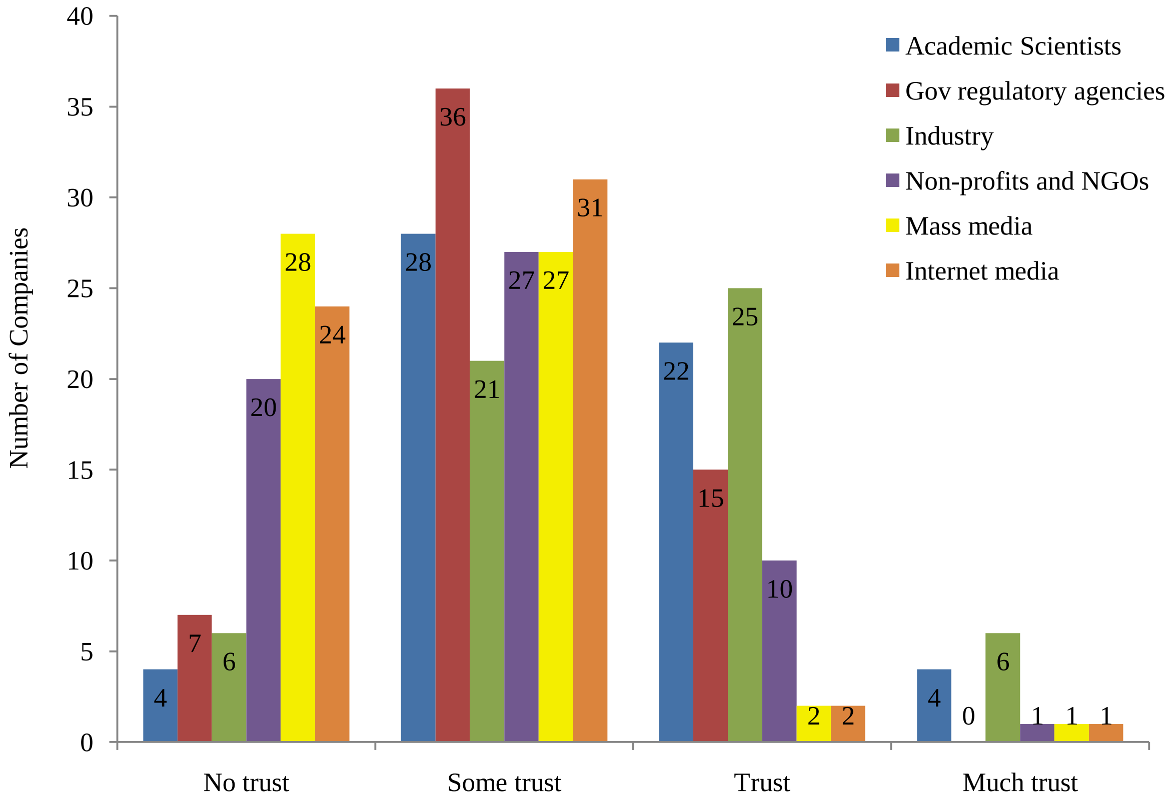

Figure 78. Reported level of trust in various sources to adequately communicate the benefits of nanotechnology to the public (n=58).

Reported levels of trust in sources to adequately communicate the benefits of nanotechnology to the public were compared by risk level across six sources (Figure 78). Nearly half of participants indicated some trust in academic scientists (48%). More than one-third of participants indicated having trust in academic scientists (38%). The same number of participants indicated having much trust (7%) as did participants that indicated having no trust (7%) in academic scientists to adequately communicate the benefits of nanotechnology to the public.

A majority of participants (62%) indicated having some trust in government regulatory agencies. Twice as many participants indicated having trust (26%) in government regulatory agencies than having no trust in government regulatory agencies (12%). No participants indicated having much trust in government regulatory agencies to adequately communicate the benefits of nanotechnology to the public. One participant that indicated some trust in government regulatory agencies also commented that they “don’t think it’s the government regulatory agencies’ job to communicate the benefits of nanotechnology to the public”.

Most participants indicated having trust (43%) in industry to adequately communicate the benefits of nanotechnology to the public. More than one-third of participants (36%) reported some trust in industry. A similar number of participants reported much trust (10%) as did no trust (10%) in industry to adequately communicate the benefits of nanotechnology to the public.

Most participants (47%) reported some trust in non-profits and NGOs. One-third of participants reported no trust in non-profits and NGOs (34%). Few participants reported trust (3%) and only one respondent reported much trust in non-profits and NGOs to adequately communicate the benefits of nanotechnology to the public.

Half of the participants indicated having some trust in traditional mass media (53%). Next, 41% of participants indicated having no trust in traditional mass media to adequately communicate the benefits of nanotechnology to the public. Few participants (3%) reported trust and only one participant reported much trust in traditional mass media to adequately communicate the benefits of nanotechnology to the public. One respondent commented, "mass media sells mass hysteria!"

A majority of participants (53%) reported some trust in internet media. More than one-third of participants (44%) reported no trust in internet media. Few participants (3%) reported trust and only one participant reported much trust in internet media to adequately communicate the benefits of nanotechnology to the public.

Overall, more participants reported having no trust in non-profits and NGOs, traditional mass media, and internet media than academic scientists, government regulatory agencies, and industry. A similar distribution of participants indicated having some trust in all sources to adequately communicate the benefits of nanotechnology to the public. More participants indicated having trust in industry and academic scientists than the other four sources to adequately communicate the benefits of nanotechnology to the public. Finally, while more respondents indicated having much trust in industry as compared to other sources, overall very few participants indicated much trust in any of these sources.

Respondents also reported topics that were not addressed in the survey that they thought were important. Two respondents thought the survey was too generic or general, and did not know where they fit based on activities. Two mention safety and handling concerns in university labs conducting research and development, such as inadequate equipment and attention to novel particles. One respondent stated that fire protection should be a higher priority than all concerns mentioned in the survey. Another thought that the fears of hazardous waste handlers needed to be addressed and that industry needed specific resources. Also, the transportation industry needed nano-specific guidance and regulations because packaging and shipping practices are very inconsistent. One respondent recommended asking about how well organizations communicate the risks of nanotechnology as well as the benefits. Another advised asking, "Do businesses see the utility of regulation? Are the current regulations sufficient for your industry?" Finally, one participant recommended asking about particle morphology.

Some respondents had further thoughts on the issues discussed in the survey. One felt that many of the academic exposure analysis reports were not realistic, due to the extreme scenarios involved, like "using rats in a vat of carbon nanotubes."

They stated that a better understanding of possible exposures in the workplace would be useful. Another participant reiterated the importance of size, material, and application matters for the level of hazard of nanomaterials. One respondent said that government should put more money into research regarding the size effects of nanoparticles. Another expressed concern that extremes are often lost in the report; they wanted to know how strongly respondents feel about the issues. Finally, one respondent emphasized that fullerenes should be classified as a chemical, and not a nanoparticles.

12 Discussion of Results

12.1 Interview Subject Information

Given that the average tenure was over 7 years and that most respondents were in senior level positions within their companies, it is assumed respondents reported accurate knowledge of their company's handling practices. Despite the variety of job titles it is assumed that overall, respondents have equivalent levels of knowledge regarding EHS programs. Henceforth, the company is considered the unit of measurement for analysis of data.

12.2 Company Information

A large majority of respondents (88%) reported that their company performs research and development for nanomaterials. More than half of companies (55%) manufacture and sell nanomaterials. A similar proportion (55 %) reported that their company manufactures and incorporates nanomaterials into other products. Only 32% of companies surveyed engage in nanomaterials characterization or other consultancy. Company nanomaterial activities determine potential worker exposure. Also, company activities with regards to nanomaterials determine the amount of nanomaterial handled.

The nanomaterials sector in which a company participates may influence current practices or reported views on risk. Companies which engage in nanomaterials activities that involve topically applied or ingested consumer goods, such as food and beverage, medicine and pharmaceuticals, and cosmetics, may perceive higher risks associated with nanomaterials. Less than 25% of companies had nanomaterials activities oriented towards food and beverage, medicine and pharmaceuticals, and cosmetics. Conversely, companies participating in sectors that incorporate nanomaterials into a "permanent" matrix, for example, aerospace, construction materials, energy, and electronics and IT, may perceive lower risks associated with nanomaterials. Most respondents (62%) represented companies with nanomaterials activities oriented towards electronics and IT. Similarly, 58% and 57% of respondents reported that their company's nanomaterials activities were oriented towards coatings and energy respectively.

The majority of respondents (72%) work for companies headquartered in the United States. Seventeen respondents (28%) represented companies headquartered outside the United States. The location of company headquarters may influence EHS programs, based on regulations and access to information. Companies headquartered in countries that provide nano-specific guidance documents may implement more nano-specific EHS controls.

A majority of respondents (73%) reported using and/or manufacturing nanomaterials in the same country as their company headquarters. Sixteen respondents (27%) reported using and/or manufacturing nanomaterials in 1 to 7 countries foreign to their company headquarters. The geographical range in which companies use and/or manufacture nanomaterials may also influence EHS programs, based on regulation and access to information. Companies with foreign nanomaterial manufacturing may not manage foreign operations consistently. Instead, they may rely on country-specific regulations and access to information to dictate EHS practices.

Table 2 shows identifiable relationships among different company characteristics. The majority of smaller companies, those with less than 20 employees, are also young companies less than 10 years old (n=20, 83.3%, p=0.000) (Table 2). Most companies that have been handling nanomaterials for less than 10 years are also young companies (n=29, 72.5%, p=0.000) (Table 3). Finally, smaller companies are more likely to have been handling nanomaterials for less than ten years (n=20, 83.3%, p=0.023) (Table 3). Smaller, younger companies that have been handling nanomaterials for a shorter amount of time may report different views on risk and EHS practices than larger or older companies.

Table 2. Significant relationships between company characteristics.

	Young Companies (<10 years)	**Older companies (10 or more years)**	**Chi-square**	**Less Experience Handling Nanomaterials (<10 years)**	**More Experience Handling Nanomaterials (10 or more years)**	**Chi-square**
Less Experience Handling Nanomaterials (<10 years)	29 (72.5%)	11 (27.5%)	**0.000**	-	-	-
More Experience Handling Nanomaterials (≥ 10 years)	2 (10.0%)	18 (90.0%)		-	-	-
Smaller Companies (<20 employees)	20 (83.3%)	4 (16.7%)	**0.000**	20 (83.3%)	4 (16.7%)	**0.023**
Larger Companies (≥20 employees)	11 (30.6%)	25 (69.4%)		20 (55.6%)	16 (44.4%)	
Handles Nano-clay	2 (20.0%)	8 (80.0%)	**0.031**	4 (40.0%)	6 (60.0%)	**0.059**
Does Not Handle Nano-clay	29 (58.0%)	21 (42.0%)		36 (72.0%)	14 (28.0%)	

12.3 Nanoparticle-specific Product Information

Companies worked with many types of nanoparticles. Most companies reported handling silica nanoparticles (38%), silver nanoparticles (37%), and/or titanium dioxide (37%). However the variety of responses is well distributed across the fourteen nanoparticle types provided in the survey. Respondents also handled nanoparticles not included in the categories provided.

Within one type of nanoparticle, some companies worked with a wide range of: 1) sizes, from less than 2.5 nm to greater than 100 nm; 2) product forms, such as dry powders, aerosols, liquids, and embedded; and 3) scales of production such as at a small scale, at the pilot scale within larger industry, and at the full or commercial scale. Nanoparticle-specific product information is an important characteristic to capture because this determines the relative risk and potential hazard.

Independent of nanoparticle type, the variety of reported nanoparticle sizes as manufactured, and product forms, is well distributed across the size classes and product form categories provided. Excluding quantum dots, nano gold and cerium oxide, most companies reported the nanoparticles they worked with agglomerate. Most companies also reported that these nanoparticles agglomerated to larger than 100 nm. Once nanoparticles agglomerate to larger than 100 nm they are no longer at the nanoscale, and unique properties may no longer be present. Finally, the scale of production was evenly distributed across the categories of: at a small scale, at the pilot scale within larger industry, and at the full or commercial scale.

12.4 Occupational and Environmental Health and Safety Programs

The majority of companies (92%) reported having a general EHS program. However, only 45% of companies reported having a nano-specific EHS program. Companies that reported not having a general EHS program also reported not having a nano-specific EHS program.

Company age was not determined to have a statistically significant effect on presence of a general EHS program. The majority of younger companies (90%) and older companies (93%) reported having a general EHS program. However, there was a relationship between company age and nano-specific EHS program. Younger companies are more likely than older companies to have a nano-specific EHS program (n=19, 63.3%, p=0.006) (Table 3). Younger companies were also more likely to have at least one part-time employee staffing their nano-specific EHS program (n=10, 50.0%, p=0.012) (Table 3).

Handling carbon nanotubes was determined to have a statistically significant effect on presence of a nano-specific EHS program. Companies that handle either single- or multi-walled carbon nanotubes are more likely to have a nano-specific EHS program than companies that do not (n=14, 63.3%, p=0.032) (Table 4). Companies that handle nano-silver are more likely to have at least one part-time employee in the nano-specific EHS program (n=7, 58.3%, p=0.022) (Table 5). On the other hand, companies that handle clay are less likely to have a nano-specific EHS program (n=1, 10.0%, p=0.032) (Table 6). Handling certain nanomaterials may have an effect on the presence of some nano-specific EHS practices and programs.

Most respondents (70%) reported implementing risk framework or other risk assessment, which is recommended by several guidance documents including NIOSH. Similarly, most respondents that implement a nano-specific EHS program reported offering training (89%) and inspection or other oversight (78%) which are important components of any EHS program.

Most companies with a nano-specific EHS program reported offering training during singular events, such as at employee orientation (74%) or when a new material is introduced (67%). Approximately half of the respondents reported offering nano-specific training on an annual basis (44%) and a smaller proportion reported some other time at which this training is offered (26%). If training is offered only at employee orientation, employees may not stay up-to-date with new information or techniques for safely handling nanomaterials. Conversely, if training is only offered annually, new employees may have been working a long time before receiving training. This is why a regular training schedule for employees is important.

Table 3. Significant relationships between company age and EHS program.

	Nano-specific EHS Program	**No Nano-specific EHS Program**	**Chi-square**	**At least 1 part-time employee in the Nano-specific EHS Program**	**No part-time employees in the Nano-specific EHS Program**	**Chi-square**
Young Companies (<10 years)	19 (63.3%)	11 (36.7%)	**0.006**	10 (50.0%)	10 (50.0%)	**0.012**
Older companies (10 or more years)	8 (27.6%)	21 (72.4%)		2 (11.1%)	16 (88.9%)	

Table 4. Significant relationships between carbon nanotubes handled and EHS program.

	Nano-specific EHS Program	**No Nano-specific EHS Program**	**Chi-square**
Handles CNTs	14 (63.6%)	8 (36.4%)	**0.032**
Does Not Handle CNT	13 (35.1%)	24 (64.9%)	

Table 5. Significant relationships between nano-silver handled and EHS program.

	At least 1 part-time employee in the Nano-specific EHS Program	No part-time employees in the Nano-specific EHS Program	Chi-square
Handles Nano-silver	7 (58.3%)	5 (41.7%)	**0.022**
Does Not Handle Nano-silver	5 (19.2%)	21 (80.8%)	

Table 6. Significant relationships between nano-clay handled and EHS program.

	Nano-specific EHS Program	No Nano-specific EHS Program	Chi-square
Handles Nano-clay	1 (10.0%)	9 (90.0%)	**0.013**
Does Not Handle Nano-clay	23 (46.9%)	26 (53.1%)	

12.5 Employee Area and Exposure Monitoring

Most companies (61%) report that they do not monitor the workplace for nanomaterials. Out of the 20 respondents that did indicate the type of equipment used to monitor the monitoring the workplace for nanomaterials, 52% used some other method than the options provided. More companies (52%) reported using diffusion chargers than any of the other monitoring equipment options. Many respondents (64%) do not monitor on a regular basis. The cost of monitoring equipment may be prohibitive. This may prevent companies from monitoring regularly, or at all. Small companies with less than 20 employees are less likely to monitor the workplace for nanomaterials (n=7, 41.2%, p=0.027) (Table 7).

However, type of nanomaterial handled may have an effect on monitoring practices. Companies that handle carbon nanotubes (either single- or multi-walled carbon nanotubes) are more likely than companies that do not handle carbon nanotubes to monitor the workplace for nanomaterials (n=12, 54.5%, p=0.054) (Table 7). Nano-silver companies are also more likely to monitor the workplace for nanomaterials (n=12, 54.5%, p=0.054) (Table 7).

Table 7. Significant relationships between company characteristics and monitoring practices.

	Monitor the Workplace for Nanomaterials	**Does Not Monitor the Workplace for Nanomaterials**	**Chi-square**
Small Companies (<20 employees)	7 (41.2%)	10 (58.8%)	**0.027**
Large Companies (20 or more Employees)	18 (50.0%)	18 (50.0%)	
Handles CNTs	12 (54.5%)	10 (45.5%)	**0.054**
Does Not Handle CNT	11 (29.7%)	26 (70.3%)	
Handles Nano-silver	12 (54.5%)	10 (45.5%)	**0.054**
Does Not Handle Nano-silver	11 (29.7%)	26 (70.3%)	

12.6 Containment and Exposure Controls

The amount of nanomaterial handled at one time may affect a company's EHS practices. Most companies (38%) reported handling between 1 gram to less than 1 kilogram, and 28% of companies reported handling more than 1 kilogram at one time. The remaining companies handled less than 1 gram at a time.

Most companies (82%) reported using a fume hood to manage employee exposure to nanomaterials. A majority of companies (63%) also reported using HEPA filtration, and 60% reported designated or separate work areas. Approximately half of the respondents reported using pressure differentials, glove boxes, and/or a separate HVAC system. Less than 40% of respondents reported using clean rooms, closed piping systems, glove bags, laminar flow clean benches, and/or biological safety cabinets. Few respondents reported using ULPA to manage employee exposure to the nanomaterials. The use of ULPA filtration is not recommended by guidance documents as it is not thought to filter nanoscale particles adequately. One participant indicated that none of the facility design and engineering controls listed in the survey were used to manage employee exposure to nanomaterials.

Conti *et al*. (2008) found that while many companies used fume hoods, some respondents reported turning off fume hoods while working with nanopowders to prevent loss of material. In this survey, most respondents reported always using engineering controls, but 21% indicated using controls some of the time. It is possible that avoiding product loss is similarly the reason.

Most respondents (88%) reported wet wiping as a cleaning method for areas in which nanomaterials are handled. Many companies also reported using HEPA vacuums (45%), absorbent materials (39%), and soaps or cleaning oils (38%). Less than one-third of respondents reported using sweeping, household or shop vacuums, and compressed air for cleaning areas in which nanomaterials are handled. Guidance documents recommend against using compressed air and sweeping, as these methods can cause nanoparticles to become airborne and increase risk of exposure. Vacuums without HEPA filtration are also discouraged. The use of these methods despite recommendations against these practices may indicate a lack of information regarding nano-specific cleaning methods. Most respondents (67%) reported cleaning after spills. Approximately 30% respondents reported cleaning at the end of every shift or at the end of every work day.

Most participants (69%) reported always transporting nanomaterials in closed containers within the facilities. Nearly one-quarter of respondents reported sometimes transporting nanomaterials in closed containers, and 9% of respondents reported never transporting nanomaterials in closed containers. Some respondents also stated that closed containers are mainly used to protect the product due to the heavy costs associated with product loss. Companies also indicated that material type determined how nanomaterials were transported.

12.7 Personal Protective Equipment

Companies reported requiring or recommending many different types of PPE. All respondents reported recommending or requiring eye protection. Nearly 90% of respondents also reported that their company required or recommended lab coats and nitrile gloves. At least 69% of companies report requiring or recommending latex gloves and dust masks, despite the recommendations of some guidance documents. Latex gloves are not thought to provide as much protection as nitrile gloves, and dust masks do not provide sufficient respiratory protection. Approximately half of respondents reported requiring or recommending hair bonnets or coveralls. This is another instance where lack of information could be an impediment to following recommended practices. Fewer respondents reported requiring or recommending building suits. Some PPE, such as hair bonnets or building suits, is also used to protect the product from contamination.

Most respondents (61%) reported that employees use respiratory protection when working with nanomaterials. Disposable filtering face piece is the most reported type of respiratory protection. In a hierarchical risk management program, respiratory protection is to be used as a last measure of protection if engineering and administrative controls are not sufficient. The extensive use of respiratory protection may imply that companies feel that other controls do not provide complete protection from nanomaterials, and perceived a high risk to workers' safety.

12.8 Barriers to Implementing Nano-Specific Health and Safety Practices

Respondents reported their level of agreement with statements that addressed potential barriers perceived to exist by companies who currently have or intend to implement a nano-specific EHS program. Few respondents overall (30%) agreed or strongly agreed that budget constraints were an impediment to a nano-specific EHS program. However, companies that had been working with nanomaterials for ten or more years were more likely to consider budget constraints an impediment in this regard (n=10, 52.6%, p=0.021) (Table 8).

More than three-quarters of respondents disagreed that internal enforcement was an impediment. This question was meant to capture complications in internal communication, employee adherence to workplace policies, and lack of EHS prioritization within the company. Generally, respondents also disagreed that lack of EHS guidance or regulations are impediments to a nano-specific EHS program. However, companies that handle nano-silver are more likely to agree that lack of regulations are an impediment (n=14, 66.7%, p=0.033) (Table 8).

Conti *et al*. (2008) found that 71% of organizations reported lack of information as an impediment in implementing a nano-specific EHS program. More than half of the respondents in this survey agreed that lack of information was a barrier. Though a smaller proportion of companies reported lack of information as a barrier, this still seems to be a hindrance to implementing a nano-specific EHS program. Certain companies are less likely to perceive lack of information as an impediment, such as small companies with less than 20 employees (n=9, 39.1%, p=0.021) (Table 8).

Table 8. Significant relationships between company characteristics and impediments.

		Agree	Disagree	Chi-square
Budget is an impediment in implementing a nano-specific EHS program.	**Companies Handling Nanomaterials (<10 years)**	8 (21.6%)	29 (78.4%)	**0.021**
	Companies Handling Nanomaterials (10 or more years)	10 (52.6%)	9 (47.4%)	
Lack of information is an impediment in implementing a nano-specific EHS program.	**Small Companies (<10 Employees)**	9 (39.1%)	14 (60.9%)	**0.021**
	Large Companies (10 or more Employees)	10 (52.6%)	9 (47.4%)	
Lack of regulations is an impediment in implementing a nano-specific EHS program.	**Handles Nano-silver**	14 (66.7%)	7 (33.3%)	**0.033**
	Does Not Handle Nano-silver	14 (37.8%)	23 (62.2%)	

12.9 Waste Management and Product Stewardship

Less than half of the respondents reported having a nano-specific waste program. However, companies that handle carbon nanotubes (either single- or multi-walled carbon nanotubes) are more likely to have a nano-specific waste program (n=11, 52.4%, p=0.050) (Table 9). In addition, companies that handle silver nanoparticles are more likely to have a nano-specific waste program than other companies (n=12, 57.1%, p=0.014) (Table 9). Furthermore, companies that had a nano-specific EHS program were more likely to have a nano-specific waste program (n=17, 63.0%, p=0.000).

Most companies (67%) reported that they disposed of their nanomaterials as hazardous waste. Many companies also indicated that their decision to dispose of materials as hazardous waste was determined by the substance itself, not the size or structure. Younger companies are more likely to dispose of their nanomaterials as hazardous waste (n=26, 86.7%, p=0.001) (Table 10). Companies that have been working with nanomaterials for less than 10 years are also more likely to dispose of nanomaterials as hazardous waste (n=30, 75.0%, p=0.042) (Table 10).

More than half of the companies reported that their company did not use separate disposal containers in the lab or waste storage areas. Some respondents indicated that disposal varied based on material type. Companies that handle clay are even less likely to use separate containers than other companies (n=0, 0.0%, p=0.008) (Table 11). Also, 77% of respondents reported that their company did not list nanomaterials separately as “nanomaterials” on waste manifests. However, age of company and years handling nanomaterials appear to have a significant effect on this. Younger companies are more likely to list their nanomaterials separately (n=10, 34.5%, p=0.033) (Table 12). Companies that have been handling nanomaterials for longer are also more likely to list nanomaterials separately (n=12, 30.8%, p=0.032) (Table 12).

A majority of respondents (77%) reported that their company advertise or otherwise disclose that their products contain nanomaterials. Additionally, some respondents indicated that they use the disclosure of nanomaterials within the product as a marketing tool. Younger companies are more likely to advertise or otherwise disclose that their products contain nanomaterials (n=27, 93.1%, p=0.003) (Table 13). Companies with fewer than 20 employees are extremely likely to advertise or otherwise disclose the nanomaterials in their products (n=22, 100.0%, p=0.000) (Table 13). Companies with headquarters outside the US are also much more likely to advertise or otherwise disclose that their products contain nanomaterials (n=16, 94.1%, p=0.039) (Table 13).

More than 80% of companies also report that their company provides guidance to their customers regarding safe use and/or disposal or their products. Companies that handle silica are more likely to provide this guidance (n=22, 95.7%, p=0.018). While a majority of the companies indicate providing guidance to their customers for the safe use and/or disposal of their products, most of the information listed was not nano-specific. Some companies reported supplying MSDS as nano-specific guidance.

However, most MSDS sheets provide information specific to the bulk material, not nano-specific information.

Table 9. Significant relationships between nanomaterial handled and waste programs.

	Nano-specific Waste Program	**No Nano-specific Waste Program**	**Chi-square**
Handles CNTs	11 (52.4%)	10 (47.6%)	**0.050**
Does Not Handle CNT	10 (27.0%)	27 (73.0%)	
Handles Nano-silver	7 (58.3%)	5 (41.7%)	**0.022**
Does Not Handle Nano-silver	5 (19.2%)	21 (80.8%)	

Table 10. Significant relationships between company characteristics and waste programs.

	Dispose of Nano-materials as Hazardous Waste	**Do Not Dispose of Nano-materials as Hazardous Waste**	**Chi-square**
Young Companies (<10 years)	26 (86.7%)	4 (13.3%)	**0.001**
Older companies (10 or more years)	12 (44.4%)	15 (55.6%)	
Companies Handling Nanomaterials <10 years	30 (75.0%)	10 (25.0%)	**0.042**
Companies Handling Nanomaterials for 10 or more years	8 (47.1%)	9 (52.9%)	

Table 11. Significant relationships between nanomaterial handled and disposal practices.

	Uses Separate Containers to Dispose of Nano-materials	**Does Not Use Separate Containers to dispose of Nano-materials**	**Chi-square**
Handles Nano-clay	0 (0.0%)	8 (100.0%)	**0.008**
Does Not Handle Nano-clay	24 (49.0%)	25 (51.0%)	

Table 12. Significant relationships between company characteristics and waste practices.

	List Nano-materials Separately on Waste Manifests	**Do Not List Nano-materials Separately on Waste Manifests**	**Chi-square**
Young Companies (<10 years)	10 (34.5%)	19 (65.5%)	**0.033**
Older companies (10 or more years)	1 (5.6%)	17 (94.4%)	
Companies Handling Nanomaterials <10 years	12 (30.8%)	27 (69.2%)	**0.032**
Companies Handling Nanomaterials for 10 or more years	1 (5.6%)	17 (94.4%)	

Table 13. Significant relationships between company characteristics and advertising or disclosure practices.

	Advertise that their products contain Nanomaterials	**Do Not Advertise that their products contain Nanomaterials**	**Chi-square**
Young Companies (<10 years)	27 (93.1%)	2 (6.9%)	**0.003**
Older companies (10 or more years)	16 (59.3%)	11 (40.7%)	
Small Companies (<20 employees)	22 (100.0%)	0 (0.0%)	**0.000**
Large Companies (20 or more Employees)	21 (61.8%)	13 (38.2%)	
Companies Located in the United States	27 (69.2%)	12 (30.8%)	**0.039**
Companies Not Located in the United States	16 (94.1%)	1 (5.9%)	

12.10 Views on Risk Associated with Nanomaterials

When asked about risks to human health and the environment associated with certain nanomaterials, participants provided a variety of responses. The nanomaterial most often considered almost no risk to human health and the environment was heavy metals. More respondents rated metal oxides as a slight risk. Next, more respondents rated other carbonaceous materials as a moderate risk to human health and the environment. According to respondents, carbon nanotubes pose the highest risk to human health and the environment, as compared to other nanomaterial categories. Respondents generally reported that they did not know the level of risk associated with dry powders and quantum dots. The broad nature of the question could have prompted the abundance of “don’t know” responses. However, it is also possible that lack of information was preventing participants from determining the levels of risks associated with these nanomaterials. This question also elicited a number of negative reactions. Two participants declined to answer the question because they indicated their answers would be too subjective. Three respondents answered, “don’t know,” to one or all comparative items because they thought that the category was “too broad” or “too generic.”

12.11 Views on Risk

Respondents reported their level of agreement with statements that addressed factors that could constrain scientific innovation, and how best to limit the potential risks of nanomaterials. In general, respondents more frequently agreed to statements presented than strongly agreed, disagreed, strongly disagreed, or answered "don't know." A majority of respondents agreed or strongly agreed that industries working with nanomaterials can be trusted to regulate the safe-handling of those materials. Most respondents agreed or strongly agreed that it is reasonable to assume that industries working with nanomaterials will adapt or alter their safe-handling practices when new hazards are discovered. Companies that handle silica were even more likely to agree with this statement than other companies (n=19, 90.5%, p=0.024) (Table 14). However, small companies were more likely to disagree with this statement (n=5, 21.7%, p=0.041) (Table 14).

Most respondents agreed or strongly agreed that in the case of nanotechnologies, the benefits of advancements in science and technology outweigh the risks involved in research, development, and production. Most respondents agreed or strongly agreed that waiting until safety studies are complete to commercialize nanotechnology will deprive society of too many potential benefits. This implies that respondents believe the possible benefits of nanotechnology outweigh the uncertainties.

A majority of respondents reported agreeing or strongly agreeing that in their company, they worry that nanotechnologies may encounter unwarranted public backlash such as that which accompanied genetically modified foods in Europe. However, companies with headquarters located in the United States were less likely to fear public backlash (n=25, 64.1%, p=0.038) (Table 14). A majority of respondents agreed or strongly agreed that businesses are better informed about their own workplace safety needs than are government agencies. Most respondents agreed or strongly agreed that workplace safety should take priority over scientific and technological advances. However, companies that handled carbon nanotubes were more likely disagree with this statement (n=5, 23.8%, p=0.006) (Table 14).

Respondents were almost evenly split on their agreement or disagreement that voluntary reporting approaches for risk management are effective for protecting human health and the environment. While most respondents agreed or strongly agreed with this statement, a similar number of respondents reported some level of disagreement with this statement. More than half of respondents agreed or strongly agreed that employees are ultimately responsible for their own safety at work. Some respondents disagreed that employees are ultimately responsible for their own safety at work, but no respondents answered "don't know."

Most respondents disagreed or strongly disagreed that direct involvement of citizens in policy decisions about research and development of new technologies is beneficial, while approximately 10% of respondents reported that they did not know. Nearly 40% of respondents did not know if insurers in their industry are increasingly concerned about nano-specific risks, and a similar proportion of respondents agreed and disagreed that insurers in their industry are increasingly concerned about nano-specific risks.

When comparing the perceived risk and benefits of nanotechnology, most respondents perceived a greater benefit rather than risk. Pidgeon *et al*. (2005) described a matrix of risk responses, where high perceived risk and low perceived benefits would be a negative attitude towards nanotechnology. Correspondingly the opposite would exist; low perceived risk and high perceived benefits would be a positive attitude toward nanotechnology. Perceiving high risk and high benefit is described by Pidgeon *et al*. (2005) as ambivalent. In this case, the majority of respondents perceive nanotechnology positively. Although, in this study, a few outliers were also present. Three respondents indicated the highest perceived risk and benefit score resulting in ambivalence. They indicated that while they perceive high risks to nanotechnology, that these risk are mitigated by the high perceived benefits.

Table 14. Significant relationships between company characteristics and views on risk.

	Agree with "*It is reasonable to assume that industries working with nanomaterials will adapt or alter their safe-handling practices when new hazards are discovered*."	Disagree with "*It is reasonable to assume that industries working with nanomaterials will adapt or alter their safe-handling practices when new hazards are discovered*."	Chi-square
Small Companies (<20 employees)	18 (78.3%)	5 (21.7%)	**0.041**
Large Companies (20 or more Employees)	31 (96.9%)	1 (3.1%)	
Handles Silica	19 (90.5%)	2 (9.5%)	**0.024**
Does Not Handle Silica	18 (62.1%)	11 (37.9%)	
	Agree with "*In my company, we worry that nanotechnologies may encounter unwarranted public backlash such as that which accompanied genetically modified foods in Europe.*"	**Disagree with "*In my company, we worry that nanotechnologies may encounter unwarranted public backlash such as that which accompanied genetically modified foods in Europe*."**	**Chi-square**
US Companies	25 (64.1%)	14 (35.9%)	**0.038**
Non US Companies	13 (92.9%)	1 (7.1%)	
	Agree with "*Workplace safety should take priority over scientific and technological advances*."	**Disagree with "*Workplace safety should take priority over scientific and technological advances*."**	**Chi-square**
Handles CNTs	16 (76.2%)	5 (23.8%)	**0.006**
Does Not Handle CNT	34 (100.0%)	0 (0.0%)	

12.12 Views on Risk Management

Participants rated their levels of trust in US, Canadian, and UK government agencies, and international organizations to effectively assess and manage nano-specific EHS risks. Many respondents with companies headquartered in countries foreign to the government agency in question reported that they were not familiar with the agency. However some respondents did rate their level of trust based on their knowledge of, or experience working with, the foreign government agency.

Regardless of location of company headquarters, most participants have much trust in NIOSH to effectively assess and manage nano-specific EHS risks. Similarly, most participants trust EPA and FDA to effectively assess and manage nano-specific EHS risks (37% and 41% respectively). Most participants (30%) were not familiar with the USDA. The majority of participants reported not being familiar with Health Canada and Environment Canada (62% and 64% respectively). The majority of participants reported not being familiar with DEFRA and HSE (60% and 66% respectively).

Tables 15, 16 and 17 show identifiable relationships among reported levels of trust in different government agencies within the same country. Generally, participants consistently reported similar levels of trust across all government agencies within the same country. However, some participants did report varying levels of trust based on their experiences working with each government agency. For example, participants that reported less trust in EPA are more likely to report less trust in FDA (n=15, 78.9%, p=0.007), NIOSH (n=15, 83.3%, p=0.000), and USDA (n=17, 85%, p=0.001).

Table 18 shows identifiable relationships among reported levels of trust in different government agencies across different countries. Participants that reported more trust in both Canadian government agencies are more likely to report more trust in both UK government agencies. Also, participants that reported more trust in NIOSH in the US, are more likely to report more trust in DEFRA in the UK (n=12, 92.3%, p=0.048).

Unlike the government agencies, more participants reported their level of trust than reported not being familiar with the three international organizations. However, more than one-quarter of participants reported not being familiar with REACH (28%) and ASTM International (28%) to effectively assess and manage nano-specific EHS risks. Overall, most participants reported some trust in REACH, ISO and ASTM International to effectively assess and manage nano-specific EHS risks (33%, 34%, and 33% respectively). More participants reported no trust in REACH (17%) than much trust in REACH (2%). Conversely, more participants reported much trust in ISO (16%) than no trust in ISO (10%). A similar number of participants reported no trust (5%) as reported much trust (5%) in ASTM International.

Participants rated their level of trust in a variety of sources to adequately communicate the benefit of nanotechnology to the public: academic scientists, government regulatory agencies, industry involved in nanotechnology, non-profits and non-governmental organizations, traditional mass media, and internet media. A greater number of respondents reported having no trust in non-profits and non-governmental organizations, traditional mass media, and internet media than in academic scientists, government regulatory agencies and industry. Correspondingly, a greater number of respondents reported having trust in academic scientists, government regulatory agencies and industry.

More participants reported having trust in industry rather than trust in any other source to adequately communicate the benefits of nanotechnology to the public. More participants reported some trust in government regulatory agencies rather than some trust in any other source. No participants reported much trust and few participants (26%) reported trust in government regulatory agencies. It is important to restate that most participants (55%) reported using government guidance documents from organizations, such as NIOSH, EPA, and HSE, as sources of nano-specific guidance for development of EHS programs. Based on these findings, companies seem to rely on guidance documents from government regulatory agencies even though they do not trust government to adequately communicate the benefit of nanotechnology to the public.

A factor analysis was performed on the measures of trust perceived by industry. Four components were extracted, with most contributing low percent variance. One significant finding included the individual measurements in the level of trust in US, Canada, and U.K government agencies to effectively assess and manage nano-specific environmental health and safety risks and contributed 63-96% variance to one component. In future research, the statements of US government agencies may be compared as a composite measurement, as their Cronhach's alpha of internal consistency was significant (alpha = 0.835, n =35). Canada's government agencies received a similar score (alpha = 0.837). The internal consistency value of UK government agencies was the most significant Cronbach's alpha of 0.938.

Trust in organizations, such as government, is known to be a somewhat tenuous and not easily manipulated characteristic. Poortinga & Pidgeon (2005) also suggested that sometimes the best way to influence trust to decrease risks is not through direct involvement, like solely distributing information. This type of direct measure may be interpreted as not evaluating the concerns of the target and can actually create distrust. Government entities must understand that trust is dependent upon a dual line of communication, where the interactions between both entities increase trust. Active and collaborative interactions, such as NIOSH's workplace monitoring consultations and testing, appear to be a positive effect on trust between industry and NIOSH. Many respondents reported participating in NIOSH-related monitoring activities and this government agency scored relatively high trust in comparison to other governmental organizations. A strong level of trust is an important measurement considering that trust may aid in buffering negative reactions to non-catastrophic breakdowns in emerging technologies.

Table 15. Significant Distributions of Rated Levels of Trust in US Government Agencies.

	FDA: Less Trust	FDA: More Trust	Chi-square	NIOSH: Less Trust	NIOSH: More Trust	Chi-square	USDA: Less Trust	USDA: More Trust	Chi-square
EPA: Less Trust	15 (78.9%)	4 (21.1%)	**0.007**	15 (83.3%)	3 (16.7%)	**0.000**	17 (85.0%)	3 (15.0%)	**0.001**
EPA: More Trust	2 (22.2%)	7 (77.8%)		1 (9.1%)	10 (90.9%)		1 (12.5%)	7 (87.5%)	
USDA: Less Trust	16 (80.0%)	2 (20.0%)	**0.003**	13 (76.5%)	5 (35.7%)	**0.027**	-	-	-
USDA: More Trust	4 (20.0%)	8 (80.0%)		4 (23.5%)	9 (64.3%)		-	-	
NIOSH: Less Trust	14 (77.8%)	2 (18.2%)	**0.003**	-	-	-	-	-	-
NIOSH: More Trust	4 (22.2%)	9 (81.8%)		-	-		-	-	

Table 16. Significant Distributions of Rated Levels of Trust in Canadian Government Agencies.

	Environment Canada: Less Trust	Environment Canada: More Trust	Chi-square
Health Canada: Less Trust	6 (85.7%)	1 (14.3%)	**0.000**
Health Canada: More Trust	0 (0%)	26 (100.0%)	

Table 17. Significant Distributions of Rated Levels of Trust in UK Government Agencies.

	HSE: Less Trust	HSE: More Trust	Chi-square
DEFRA: Less Trust	7 (100.0%)	0 (0.0%)	**0.000**
DEFRA: More Trust	0 (0.0%)	25 (100.0%)	

Table 18. Significant Distributions of Reported Levels of Trust Across Government Agencies in Different Countries.

	DEFRA: Less Trust	DEFRA: More Trust	Chi-square	HSE: Less Trust	HSE: More Trust	Chi-square
Health Canada: Less Trust	5 (83.3%)	1 (16.7%)	**0.001**	6 (85.7%)	1 (14.3%)	**0.000**
Health Canada: More Trust	2 (8.3%)	22 (91.7%)		2 (8.0%)	23 (92.0%)	
Environment Canada: Less Trust	5 (100.0%)	0 (0.0%)	**0.000**	6 (100.0%)	0 (0.0%)	**0.000**
Environment Canada: More Trust	2 (8.0%)	23 (92.0%)		2 (7.7%)	24 (92.3%)	
NIOSH: Less Trust	6 (42.9%)	8 (57.1%)	**0.048**	-	-	-
NIOSH: More Trust	1 (7.7%)	12 (92.3%)		-	-	

13 Conclusions

Traditionally, start-up companies are thought to be more concerned with growth and profits than environmental performance. However, the smaller, younger companies that responded to this survey appear to be more attentive to risks and risk management associated with nanomaterials. Company age, size, and the number of years working with nanomaterials appear to be correlated for most of the survey respondents. Younger companies tend to be smaller and have spent a fewer number of years working with nanomaterials. These companies can be thought of as start-ups. Younger companies are more likely to have a nano-specific EHS program, as well as have at least one part-time equivalent employee in the nano-specific EHS program. In regards to waste stewardship, younger companies are more likely to dispose of their nanoparticles as hazardous waste and to list them separately as "nanomaterials" on waste manifests. Smaller and younger companies are more likely to advertise or otherwise disclose to their customers that their products contain nanomaterials. Smaller companies were also less likely to report lack of information being a barrier to implementing nano-specific EHS practices.

Older, larger companies are less likely to have a nano-specific EHS program, and are more likely to report that a lack of information and budget constraints are barriers to implementing nano-specific EHS practices. In addition, larger companies have more employees that work directly with nanomaterials (on average 76 employees) compared to smaller companies, who average six employees. This means that larger companies who tend to have fewer nano-specific controls are more likely to have a greater number of employees potentially at risk of being exposed to nanomaterials. However, larger companies are also more likely to agree that it is reasonable to assume that industries working with nanomaterials will adapt or alter their safe-handling practices when new hazards are discovered. Therefore, there is a disconnect between larger companies believing that industry will adapt to new risks and their likelihood of implementing nano-specific EHS practices.

These start-up companies could represent a new direction for the nanomaterials industry. This group of companies is not inhibited by a lack of information about nano-specific risks and EHS programs. In addition, they inform consumers about the nanotechnology in their products. As start-up companies grow larger and become established in the industry, their practices may influence the nanomaterials industry as a whole.

Toxicological research has been done on the effects of carbon nanotubes, and long, straight multi-walled carbon nanotubes have been shown to have properties similar to asbestos in the lungs of mice (Poland *et al.*, 2008, HSE 2009). Companies that handle CNTs generally tend to be larger in size and older. They are also more likely to disagree that workplace safety should take priority over scientific and technological advances. Based on previous relationships between company size, age, and likelihood of having a nano-specific EHS program, one might expect that these CNT companies would be less likely to have nano-specific EHS practices. However, companies that handle CNTs tend to participate in more nano-specific EHS activities. These companies are more likely to have a nano-specific EHS program, to monitor the workplace for nanomaterials, and to have a nano-specific waste program. It is possible that companies that handle CNTs may feel constrained by the toxicological research findings and therefore may feel obligated to take a more precautionary approach.

The California Department of Toxic Substances Control (DTSC) recently performed a call-in for information on EHS practices, such as monitoring methods and chemical safety knowledge, for manufacturers or importers of carbon nanotubes (DTSC 2009). Trends in this survey data suggest that companies that handle carbon nanotubes may be better environmental performers. Therefore, if regulators use the carbon nanotube call-in data as a proxy for the whole industry, an inaccurate view of nanomaterials industry practices and views may emerge.

Even within this survey, differences in practices between companies that handled different types of nanomaterials were apparent. The majority of respondent companies handled more than one type of nanomaterial; for example, companies that handled nano-silver were more likely to also handle titanium dioxide and quantum dots. However, nano-clay companies were less likely to handle additional types of nanomaterials. Qualitative responses indicated that companies that handled nano-clays tended not to view themselves as nano-companies or the materials they handled as engineered nanomaterials. Nano-clay companies were also less likely to have a nano-specific EHS program and less likely to dispose of their materials in separate containers. The lack of nano-specific EHS practices within nano-clay companies may be related to their tendency to disassociate themselves from the engineered nanomaterials classification.

Conti *et al.* (2008) found that 58% of companies reported implementing a nano-specific EHS program. Of the respondents to this survey, only 45% reported a nano-specific EHS program, a decrease of 13%. It is possible that this decrease is the due to the difference in companies surveyed. Research laboratories made up 28% of Conti *et al*.'s (2008) sample, while this survey only interviewed nano-companies. If it is true that fewer companies have nano-specific EHS programs than did three years ago, this has important implications for human health and the environment, as well as regulation. When asked whether voluntary reporting practices were effective for protecting human health and the environment, respondents were split fairly evenly, with 48% agreeing that voluntary reporting could be effective and 43% disagreeing.

Companies with headquarters located in the United States were less likely to advertise or otherwise disclose that their products contained nanomaterials. A possible explanation for this is that companies may fear an adverse customer reaction to the presence of nanomaterials in their products. The survey also asked if respondents worried that nanotechnologies may encounter unwarranted public backlash, such as that which accompanied genetically modified foods in Europe. Companies from the United States were more likely to disagree with this statement, implying that they were not worried about this repercussion. If a fear of backlash is indeed what is keeping US companies from advertising or otherwise disclosing the presence of nanomaterials in their products, there is a divergence between the respondents' beliefs and their practices in this particular case.

According to respondents, carbon nanotubes pose the highest risk to human health and the environment. Respondents did not know or were unwilling to report the level of risk associated for other types of nanomaterials. Overall, respondents indicated that evaluation of risk associated with nanomaterials depended on many particle characteristics. This implies that generalizing across particle type is insufficient for evaluating risk associated with nanomaterials.

Nanotechnology will increasingly become a greater part of day to day life. Along with the potential for large benefits come uncertainties about associated risks. Individuals in industry have a positive view of nanotechnology, perceiving more benefits than risks. However, it is the duty of the nanomaterials industry to take the first step in the protection of human health and the environment from the risks associated with nanomaterials through its risk management techniques and EHS programs. It is the hope of the research team that these findings are able to inform and illuminate the views and practices of the nanomaterials industry for the benefit of human health and the environment.

14 Limitations

The sample population interviewed for this survey may not have been able to represent the nano-industry as a whole. The survey population was over 50% companies from the United States, and Asian nanotechnology companies were under-represented. As this survey was voluntary, there was also a self-selection bias in the companies that chose to participate. The respondents represent a bias in their selfreporting, such that those willing to participate may have been the ones with the safest handling-practices or perceive less risk to possible public backlash of nanotechnology. Additionally, some information was gathered through internet surveys, and these respondents were not able to be probed for more information or clarification. Furthermore, the information regarding company characteristics and environmental health and safety practices were self-reported and not subjected to verification by a third party.

Moreover, socioeconomic status, gender, race, and other demographic information were not collected. These individual characteristics are known to influence views on risk and trust. For example, women perceive greater personal risk to technological hazards (Frewer, 1999). Furthermore, risk and benefit scales only consist of a few items, but were internally consistent. Poortinga & Pidgeon (2003) indicate that scales that are predetermined by researcher may not correctly match participants' scale of perception. In this way, quantitative questions many have not fully captured an individual's response.

15 Recommendations for Future Research

The survey and its accompanying data can potentially be improved, built on, and further analyzed in the future. There were two general recommendations as additional ways to develop the project. First, it is recommended that further work using the survey also includes a larger sample of nanotechnology organizations. Second, we recommend that the data gathered by the surveys receive additional analysis such as regression analysis and analysis of covariance. Surveying more companies would better characterize nanotechnology in industry as a whole.

It is recommended that the sample of nanomaterial producing companies be expanded in three ways: sending additional solicitations to the companies already in the pool of invitees, inviting more companies to participate in the study, and extending the survey period. The current survey has a response rate of roughly 13%, and this number represents a low response rate, relative to other industry surveys that have been performed since 2006. During the final weeks of survey solicitation, the survey protocol successfully recruited many additional respondents from the original sample by using persistent, bi-weekly emails. The success of the final series of emails demonstrates that additional solicitation of the 487 initial invitees could increase the response rate.

The number of survey responses could also be increased by recruiting companies from outside the original pool of invitees. Recruiting through third parties, business organizations and professional conferences may not lower the number of non-responses, but would be useful in increasing the number of survey responses. As the project continues in the future, industry awareness of the survey could contribute significantly to additional responses from outside the pool of initial invites.

Finally, the number of survey responses could be increased by using a longer survey period. Whether recruiting participants from within the original sample or going outside of the sample, a longer survey period would result in more responses.

Recruitment was consistent for the entire solicitation period. There is strong evidence to suggest that additional surveys would have been completed, had the survey period been extended.

It is also recommended that solicitation should specifically have a greater focus from outside the United States. Preliminary analysis of the data shows interesting US versus Non-US trends, but more data from outside the United States would improve this aspect of the study. Specifically, there was limited success soliciting in Asia, and the research would benefit from increasing responses from that region.

The data in the current project consists of reported frequency data for individual questions, as well as independence testing for many pairs of questions using Fisher’s exact chi-square test for significance. While the data analysis yielded many interesting conclusions, additional analysis would result in more intricate findings. For instance, using regression analysis to test for correlations between combinations of questions could yield more significant findings. In another example of factor analysis, specific combinations of question responses could be used to create company profiles, which could then be examined for relevant correlations and relationships.

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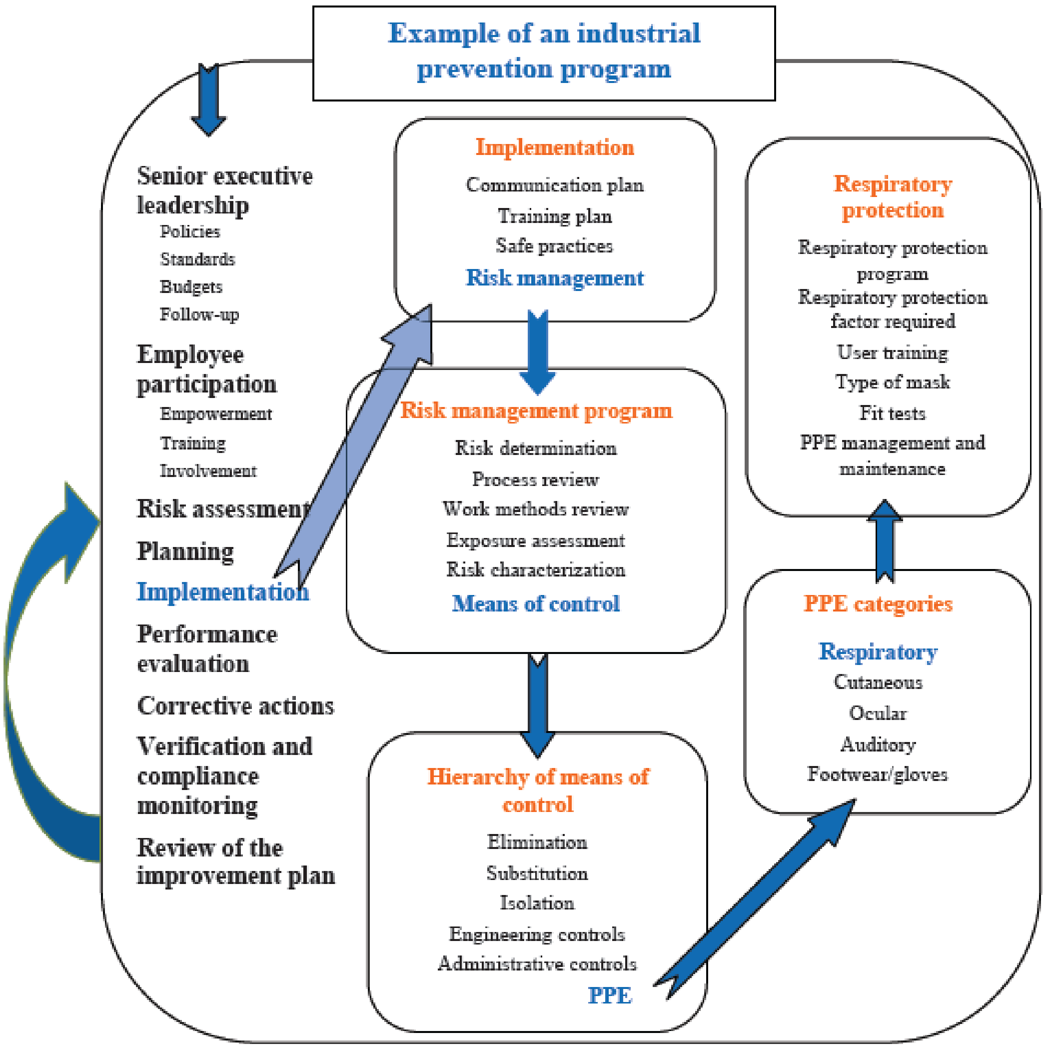
17 Appendices

Appendix A. IRRST



Appendix B. The Survey Instrument.

UNIVERSITY OF CALIFORNIA, SANTA BARBARA

BERKELEY • DAVIS • IRVINE • LOS ANGELES • MERCED • RIVERSIDE • SAN DIEGO • SAN FRANCISCO   SANTA BARBARA • SANTA CRUZ

Survey of Current Health and Safety Practices in the Nanomaterial Industry

Thank you for agreeing to take part in this survey of nanotechnology industry current practices in workplace and environmental health, safety and product stewardship.

All efforts will be made to maintain confidentiality as described in the confidentiality protocol accompanying the invitation package.

The survey will be administered through a telephone interview with one of the following researchers who will be contacting you:

Lynn Baumgartner
Allison Fish
John Meyerhofer
Benjamin Carr

If you have any questions, please contact the project team through the confidential email account: nanoresearch@cns.ucsb.edu

Project Coordinator:
Cassandra Engeman

Project Principal Investigator:
Barbara Herr Harthorn, Director
Center for Nanotechnology in Society
University of California, Santa Barbara

Project Co-Principal Investigator:
Patricia Holden, Professor
Bren School of Environmental Science & Management
University of California, Santa Barbara

Section One: Interview Subject Information

Section 1 is to learn about you, the respondent.

1. What is your job title?

2. What is your job function?

3. How long have you been in this position?

Section Two: Company Information

Section 2 is to learn more about your company and its involvement with the production or use of nanomaterials.

4. What are your company's activities with regards to nanomaterials? (Check all that apply)
    - Research & Development
    - Manufacture and sell nanomaterials
    - Manufacture and incorporate nanomaterials into other products
    - Buy nanomaterials and manufacture products for sale using the purchased nanomaterials
    - Nanomaterials characterization or other consultancy

5. Towards which sectors are your company's nanomaterials activities oriented? (Check all that apply)
    - Defense
    - Energy
    - Aerospace
    - Electronics/IT
    - Automotive
    - Construction materials
    - Coatings
    - Textile/apparel
    - Cosmetics or other personal care products
    - Food & beverage
    - Medicine or other health
    - Sensors
    - Environment
    - Recreation
    - Other (please specify) _______________

6. Approximately what year was your company formed?

7. For how many years has your company been working with nanomaterials?

8. Where are your company's headquarters located? Please indicate the Country and State/Province.

9. In what countries does your company use and/or manufacture nanomaterials?

10. How many employees are in your company overall?

11. How many employees work directly with (i.e. handle, produce, and/or research) nanomaterials in your company?

Section Three: Nanoparticle-Specific Product Information

Section 3 is designed to learn about the nanoparticles your company handles. This will involve describing each individual nanoparticle produced and/or handled by your company in <u>non-technical</u> terms. <u>No proprietary information is requested</u>.

12. What are all the different types of nanoparticles that your company works with?

- o Single-walled carbon nanotubes
- o Multi-walled carbon nanotubes
- o Carbon black
- o Fullerenes (bucky balls)
- o Nano-silver
- o Nano-gold
- o Titanium dioxide
- o Zinc oxide
- o Cerium oxide
- o Silica
- o Quantum dots
- o Clay
- o Dendrimers/polymers
- o Other (please specify) ____________________

The following questions, questions 13 through 17, will be asked of each individual nanoparticle identified above in question 12.

13. What size are the nanoparticles as manufactured? *(List the nanoparticles identified in question 12 in the 'Nanoparticle' column.)*

Nanoparticle	**< 2.5 nm**	**2.5 - 10 nm**	**> 10 to 50 nm**	**>50 to 100 nm**	**> 100 nm**
________	☐	☐	☐	☐	☐
________	☐	☐	☐	☐	☐
________	☐	☐	☐	☐	☐

14. In what product form are nanoparticles handled at your company? (*List the nanoparticles identified in question 12 in the 'Nanoparticle' column*)

Nanoparticle	**Dry Powder**	**Aerosol**	**Liquid**	**Embedded**
________	☐	☐	☐	☐
________	☐	☐	☐	☐
________	☐	☐	☐	☐

15. Do the nanoparticles that your company works with agglomerate? *(List the nanoparticles identified in question 12 in the 'Nanoparticle' column)*

Nanoparticle	**Yes**	**No**	**Not Sure (please explain)**
________	☐	☐	☐
________	☐	☐	☐
________	☐	☐	☐

16. If so, to what size do these particles agglomerate? *(List the nanoparticles identified in question 12 in the 'Nanoparticle' column)*

Nanoparticle	≤ 100 nm	>100 nm
________	☐	☐
________	☐	☐
________	☐	☐

17. At what scale of production are these nanomaterials? *(List the nanomaterials identified in question 12 in the 'Nanomaterial' column)*

Nanomaterial	At a small scale (start up or R&D)	At the pilot scale within larger industry	At the full or commercial scale
________	☐	☐	☐
________	☐	☐	☐
________	☐	☐	☐

Section Four: General EHS and Nano-EHS

Section 4 regards your company's occupational and environmental health and safety programs, including both staffing and training. Specific practices are addressed in later sections of the survey.

18. Does your company implement a general health and safety program?

- Yes*(If yes, continue to question 19)*
- No*(If no, skip to question 20)*

19. How many full-time equivalent health and safety staff are employed?

20. Does your company have a nano-specific health and safety program?

- Yes *(If yes, continue to question 21)*
- No *(If no, why not?) (skip to question 25)*

21. How many full time equivalent EHS employees are staffed specifically in the nano-specific program?

22. What does your nano-specific EHS program consist of?

- Training
- Employee handbook
- Inspection or other oversight
- Risk framework or other risk assessment
- Workplace postings
- Other, please specify_______________

23. Where did you find the information used to guide the development of your nano-specific EHS program?

24. How often do employees receive nano-specific health and safety training? (Check all that apply)

- Annually
- At employee orientation
- When general EHS training is offered
- When new material is introduced
- Other (please specify) _______________

Section Five: Employee and Area Exposure Monitoring

Section 5 regards your company's employee and area exposure monitoring practices.

25. Does your company monitor the workplace for nanoparticles?

- o Yes *(continue to question 26)*
- o No *(skip to question 28)*

26. What monitoring equipment is used? (Check all that apply and specify what is being measured with the method- mass, number, and/or surface area.)

- o Electrical low pressure impactor (ELPI); mass, number, surface area:__________________________
- o Differential mobility analyzing system; mass, number surface area:__________________________
- o Condensation particle counter (CPC); number:_____
- o Optical particle counter (OPC); number:_____
- o Scanning mobility particle sizer (SMPS); number:_____
- o Diffusion charger; surface area:_____
- o Electron microscopy; surface area:_____
- o Other (please specify) ____________________

27. When is monitoring performed?

Section Six: Containment and Exposure Controls

Section 6 regards your company's containment and exposure controls.

28. For employees who work with nanomaterials, what is the maximum amount typically handled at a time?

- o Micrograms to less than one milligram
- o Milligrams to less than one gram
- o One gram to less than one kilogram
- o One kilogram or more
- o Other (please specify) ___________________

29. Which of the following facility design and engineering controls are used to manage employee exposure to nanomaterials? (Check all that apply)

- Separate HVAC system
- Pressure differentials
- Clean room
- Designated or separate work areas
- Closed piping system
- HEPA filtration
- ULPA filtration
- Fume hood
- Laminar flow clean bench
- Biological safety cabinet
- Glove bag
- Glove box
- Other (please specify) ___________________

30. When are engineering controls used?

- Always
- Sometimes
- Never

31. What methods are used for cleaning areas in which nanomaterials are handled? (Check all that apply)

- Household or shop vacuum
- HEPA vacuum
- Sweeping
- Compressed air
- Wet wiping
- Soaps or cleaning oils
- Absorbent materials
- Liquid traps
- Other (please specify) _______________

32. When is cleaning performed?

- After spills
- At the end of every shift
- At the end of every work day
- Other (please specify) ______________

33. Are nanomaterials transported in closed containers within the facilities?

- Always
- Sometimes
- Never

34. Which of the following personal protective equipment does your company either require or recommend for handling nanomaterials?

	Required	Recommended	Not required or recommended
Lab coat	☐	☐	☐
Coveralls	☐	☐	☐
Shoe covers	☐	☐	☐
Latex gloves	☐	☐	☐
Nitrile gloves	☐	☐	☐
Eye protection	☐	☐	☐
Hair bonnets	☐	☐	☐
Dust masks	☐	☐	☐
Building suits	☐	☐	☐

Other (please specify) ____________________

35. Do employees working with nanomaterials use respiratory protection?

- Yes *(if yes, what kind of protection is used? See below)*
  - Disposable filtering facepiece
  - Elastomeric half-facepiece
  - Powered loose-fitting facepiece
  - Powered tight-fitting half-facepiece
  - Powered tight-fitting full-facepiece
  - Elastomeric full-facepiece with N-100, R-100, or P-100 filter
- No

36. Are there any EHS practices other than the ones asked about so far that are used in your company?

The next four questions address potential barriers perceived to exist by companies who currently have or intend to implement a nano-specific health and safety program. Please indicate the level of your agreement with the following statements:

37. Budget constraints are an impediment in implementing nano-specific health and safety practices.

Strongly agree	Agree	Disagree	Strongly disagree	Don't know
☐	☐	☐	☐	☐

38. Lack of information is an impediment in implementing nano-specific health and safety practices.

Strongly agree	Agree	Disagree	Strongly disagree	Don't know
☐	☐	☐	☐	☐

39. Lack of health and safety guidance or regulations is an impediment in implementing nano-specific health and safety practices.

Strongly agree	Agree	Disagree	Strongly disagree	Don't know
☐	☐	☐	☐	☐

40. Internal enforcement is an impediment in implementing nano-specific health and safety practices.

Strongly agree	Agree	Disagree	Strongly disagree	Don't know
☐	☐	☐	☐	☐

41. Please describe any other barriers to implementing nano-specific health and safety practices.

Section Seven: Waste Management and Product Stewardship

Section 7 regards waste management and product stewardship practices.

42. Does your company have a nano-specific waste program?

    - Yes
    - No

43. Does your company dispose of its nanomaterials as hazardous waste?

    - Yes
    - No

44. Are there separate disposal containers for nanomaterials used either in the lab or in waste storage areas?

    - Yes
    - No

45. Are nanomaterials listed separately as "nanomaterials" on waste manifests?

    - Yes
    - No

46. Do you advertise or otherwise disclose that your products contain nanomaterials?

    - Yes
    - No

47. Do you provide guidance to your customers regarding safe use, and/or disposal of your products?

    - Yes (*If yes, what aspects of the information are nano-specific?*)
    - No

Section Eight: Views on Risk Assessment and Risk Management

While the survey thus far has focused on your company's practices, in section 8 we will be asking you about your personal views regarding factors that could constrain scientific innovation, as well as the potential risks of nanomaterials, and how best to limit those risks. Many of these questions are a matter of personal opinion and are simply intended to capture varying perspectives from within industry.

48. For the following list of nanomaterials, please rate the level of risk you think each material poses to human health and/or the environment.

Comparative Items	**Almost no risk**	**Slight risk**	**Moderate risk**	**High risk**	**Don't know**
Carbon nanotubes	☐	☐	☐	☐	☐
Other carbonaceous materials (excluding CNT)	☐	☐	☐	☐	☐
Dry powders	☐	☐	☐	☐	☐
Quantum dots	☐	☐	☐	☐	☐
Metal oxides	☐	☐	☐	☐	☐
Heavy metals (e.g., gold, silver)	☐	☐	☐	☐	☐

Please indicate the level of your agreement with the following statements:

49. Industries working with nanomaterials can be trusted to regulate the safe-handling of these materials.

Strongly agree	Agree	Disagree	Strongly disagree	Don't know
☐	☐	☐	☐	☐

50. It is reasonable to assume that industries working with nanomaterials will adapt or alter their safe-handling practices when new hazards are discovered.

Strongly agree	Agree	Disagree	Strongly disagree	Don't know
☐	☐	☐	☐	☐

51. In the case of nanotechnologies, the benefits of advancements in science and technology outweigh the risks involved in research, development, and production.

Strongly agree	Agree	Disagree	Strongly disagree	Don't know
☐	☐	☐	☐	☐

52. Waiting until safety studies are complete to commercialize nanotechnology will deprive society of too many potential benefits.

Strongly agree	Agree	Disagree	Strongly disagree	Don't know
☐	☐	☐	☐	☐

53. Voluntary reporting approaches for risk management are effective for protecting human health and the environment.

Strongly agree	Agree	Disagree	Strongly disagree	Don't know
☐	☐	☐	☐	☐

54. Direct involvement of citizens in policy decisions about research and development of new technologies is beneficial.

Strongly agree	Agree	Disagree	Strongly disagree	Don't know
☐	☐	☐	☐	☐

55. In my company, we worry that nanotechnologies may encounter unwarranted public backlash such as that which accompanied genetically modified foods in Europe.

Strongly agree	Agree	Disagree	Strongly disagree	Don't know
☐	☐	☐	☐	☐

56. Businesses are better informed about their own workplace safety needs than are government agencies.

Strongly agree	Agree	Disagree	Strongly disagree	Don't know
☐	☐	☐	☐	☐

57. Employees are ultimately responsible for their own safety at work.

Strongly agree	Agree	Disagree	Strongly disagree	Don't know
☐	☐	☐	☐	☐

58. Workplace safety should take priority over scientific and technological advances.

Strongly agree	Agree	Disagree	Strongly disagree	Don't know
☐	☐	☐	☐	☐

59. Insurers in my industry are increasingly concerned about nano-specific risks.

Strongly agree	Agree	Disagree	Strongly disagree	Don't know
☐	☐	☐	☐	☐

60. Please rate your level of trust in the following government agencies to effectively assess and manage nano-specific environmental health and safety risks:

IN THE U.S.	No trust	Some trust	Trust	Much trust	Not familiar with agency
Environmental Protection Agency (EPA)	☐	☐	☐	☐	☐
Food and Drug Administration (FDA)	☐	☐	☐	☐	☐
National Institute of Occupational Safety and Health (NIOSH)	☐	☐	☐	☐	☐
U.S. Department of Agriculture (USDA)	☐	☐	☐	☐	☐

IN CANADA	No trust	Some trust	Trust	Much trust	Not familiar with agency
Health Canada	☐	☐	☐	☐	☐
Environment Canada	☐	☐	☐	☐	☐

IN THE U.K.	No trust	Some trust	Trust	Much trust	Not familiar with agency
Department for Environment, Food & Rural Affairs (DEFRA)	☐	☐	☐	☐	☐
Health & Safety Executive (HSE)	☐	☐	☐	☐	☐

61. Please rate your level of trust in the following international organizations to effectively assess and manage nano-specific environmental health and safety risks:

TRANSNATIONAL	No trust	Some trust	Trust	Much trust	Not familiar with agency
Regulation on Registration, Evaluation, Authorization & Restriction of Chemicals (REACH)	☐	☐	☐	☐	☐
International Organization for Standardization (ISO)	☐	☐	☐	☐	☐
ASTM International	☐	☐	☐	☐	☐

62. Please indicate your level of trust in the following sources to adequately communicate the *benefits* of nanotechnology to the public:

	No trust	Some trust	Trust	Much trust
Academic Scientists	☐	☐	☐	☐
Government regulatory agencies	☐	☐	☐	☐
Industry (companies involved in nanotech)	☐	☐	☐	☐
Non-profits and non-governmental organizations	☐	☐	☐	☐
Traditional Mass media (television, radio, newspapers)	☐	☐	☐	☐
Internet media (web logs (blogs), web-based news)	☐	☐	☐	☐

Section Nine: Closing Questions

In closing,

63. Can you recommend other companies and/or individuals that you think we should invite to participate in our survey?

64. Is there anything that we haven't covered in this interview that you think is relevant and we need to understand and include in this survey?

65. If we have additional questions or need to follow up with you, are you willing to be contacted?

Appendix C. Question Rationales.

2009-10 Nano Survey: Question Rationales
Created July 28, 2009

**Note: this document was created in regards to a previous iteration of the questionnaire and does not directly reflect the final ordering or wording the questionnaire used to survey participants.*

Section: Interview Subject Information

Variable: No variable.
Potential hypothesis: No hypothesis
What we expect: Verification that the person we are interviewing is in fact the correct person in the company.

Variable: No variable.
Potential hypothesis: No hypothesis
What we expect: Verification of what the interviewee does will confirm that we are speaking with the correct company representative.

Variable: No variable.
Potential hypothesis: Verifies that we are speaking with the correct person.
What we expect: Longevity with a company would mean greater understanding of the current practices and risk perceptions of that company.

Section: Company Information

Variable: Industry type.
Potential hypothesis: Manufacturing nanomaterials creates the potential for greater exposure to nanomaterials in the workplace, as compared to strictly purchasing nanomaterials for use.
What we expect: A company whose employees manufacture nanomaterials would implement nano-specific EHS programs and safety measures in the workplace. We would expect that a company who only purchases nanomaterials would still have an EHS program and safety measures, but not necessarily nano-specific controls.

Variable: Industry type.
Potential hypothesis: A company's activities with regards to nanomaterials determine the amount of nanomaterial handling and/or exposure in the workplace, which influences current EH&S practices and risk perceptions.
What we expect: Companies manufacturing nanomaterials, and/or materials that incorporate nanomaterials may have a perception of greater risk, and therefore use more EH&S controls in the workplace.

Variable: Industry type.
Potential hypothesis: The nanomaterial line of business in which a company participates may correlate with their risk perception and/or current practices.
What we expect: Companies participating in lines of business that are not publicly oriented (e.g. aerospace, construction materials, energy, electronics/IT) have a lower perceived risk of nanomaterials. Companies participating in lines of business that cater to consumer goods ingested, or applied by the public (e.g. cosmetics, food & beverage, medicine/pharmaceuticals) have higher perceived risk of nanomaterials.

Variable: Age of company.
Potential hypothesis: The age of a company may be correlated with current EH&S practices, and with risk perception
What we expect: Older companies may have fewer nano-specific EHS controls and a perception of lower risk. Newer companies may have more nano-specific EHS controls and a perception of higher risk.

Variable: Age of company.
Potential hypothesis: Length of nanomaterial-use by a company may be correlated with company practices and risk perceptions.
What we expect: Companies which have been using nanomaterials for a long time will have a lower perceived risk, and will use fewer nano-specific EHS controls as compared to companies which have only recently started using nanomaterials.

Variable: Company location.
Potential hypothesis: Company headquarters-location indicates access to information, which may be correlated with company practices and risk perceptions.
What we expect: Companies located in countries with nano-specific government guidance documents will use more nano-specific EHS controls.

Variable: Company location.
Potential hypothesis: Location of nanomaterial-activities of a company indicates access to information, which may be correlated with company practices and risk perceptions.
What we expect: Companies with offices in countries foreign to the location of the headquarters might not consistently manage foreign office-activities, relying instead on country specific access to information to dictate EH&S practices.

Variable: Company size.
Potential hypothesis: Overall size of company may indicate availability of EH&S resources and/or access to information, which may be correlated with company practices.

What we expect: Larger companies will have more resources available for a nano-specific EHS program. Smaller companies may not have resources (staff, money) available for a nano-specific EHS program.

Variable: Company size.
Potential hypothesis: Number of employees working directly with nanomaterials may be correlated with company practices.
What we expect: Nano-specific EHS programs would be used if a greater number of employees were working directly with nanomaterials.

Section: Nanoparticle-Specific Information

Variable: Type of nanomaterial.
Potential hypothesis: A company's perception of risk will be correlated with the specific type of nanomaterial handled, which might influence company practices. The more nanomaterials a company works with will be correlated with company practices.
What we expect: Companies that work with nanomaterials for which toxicological research has been performed (CNTs) will implement nano-specific EHS programs.

Variable: Type of nanomaterial.
Potential hypothesis: Individual nanoparticle-size is correlated with a number of nano-specific government guidance document recommendations. Nanoparticle size may influence company practices and/or risk perceptions.
What we expect: Companies using nanoparticles smaller than 2.5 nm may rely on different EHS controls as compared to companies handling larger nanoparticles.

Variable: Type of nanomaterial
Potential hypothesis: Nanomaterials in powder form may be more dangerous than in other states, so state may affect practices and risk perception
What we expect: Companies that handle nanomaterials in powder form may have a perception of higher risk and more controls in place.

Variable: Type of nanomaterial
Potential hypothesis: Many nanomaterials agglomerate, possible to sizes larger than 100 nm, after which they may not have the unique properties associated with nanomaterials. Agglomeration my affect practices and risk perception.
What we expect: Companies whose particles agglomerate to greater than 100 nm will have a perception of lower risk and use fewer nano-specific controls.

Variable: Company size and industry type
Potential hypothesis: The scale of production may have an affect on industry practices.
What we expect: Companies further along in the production scale would have a stronger nano-specific EHS program

Section: General EHS and Nano-EHS

Variable: Risk perception and industry practice
Potential hypothesis: The presence of a general EHS program may affect the presence or absence of a nano-specific EHS program
What we expect: Companies further along in the production scale would have more

Variable: Industry practice, extent of the EHS program, risk perception
Potential hypothesis: The number of employees in the health and safety program may indicate the extent of the EHS program and may be correlated with risk perception
What we expect: Companies that employ more people in the EHS program may have more nano-specific EHS controls and a perception of higher risk

Variable: Industry practice, extent of the EHS program, EHS practice
Potential hypothesis: The presence of a nano-specific EHS program may affect the extent of EHS controls and correlate with risk perception
What we expect: Companies with a nano-specific EHS program will employ more EHS controls, and companies that perceive a higher risk are more likely to have a nano-specific EHS program.

Variable: Industry practice, extent of the EHS program, and EHS practice
Potential hypothesis: The number of employees in the nano-specific health and safety program may indicate the extent of the EHS program and may be correlated with risk perception
What we expect: Companies that employ more people in the nano-specific EHS program may have more nano-specific EHS controls and a perception of higher risk

Variable: Industry practice, extent of industry practices, and the following of guidance docs.
Potential hypothesis: Companies that are following recommendations from the guidance documents may have performed a risk assessment
What we expect: Companies that are following recommendations from the guidance documents are more likely to have performed a nano-specific risk assessment.

Variable: Industry practice, extent of the EHS program, and risk perception
Potential hypothesis: Some companies may consider certain nanomaterials as more dangerous than others, and this may affect their practices and is related to their risk perceptions
What we expect: Companies that view some nanomaterials as more dangerous than others will have more controls for the nanomaterials seen as more dangerous, and their risk perception will vary across nanomaterial.

Variable: Industry practice, extent of the EHS program

Potential hypothesis: The practice of health and safety training for nanomaterial handling may be related to the presence of other EHS practices
What we expect: We expect that companies that have nano-specific EHS programs will train their employees on the handling of nanomaterials.

Variable: Industry practice, extent of the EHS program, EHS practice, and management centrality
Potential hypothesis: How nano-specific health and safety training is administered may be related to other EHS practices. This question also looks to gain insight the extent of the EHS program.
What we expect: A company with an extensive EHS program will administer training through multiple avenues.

Variable: Industry practice, extent of the EHS program, and the following of guidance docs
Potential hypothesis: Guidance documents recommend training employees in certain areas and this may affect a company's EHS practices.
What we expect: Companies following recommendations of the guidance documents will train in these areas.

Variable: Industry practice, extent of the EHS program, and the following of guidance docs
Potential hypothesis: Guidance documents recommend training at certain times and this may affect a company's EHS practices.
What we expect: Companies following recommendations of the guidance documents will train at these times.

Variable: Access to information
Potential hypothesis: There are few guidance documents available.
What we expect: Most (US) companies will be getting guidance from NIOSH.

Section: Employee and Area Exposure Monitoring

Variable: Extent of industry practices, risk perception
Potential hypothesis: Monitoring nanoparticles may be related to other industry practices and correlated with risk perception.
What we expect: Companies that perceive a higher risk are more likely to monitor the workplace for nanoparticles. Companies with an extensive EHS program are more likely to monitor for nanoparticles.

Variable: Extent of industry practice
Potential hypothesis: A company's perception of the risks surrounding nanomaterials will have a correlation to their monitoring practices.

What we expect to get: Very few monitoring practices among survey participants expect for the most risk aware and averse few, who will implement a monitoring program.

Variable: extent of industry practices

Potential hypothesis: Companies that are risk sensitive and utilize guidance documents will use monitoring equipment recommended by NIOSH or other guidance documents

What we expect: A correlation between companies that use guidance documents and what monitoring equipment they use

Containment and Exposure Controls

Variable: Industry practices

Potential hypothesis: The greater the company's perception of risk, the smaller the quantity of nanomaterial will be worked with at a time by employees.

What we expect: The quantity of material worked with will vary greatly depending on risk perception, as well as other company characteristics such as size, location and the type of material they produce.

Variable: Industry practices and extent of industry practice

Potential hypothesis: risk sensitivity leads to a greater use of exposure controls.

What we expect: Risk sensitivity as well as other company characteristics will directly correlate with their use of exposure controls.

Variable: industry practice and extent of industry practice

Potential hypothesis: Risk perception correlates with cleaning frequency

What we expect: companies that are risk aware and use guidance documents will clean at the end of every shift, while other companies clean much less frequently.

Variable: Industry practice and extent of industry practice

Potential hypothesis: Those companies following guidance documents will follow the cleaning procedures listed in guidance document such as NIOSH

What we expect: Both to test the hypothesis and also see if there is a correlation between risk sensitivity and using ill-advised cleaning techniques such as compressed air.

Variable: Industry practice and extent of industry practice

Potential hypothesis: Risk sensitive companies and those that follow guidance documents such as NIOSH will transport nanomaterials in closed containers, or have policies to encourage doing so.

What we expect: For the use of closed containers to vary more with the material transported than risk perception of guidance documents usage.

Variable: Industry practice and extent of industry practice

Potential hypothesis: Risk sensitive companies and those that follow guidance documents such as NIOSH will transport nanomaterials in closed containers, or have policies to encourage doing so.

What we expect: For the use of closed containers to vary more with the material transported than risk perception of guidance documents usage.

Variable: Industry practice and extent of industry practice

Potential hypothesis: Risk sensitive companies and those following guidance documents will not only use respiratory protection, but a respirator specifically approved by NIOSH or some other safety agency. Also, for there to be a correlation between risk and the use of dust masks.

What we expect: For companies to recommend respirators but not necessary do much more than that. The question will also tell us if there is much uniformity between industries in terms of their respirator usage.

Variable: Industry practices and extent of industry practice

Potential hypothesis: Risk sensitive companies and those that follow guidance documents such as NIOSH will use the appropriate protective equipment, or have policies to encourage doing so.

What we expect: In addition to testing the hypothesis, the question will also tell us how popular certain forms of protective equipment are, and other industry trends.

Variable: Industry practice and extent of industry practice

Potential hypothesis: Risk sensitive companies and those following guidance documents will provide hygiene facilities and require their use

What we expect: In addition to the hypothesis, this question will also tell us how important hygiene is to companies, and possibly reveal other hygiene practices.

Waste Management and Product Stewardship

Variable: Industry practice and risk perception

Potential hypothesis: Only the most risk oblivious companies will lack a hazardous waste program.

What we expect: This question is more targeted toward foreign companies where regulation might not be so strict. Regardless, the presence of a hazardous waste program should correlate in some way with risk perception.

Variable: Industry practice and risk perception

Potential hypothesis: Risk sensitive companies will have a waste program specifically designed to handle their nano waste.

What we expect: For most companies to at least have given some thought to handling nano waste separately from non-nano waste.

Variable: Industry practice and risk perception

Potential hypothesis: Risk averse companies will utilize separate disposal containers.

What we expect: This question will correlate with risk, and also tell us about the extent of the companies waste program (for example a company without separated waste disposal containers isn't very serious about proper handling and disposal)

Variable: Industry practice and risk perception

Potential hypothesis: Very risk sensitive companies will treat nano-waste as hazardous, while more companies will simply go on a case-by-case basis.

What we expect: This question will also be interesting in determining if very many nano-wastes are entering the hazardous waste disposal chain.

Variable: Industry practice and risk perception

Potential hypothesis: Risk sensitive companies provide their customers information about the use and disposal of their nano-products

What we expect: This question will also tell us about what kind of information companies are giving to their buyers. It will be interesting to see whether companied give as little as they have to, or volunteer information freely.

Table 19. Hypothesis Rationale Table. (*note: question numbers reflect an earlier iteration of survey design)*

Variables and survey questions		**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**25b**
Company size												■	■							■						
Age of company								■	■																	
Industry type					■	■	■							■	■	■	■	■	■	■						
Type of NMs handled/produced																										
Risk perception																					■	■				■
Access to info/guidance docs																										
Industry nano EHS practices																■					■	■	■	■	■	■
Cost of EHS																										
Company location										■	■															
Management centrality																										
Following of guidance docs																									■	

Variables and survey questions	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**	**49**	**50a**	**50b**
Company size																										
Age of company																										
Industry type																										
Type of NMs handled/produced																										
Risk perception	■							■													■	■	■	■	■	■
Access to info/guidance docs							■												■							
Industry nano EHS practices	■	■	■	■	■	■		■	■	■	■	■	■	■	■	■	■	■	■		■	■	■	■	■	■
Cost of EHS																			■							
Company location																										
Management centrality		■		■																						
Following of guidance docs					■	■																				

Appendix D. Personal Invitation Letter.

UNIVERSITY OF CALIFORNIA

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SANTA BARBARA

NSF Center for Nanotechnology in Society &
UC Center for Environmental Implications of Nanotechnology
Santa Barbara, CA 93106-2150

October 14, 2009

[FIRST_NAME] [LAST_NAME]
[COMPANY]
[ADDRESS]
[CITY], [STATE] [ZIP]
[COUNTRY]

RE: International Survey of Health and Safety Practices in the Nanotechnology Industry

Dear [FIRST_NAME] [LAST_NAME]:

We invite you to participate in an international survey of health and safety practices in the nanotechnology industry. This study is being performed by academic researchers at the University of California, Santa Barbara (UCSB), in conjunction with the National Science Foundation (NSF)-funded Center for Nanotechnology in Society (CNS) and the NSF/U.S. EPA-co-funded UC Center for Environmental Implications of Nanotechnology.

The purpose of this study is to identify industry approaches and perspectives regarding the safe handling of nanomaterials. We aim to discover and inform best practices in the nanotechnology industry. This is a follow-up to our 2006 study, also conducted at UCSB and sponsored by the International Council on Nanotechnology (ICON). The results from the inaugural study were published in 2008 in *Environmental Science and Technology* and in a comprehensive report that remains posted on the ICON and CNS-UCSB websites. Our objective in 2009 is to refresh the understanding of health and safety practices, including changes during the last three years, and to expand the knowledge regarding industry's views on risks posed by nanomaterials.

By participating, you can contribute your ideas towards developing best practices for handling nanomaterials. All responses will be kept strictly confidential, and findings from this study will be reported only in aggregate form. Participants will be asked to complete a phone interview of up to 45 minutes in length, at a date and time of their choosing between September and December 2009.

We will contact you soon to schedule an interview. If you have any questions or comments, please email the researchers at nanoresearch@cns.ucsb.edu, or either email Dr. Herr Harthorn at harthorn@cns.ucsb.edu, or call or email Dr. Patricia Holden at 805-893-3195, holden@bren.ucsb.edu. Your contribution to this study is important. We look forward to your participation.

Sincerely,

Professor Barbara Herr Harthorn, Ph.D.
Principal Investigator

Professor Patricia Holden, Ph.D.
Co-Principal Investigator

Appendix E. Fact Sheet.

Bren School of Environmental Science & Management, University of California, Santa Barbara

UCCEIN

CNS UCSB

Invitation for Interview

The Center for Nanotechnology in Society (CNS) and the UC Center for the Environmental Implications of Nanotechnology (UC CEIN) at the University of California-Santa Barbara (UCSB) are conducting an international survey of environmental safety and health practices in the nanotechnology industry. This project builds on a 2006 study that was sponsored by the International Council on Nanotechnology (ICON) at Rice University, where results contributed to industry knowledge of best practices and were published in the journal *Environmental Science & Technology*. The current survey will identify changes in industry practices over the past three years and will again provide an opportunity for industry to share its views and opinions.

Who We Are

We are a research team at the Bren School of Environmental Science and Management at UCSB. Our team is comprised of five graduate students and is led by UC CEIN Co-Investigators, Dr. Barbara Herr Harthorn, Director of the CNS at UCSB, and Dr. Patricia Holden, Professor at the Bren School. This project is co-funded by the U.S. National Science Foundation and the U. S. Environmental Protection Agency and is endorsed by ICON.

Interview Topics

- How are companies responding to new challenges posed by nanomaterials?
- What types of training do nanomaterials handlers receive?
- What engineering controls and personal protective equipment are being used in the workplace?
- Where are companies finding information regarding safe handling of nanomaterials?
- What are management's views about risks for different nanomaterials?

Value in Participating

Participants can benefit by influencing the debate in current health and safety practices in nanotechnology industries. As in the 2006 study, participants will learn from the final report regarding how their approaches to health and safety compare within the industry. Also, as with the prior study, responses to the survey will be reported in aggregate, meaning no individual responses will be tied to specific companies, **and no companies will be identified by name**. Confidentiality of the participants, products and company is of the upmost importance.

How to Participate

After our initial mailed invitation, we will email you to ask for your participation and subsequently schedule a time for a phone interview with you. The telephone interview will last up to 45 minutes. Participants will receive a copy of the survey before the interview. Electronic copies of the publication from the 2006 study can be made available upon request. If you have questions about the process or interview scheduling please email nanoresearch@cns.ucsb.edu; inquiries can also be made to Dr. Patricia Holden at (805) 893-3195 or holden@bren.ucsb.edu or to Dr. Barbara Herr Harthorn at harthorn@cns.ucsb.edu.

Appendix F. Consent Form.

ATTENTION: TRISH HOLDEN

Consent to Participate in an Interview or Survey
Regarding Health and Safety Practices in the Nanotechnology Industrial Workplace

The Study. You and your company have been selected for an interview concerning health and safety programs and practices in nanotechnology industrial workplaces. In this interview, we want to learn about your company and its products, you as a respondent, and health and safety programs and practices in your nanotechnology workplace. This research is being directed by Professors Barbara Herr Harthorn, Ph.D., in the Center for Nanotechnology in Society and Patricia A. Holden, Ph.D., in the Bren School of Environmental Science & Management at the University of California at Santa Barbara.

Participation. Your participation is entirely voluntary. The interview will last approximately 45 minutes. The interview will be audio recorded with your approval. You are free to decline to respond to any question you do not wish to answer, and you may terminate the interview and your participation in the study at any time.

Benefits. The study will contribute to the development of best practices for handling nanomaterials.

Confidentiality. Study records will be kept confidential. We will ask for your name, but a pseudonym will be used if you prefer. At the end of the project, all collected information will be aggregated so that your identity and that of your company is removed from the final report. After the project, the records will be stored in a secure and confidential manner at UCSB.

☐ I wish for my birth name to be used in the study.

☐ I wish to be assigned a pseudonym for all documentation and data storage.

Questions. If you have questions or comments or want more information, you may contact via email or phone: Professor Patricia Holden at the Bren School of Environmental Science & Management (805) 893-3195, email holden@bren.ucsb.edu . If you have any questions about your rights as a research participant, please contact Kathy Graham at UC Santa Barbara (805) 893-3807.

If you would like to participate in the study, please sign below.

____________________________________ ________________________
signature of participant date

____
name (printed)

Appendix G. Code Book.

Survey of Current Health and Safety Practices in the Nanomaterial Industry

CODE BOOK

Process: To assure consistency, each team member will take responsibility for coding specific sections.

Instructions on coding:

In naming the variable, the name needs to (a) be short because it will be a column-header and (b) be able to invoke the question/response category. Note that I include the question number to ease reference.

To code "other" responses, review the responses and either (a) fit the response with an existing category or (b) create another category if it is a frequent response. Keep "other" as a binary variable. Mark "1" if it is checked and "0" if it is not checked. Create a document with interesting responses that you may want to include qualitatively in your report.

For all qualitative responses, first see if you can recode the response to fit within a pre-existing category. If not and if other participants provide similar responses, create a document of those qualitative responses. Keep "Comment" as a variable and code as "1" if the participant comment and "0" if s/he did not.

Variable Types

Continuous (or "quantitative") Variable: Can (in theory) take on all possible numerical values in a given interval Numeric values reflect order and true magnitude of differences among cases. May be termed "metric", "interval", or "ratio." (In SPSS: "**interval**")

Discrete (or "qualitative") Variable: Measurable in terms of terms of categories that cannot be further subdivided:

- *Nominal* ("nonorderable discrete"): Based on a system of measurement in which values have no order or value (i.e., numbers stand for names). No assumptions are made about relations between values. (In SPSS: "**nominal**")
- *Ordinal* ("orderable discrete"): Based on a system of categorization in which subjects can be ranked in order on some variable. (In SPSS: "**ordinal**")
- Dichotomous or "*dummy*" variable: discrete variable with only two values – coded "1" to notate presence or "0" to notate absence. (In SPSS: "**binary**")
    - "Check all that apply" questions require that response categories be turned into dummy variables.

Understanding this codebook

In the SPSS database, each data entry column is called a "variable." Therefore, I give "variable" names to each of the questions. Our questions also measure our larger variables:

Independent variables:

1. Company size
2. Age of company
3. Industry type
4. Type of nanomaterials handled/produced
5. Risk perception
6. Access to information/guidance documents
7. Industry Practices
8. Cost of EHS
9. Company location
10. Management centrality

Dependent variables:

1. Risk perception
2. Industry practices

Coding instructions and helpful information for analysis are in black print.
Variable names entered in the SPSS database are expressed in bold.
Original text in the survey is in blue print.

Section One: Interview Subject Information

Section 1 is to learn about you, the respondent.

1Title (Variable Name)
Variable Type: Nominal
Measures Variable: Not a variable of interest; background information

1. What is your job title?
    1 EHS Officer/Safety Officer
    2 Chief Technical Officer
    3 CEO/President
    4 Scientist
    5 Marketing/PR
    6 Other

2Func (Variable Name)
Variable Type: Nominal
Measures Variable: Not a variable of interest; background information

2. What is your job function?

**No need to code. This is background information and information for quality control.

3Tenure

Variable Type: Interval
Measures Variable: Not a variable of interest; background information

3. How long have you been in this position?

**Standardize to be measured in years. Six months is expressed as 0.5 years, etc.

Section Two: Company Information

Section 2 is to learn more about your company and its involvement with the production or use of nanomaterials.

Variable Type: Binary
Measures Variable: Industry Type

4. What are your company's activities with regards to nanomaterials? (Check all that apply)

   1 Checked
   0 Not Checked
   9 Missing

4RD (Variable name)
- Research & Development

4ManSell (Variable name)
- Manufacture and sell nanomaterials

4ManUse (Variable name)
- Manufacture and incorporate nanomaterials into other products

4BuyUse (Variable name)
- Buy nanomaterials and manufacture products for sale using the purchased nanomaterials

4Cnslt (Variable name)
- Nanomaterials characterization or other consultancy

4Oth

**Code other category. Either code under existing categories or create new binary variables based on responses and code accordingly.

Variable Type: Binary
Measures Variable: Industry Type

5. Towards which sectors are your company's nanomaterials activities oriented? (Check all that apply)

   1 Checked
   0 Not checked
   9 Missing

5Def (Variable name)

- Defense

5Enrgy (Variable name)

- Energy

5Aero (Variable name)

- Aerospace

5Elect (Variable name)

- Electronics/IT

5Auto (Variable name)

- Automotive

5Const (Variable name)

- Construction materials

5Coat (Variable name)

- Coatings

5Text (Variable name)

- Textile/apparel

5Cosm (Variable name)

- Cosmetics or other personal care products

5FdBev (Variable name)

- Food & beverage

5Med (Variable name)

- Medicine or other health

5Sens (Variable name)

- Sensors

5Envmt (Variable name)

- Environment

5Rec (Variable name)

- Recreation

5Oth (Variable name)

- Other (please specify) _______________

** Code these responses into (a) existing categories (b) newly created categories. If don't belong to any category, mark 5Oth as 1 and make note of the qualitative response in another document.

6CoAge
Variable Type: Interval
Measures Variable: Age of Company
6. Approximately what year was your company formed?
** No need to code. Need to standardize. Recode: 6CoAge = 2010 – (Year company was formed). Six months is recorded as 0.5 years, etc.
-1 Missing

7YrsN
Variable Type: Interval
Measures Variable: Age of Company

7. For how many years has your company been working with nanomaterials?

**No need to code. Need to standardize. When we recode the data, we will need to make sure every data entry is in years.
-1 Missing

Variable Type: Nominal, discrete
Measures Variable: Company Location

8. Where are your company's headquarters located? Please indicate the Country and State/Province.

8HQState
See Country Appendix 1 for codes.
8HQCtry
See Country Appendix 2 for codes.

9CtryN
Variable type: Nominal, discrete
Measures Variable: Company Location

9. In what countries does your company use and/or manufacture nanomaterials?

**We will need to figure out how to code this. Consider creating dummy variables for each country.
-1 Missing

10Ees
Variable Type: Interval
Measures Variable: Company Size

10. How many employees are in your company overall?

**No need to code. Part-time employees are 0.5 FTE.
-1 Missing

10SizCensus
Variable Type: Nominal
Measures Variable: Company Size
**This variable is created from response to question 10. Categories (below) are created based on categories used by the US Census Bureau (http://www.census.gov/epcd/www/smallbus.html)

1	Small/start-up business	1-249 employees
2	Medium-sized company	250-2499 employees
3	Large company	2500 employees or more

10CoSize
Variable Type: Nominal

Measures Variable: Company Size
**This variable is created from responses to question 10. Categories (below) are based on breaks in responses. With 10SizCensus, almost all of our respondents are either small/start-up businesses or large companies; we had almost no medium sized companies. In creating this variable, we differentiate between start-up business, small business, and large company.

1	Start-up business	1-19 employees
2	Small business	20-249 employees
3	Medium-large company	250 employees or more

11NanEes

Variable Type: Interval

Measures Variable: Company Size

11. How many employees work directly with (i.e. handle, produce, and/or research) nanomaterials in your company?

**No need to code. Part-time employees are 0.5 FTE.

11NanSize

Variable Type: Nominal

Measures Variable: Company Size

**This variable is created from responses to question 11. Categories (below) are based on the breakdown of responses.

1	Start-up with regard to nanotech	1-6 employees
2	Small nanotech operation	7-30 employees
3	Larger nanotech operation	more than 30 employees

11EeRatio

Variable Type: Interval

Measures Variable: Company Size

**This variable is created from responses to questions 10 and 11. It is the proportion of employees working with nanomaterials.

Section Three: Nanoparticle-Specific Product Information

Section 3 is designed to learn about the nanoparticles your company handles. This will involve describing each individual nanoparticle produced and/or handled by your company in non-technical terms. No proprietary information is requested.

Variable Type: Binary

Measures Variable: Type of nanomaterials handled/produced

12. What are all the different types of nanoparticles that your company works with?

1 Checked
0 Not checked
9 Missing

12SWCNT (Variable name)
- Single-walled carbon nanotubes

12MWCNT (Variable name)
- Multi-walled carbon nanotubes

12CBlk (Variable name)
- Carbon black

12Full (Variable name)
- Fullerenes (bucky balls)

12NSilv (Variable name)
- Nano-silver

12NAu (Variable name)
- Nano-gold

12TO2 (Variable name)
- Titanium dioxide

12ZO (Variable name)
- Zinc oxide

12CeO (Variable name)
- Cerium oxide

12Si (Variable name)
- Silica

12QD (Variable name)
- Quantum dots

12Clay (Variable name)
- Clay

12DendPol (Variable name)
- Dendrimers/polymers

12OthCarb

** Created from responses to "other" category

12OthMetal

** Created from responses to "other" category

12Oth (Variable name)
- Other (please specify) ____________________

  ** Code these responses into (a) existing categories (b) newly created categories. If don't belong to any category, mark 12Oth as 1 and make note of the qualitative response in another document.

The following questions, questions 13 through 17, will be asked of each individual nanoparticle identified above in question 12.

Coding for questions 13-17 is tricky, because they address more than 15 nanoparticles [NPs]. Each Nanoparticle is made into a dummy variable with its own variable name. When reading coding notes for questions 13-17, "[NP]" is filled in with the corresponding nanoparticle abbreviation:

SWNT
MWCNT
CBlk
Full
NSilv
NAu
TO2
ZO
CeO
Si
QD
Clay
DendPol
OthCarg
OthMetal
Oth

CODE:
1 Checked
0 Not checked
9 Missing

13. What size are the nanoparticles as manufactured? *(List the nanoparticles identified in question 12 in the 'Nanoparticle' column.)*

Variable name:	**13[NP]1**	**13[NP]2**	**13[NP]3**	**13[NP]4**	**13[NP]5**
Nanoparticle	**< 2.5 nm**	**2.5 - 10 nm**	**> 10 to 50 nm**	**>50 to 100 nm**	**> 100 nm**
______	☐	☐	☐	☐	☐
______	☐	☐	☐	☐	☐
______	☐	☐	☐	☐	☐

**Comments should be coded or reported qualitatively.

14. In what product form are nanoparticles handled at your company? (*List the nanoparticles identified in question 12 in the 'Nanoparticle' column*)

Variable Name:	**14[NP]1**	**14[NP]2**	**14[NP]3**	**14[NP]4**
Nanoparticle	**Dry Powder**	**Aerosol**	**Liquid**	**Embedded**
______	☐	☐	☐	☐
______	☐	☐	☐	☐
______	☐	☐	☐	☐

**Comments should be coded or reported qualitatively.

15. Do the nanoparticles that your company works with agglomerate? (*List the nanoparticles identified in question 12 in the 'Nanoparticle' column)*

Variable Name:	**15[NP]1**	**15[NP]2**	**15[NP]3**
Nanoparticle	**Yes**	**No**	**Not Sure (please explain)**
______	☐	☐	☐
______	☐	☐	☐
______	☐	☐	☐

**Comments should be coded or reported qualitatively.

16. If so, to what size do these particles agglomerate? (*List the nanoparticles identified in question 12 in the 'Nanoparticle' column)*

Variable Name:	**16[NP]1**	**16[NP]2**
Nanoparticle	**≤ 100 nm**	**>100 nm**

____________	☐	☐
____________	☐	☐
____________	☐	☐

**Comments should be coded or reported qualitatively.

17. At what scale of production are these nanomaterials? *(List the nanomaterials identified in question 12 in the 'Nanomaterial' column)*

Variable Name:	**17[NP]1**	**17[NP]2**	**17[NP]3**
Nanomaterial	**At a small scale (start up or R&D)**	**At the pilot scale within larger industry**	**At the full or commercial scale**
____________	☐	☐	☐
____________	☐	☐	☐
____________	☐	☐	☐

**Comments should be coded or reported qualitatively.

Section Four: General EHS and Nano-EHS

Section 4 regards your company's occupational and environmental health and safety programs, including both staffing and training. Specific practices are addressed in later sections of the survey.

18EHS
Variable Type: Binary
Measures Variable: Industry Practices

18. Does your company implement a general health and safety program?
    1 Yes*(If yes, continue to question 19)*
    0 No *(If no, skip to question 20)*
    9 Missing

**There is a comment box with this question that needs to be coded or reported qualitatively.

19EHSFTE

Variable Type: Interval

Measures Variable: Industry Practices

19. How many full-time equivalent health and safety staff are employed?

-9 Missing

** Make sure responses are consistent and interval. Part-time employees should be recorded as 0.5 FTE. Please note that full-time equivalent (FTE) does not mean you count only full-time employees. For example, if someone says "Mature program, staffed, one full time officer. Two part time assistance, one from R&D one from production", you should record the data as "2" (1 FT employee and 2 PT employees = 2 FTE). (Example from participant 9999)

**Don't count consultants; instead consider including in report that # of respondents also reported using consultants

**Skipped is recorded as 0 when the respondent reported not having a general EHS program.

20nEHS

Variable Type: Binary

Measures Variable: Industry Practices

20. Does your company have a nano-specific health and safety program?

1 Yes *(If yes, continue to question 21)*

0 No *(If no, why not?) (skip to question 25)*

9 Missing

20nEHSY

(If no, why not?)

Variable Type: Nominal

Measures Variable: Industry Practices

-1 Skipped

9 Missing

**Create answer categories based on existing responses and code accordingly.

21EHSFTE

Variable Type: Binary

Measures Variable: Industry Practices

21. How many full time equivalent EHS employees are staffed specifically in the nano-specific program?

-9 Missing

**No need to code responses. Make sure responses are consistent. Part-time employees should be recorded as 0.5 FTE

**Don't count consultants; instead consider including in report that # of respondents also reported using consultants
**Skipped is recorded as 0 when the respondent reported not having a nano-specific EHS program.

Variable Type: Binary
Measures Variable: Industry Practices

22. What does your nano-specific EHS program consist of?

1 Checked
0 Not checked
9 Missing

22Trng (Variable name)
- Training

22Eebk (Variable name)
- Employee handbook

22 Insp (Variable name)
- Inspection or other oversight

22RskFrm (Variable name)
- Risk framework or other risk assessment

22WkPst (Variable name)
- Workplace postings

22Oth (Variable name)
- Other, please specify_______________

** Code these responses into (a) existing categories (b) newly created categories. If don't belong to any category, mark 12Oth as 1 and make note of the qualitative response in another document.

Variable Type: Nominal, Binary
Measures Variable: Access to information/guidance documents

23. Where did you find the information used to guide the development of your nano-specific EHS program?

**Count the number of respondents use/refer to a given source and report qualitatively.

Variable Type: Binary
Measures Variable: Industry Practices

24. How often do employees receive nano-specific health and safety training? (Check all that apply)

1 Checked
0 Not checked
9 Missing

24TrnAn (Variable name)
- Annually

24TrnOr (Variable name)

- At employee orientation

24TrnEHS

- When general EHS training is offered

24TrnIntro

- When new material is introduced

24Oth

- Other (please specify) ________________

  ** Code these responses into (a) under existing variables, or (b) newly created binary variables, such as:

  24Qtrly Quarterly

  24Mthly Monthly

  If don't belong to any category, mark 24Oth as 1 and make note of the qualitative response in another document.

Section Five: Employee and Area Exposure Monitoring

Section 5 regards your company's employee and area exposure monitoring practices.

25Monit

Variable Type: Binary

Measures Variable: Industry Practices

25. Does your company monitor the workplace for nanoparticles?

    1 Yes *(continue to question 26)*

    0 No *(skip to question 28)*

    9 Missing

**There is a comment box that should be reviewed. If appropriate, create a new variable with responses to this comment box. If not appropriate, consider reporting qualitatively if relevant.

Variable Type: Binary

Measures Variable: Industry Practices

26. What monitoring equipment is used? (Check all that apply and specify what is being measured with the method- mass, number, and/or surface area.)

    1 Checked

    0 Unchecked

    9 Missing

26ELPI

- Electrical low pressure impactor (ELPI); mass, number, surface area:___________________________

26DMAS

- Differential mobility analyzing system; mass, number surface area:___________________________

26CPC

- Condensation particle counter (CPC); number:______

26OPC

- Optical particle counter (OPC); number:______

26SMPS

- Scanning mobility particle sizer (SMPS); number:______

26DifCh

- Diffusion charger; surface area:______

26ElecMic

- Electron microscopy; surface area:______

26Oth

- Other (please specify) ______________________

  ** Code these responses into (a) under existing variables, or (b) newly created binary variables. If don't belong to any category, mark 26Oth as 1 and make note of the qualitative response in another document.

  **Note: if this question was skipped due to answering "no" to question 25, mark each "26" variable as 0 (not missing)

**NOTE: Did not code mass, number, surface area information, because most respondents did not know the answer to the question or were not consistently asked the question by interviewers.

Variable Type: Nominal
Measures Variable: Industry Practices
27Monit

27. When is monitoring performed?

    4 At least annually (report qualitatively how many respondents monitored annually with NIOSH)
    3 Monthly
    2 Weekly
    1 Irregularly
    0 Never

Not what we used

Section Six: Containment and Exposure Controls

Section 6 regards your company's containment and exposure controls.

28Max

Variable Type: Ordinal

Measures Variable: Industry Practices

28. For employees who work with nanomaterials, what is the maximum amount typically handled at a time?

1 Micrograms to less than one milligram

2 Milligrams to less than one gram

3 One gram to less than one kilogram

4 One kilogram or more

8 Other (please specify) ____________________

9 Missing

** Code these responses into (a) under existing variables, or (b) a newly created ordinal variable. If response doesn't belong to any category, mark 28 as 8 and make note of the qualitative response in another document.

**NOTE: Currently coded as separate binary variables (18MicroG, 18mg, 18g, 18kg, 28Oth). Needs to be recoded. For respondents who answered this question as a "check all that apply," responses will be coded for the maximum category checked. (Fixed 01/19/10)

**NOTE: I left the binary variables in SPSS for our records but not our use.

Variable Type: Binary

Measures Variable: Industry Practices

29. Which of the following facility design and engineering controls are used to manage employee exposure to nanomaterials? (Check all that apply)

1 Checked

0 Unchecked

9 Missing

29HVAC

- Separate HVAC system

29Press

- Pressure differentials

29ClnRm

- Clean room

29SepWk

- Designated or separate work areas

29CPS

- Closed piping system

29HEPA

- HEPA filtration

29ULPA

- ULPA filtration

29Hood

- Fume hood

29LamFl

- Laminar flow clean bench

29BioCab

- Biological safety cabinet

29GlvBg

- Glove bag

29GlvBx

- Glove box

29Oth

- Other (please specify) ___________________

** Code these responses into (a) under existing variables, or (b) newly created binary variables. Or report qualitatively.

30EngCntrl

Variable Type: Nominal

Measures Variable: Industry Practices

30. When are engineering controls used?

1 Always

2 Sometimes

3 Never

9 Missing

**Comment box needs to be reviewed. If appropriate create new variables from responses. If not appropriate, consider reporting qualitatively if relevant.

Variable Type: Binary

Measures Variable: Industry Practices

31. What methods are used for cleaning areas in which nanomaterials are handled? (Check all that apply)

1 Checked

0 Unchecked

9 Missing

31Vac

- Household or shop vacuum

31HEPA

- HEPA vacuum

31Swp

- Sweeping

31CmprAr

- Compressed air

31WtWp

- Wet wiping

31Soap

- Soaps or cleaning oils

31AbsMat

- Absorbent materials

31LiqTrp

- Liquid traps

31Oth

- Other (please specify) _______________

  ** Code these responses into (a) under existing variables, or (b) newly created binary variables. Or report qualitatively.

Variable type: Binary
Measures Variable: Industry Practices

32. When is cleaning performed?

    1 Checked

    0 Unchecked

    9 Missing

32Spill

After spills

32Shft

At the end of every shift

32Day

At the end of every work day

32Oth

Other (please specify) ______________

** Code these responses into (a) under existing variables, or (b) newly created nominal variables. Or report qualitatively.

33ClsdCnt

Variable Type: Nominal

Measures Variable: Industry Practices

33. Are nanomaterials transported in closed containers within the facilities?

    1 Always

    2 Sometimes

    3 Never

    9 Missing

**There is an "other, please specify" for some versions. Review the responses here and either code in existing categories or create new ones based on the responses and code accordingly.

Variable Type: Ordinal

Measures Variable: Industry Practices

34. Which of the following personal protective equipment does your company either require or recommend for handling nanomaterials?

	Required	Recommended	Not required or recommended
34LbCt Lab coat	2	1	0
34Cov Coveralls	2	1	0
34ShCov Shoe covers	2	1	0
34LatGlv Latex gloves	2	1	0
34NitGlv Nitrile gloves	2	1	0
34Eye Eye protection	2	1	0
34HairBon Hair bonnets	2	1	0
34DstMsk Dust masks	2	1	0
34BdgSt Building suits	2	1	0

9 Missing

34Oth

Other (please specify) ______________________

** Code these responses into (a) under existing variables, or (b) newly created ordinal variables. If don't belong to any category, consider reporting qualitatively.

35Resp

Variable Type: Binary

Measures Variable: Industry Practices

35. Do employees working with nanomaterials use respiratory protection?

1 Yes *(if yes, what kind of protection is used? See below)*

35RspTyp

Variable Type: Binary

Variable Measure: Industry Practices

1 Checked

0 Unchecked

9 Missing

35DisFilt

Disposable filtering facepiece

35ElastH

Elastomeric half-facepiece

35PowLos

Powered loose-fitting facepiece

35PTghtHf

Powered tight-fitting half-facepiece

35PTghtFl

Powered tight-fitting full-facepiece

35ElastF

Elastomeric full-facepiece with N-100, R-100, or P-100 filter

35Oth

**There is an "other category" here. Code in existing category/variable or create a new variable(s) and code accordingly.

0 No

9 Missing

**Did respondents use 35RspTyp as a "check all that apply" question? If so, we will want to code these responses as 0 or 1 on a binary variable

36. Are there any EHS practices other than the ones asked about so far that are used in your company?

**This is ultimately a qualitative response – something we would report descriptively rather than through any statistical analysis. I doubt responses will be worth coding and entering into SPSS.

The next four questions address potential barriers perceived to exist by companies who currently have or intend to implement a nano-specific health and safety program. Please indicate the level of your agreement with the following statements:

37Bdgt
Variable Type: Ordinal
Measures Variable: Cost of EHS

37. Budget constraints are an impediment in implementing nano-specific health and safety practices.

Strongly agree	Agree	Disagree	Strongly disagree	Don't know
1	2	4	5	3

9 Missing

**There is a comment box here. Review and consider correcting your data entry for their close-ended response to 37, creating additional variables or reporting qualitatively.

38LacInfo
Variable Type: Ordinal
Measures Variable: Access to information/guidance documents

38. Lack of information is an impediment in implementing nano-specific health and safety practices.

Strongly agree	Agree	Disagree	Strongly disagree	Don't know
1	2	4	5	3

9 Missing

**There is a comment box here. Review and consider correcting your data entry for their close-ended response to 38, creating additional variables or reporting qualitatively.

39LacReg
Variable Type: Ordinal
Measures Variable: Access to information/guidance documents

39. Lack of health and safety guidance or regulations is an impediment in implementing nano-specific health and safety practices.

Strongly agree	Agree	Disagree	Strongly disagree	Don't know
1	2	4	5	3

9 Missing

**There is a comment box here. Review and consider correcting your data entry for their close-ended response to 39, creating additional variables or reporting qualitatively.

40Enfrc
Variable Type: Ordinal
Measures Variable: Management Centrality

40. Internal enforcement is an impediment in implementing nano-specific health and safety practices.

Strongly agree	Agree	Disagree	Strongly disagree	Don't know
1	2	4	5	3

9 Missing

**There is a comment box here. Review and consider correcting your data entry for their close-ended response to 40, creating additional variables or reporting qualitatively.

41BarrOth
Variable Type: Nominal
Measures Variable: Other unknown variables

41. Please describe any other barriers to implementing nano-specific health and safety practices.

**Create answer categories based on existing responses and code accordingly or consider reporting qualitatively. This question will tell us if there are other factors we neglected.

Section Seven: Waste Management and Product Stewardship

Section 7 regards waste management and product stewardship practices.

42NWstPrgm
Variable Type: Binary
Measures Variable: Industry Practices

42. Does your company have a nano-specific waste program?

1 Yes
0 No
9 Missing

**There is a comment box for some versions. Review responses and (a) consider changing the way you entered the response to question 42, (b) create a new variable(s) based on the responses, or (c) consider reporting qualitatively.

43HazWst
Variable Type: Binary
Measures Variable: Industry Practices
43. Does your company dispose of its nanomaterials as hazardous waste?
1 Yes
0 No
9 Missing

**There is a comment box for some versions. Review responses and (a) consider changing the way you entered the response to question 42, (b) create a new variable(s) based on the responses, or (c) consider reporting qualitatively.

44SepCont
Variable Type: Binary
Measures Variable: Industry Practices
44. Are there separate disposal containers for nanomaterials used either in the lab or in waste storage areas?
1 Yes
0 No
9 Missing

**There is a comment box for some versions. Review responses and (a) consider changing the way you entered the response to question 42, (b) create a new variable(s) based on the responses, or (c) consider reporting qualitatively.

45ListSep
Variable Type: Binary
Measures Variable: Industry Practices
45. Are nanomaterials listed separately as "nanomaterials" on waste manifests?
1 Yes
0 No
9 Missing

**There is a comment box for some versions. Review responses and (a) consider changing the way you entered the response to question 42, (b) create a new variable(s) based on the responses, or (c) consider reporting qualitatively.

46Advtse
Variable Type: Binary
Measures Variable: Industry Practices
46. Do you advertise or otherwise disclose that your products contain nanomaterials?
    1 Yes
    0 No
    9 Missing

**There is a comment box for some versions. Review responses and (a) consider changing the way you entered the response to question 42, (b) create a new variable(s) based on the responses, or (c) consider reporting qualitatively.

47GdeCust
Variable Type: Binary
Measures Variable: Industry Practices
47. Do you provide guidance to your customers regarding safe use, and/or disposal of your products?
    1 Yes (*If yes, what aspects of the information are nano-specific?*)
        47Info
        Variable Type: Nominal
        Measures Variable: Industry Practices
        **Create answer categories from existing responses and code accordingly.
    0 No
    9 Missing
    -1 Skipped

Section Eight: Views on Risk Assessment and Risk Management

While the survey thus far has focused on your company's practices, in section 8 we will be asking you about your personal views regarding factors that could constrain scientific innovation, as well as the potential risks of nanomaterials, and how best to limit those risks. Many of these questions are a matter of personal opinion and are simply intended to capture varying perspectives from within industry.

Variable Type: Ordinal
Measures Variable: Risk Perception
48. For the following list of nanomaterials, please rate the level of risk you think each material poses to human health and/or the environment.

Comparative Items	Almost no risk	Slight risk	Moderate risk	High risk	Don't know

48CNT Carbon nanotubes	1	2	3	4	5
48OthC Other carbonaceous materials (excluding CNT)	1	2	3	4	5
48Dry Dry powders	1	2	3	4	5
48QD Quantum dots	1	2	3	4	5
48MetO Metal oxides	1	2	3	4	5
48HvyMet Heavy metals (e.g., gold, silver)	1	2	3	4	5

9 Missing

**There is a comment box here. Review and decide if you need to (a) change the way in which the response to 48 is recorded for the respondent, (b) create a new variable(s) based on the responses, or (c) report the response qualitatively.

Please indicate the level of your agreement with the following statements:

49TrstInd

Variable Type: Ordinal

Measures Variable: Risk Perception

49. Industries working with nanomaterials can be trusted to regulate the safe-handling of these materials.

Strongly agree	Agree	Disagree	Strongly disagree	Don't know
1	2	4	5	3

9 Missing

**There is a comment box here. Review and decide if you need to (a) change the way in which the response to 49 is recorded for the respondent, (b) create a new variable(s) based on the responses, or (c) report the response qualitatively.

50Adapt

Variable Type: Ordinal

Measures Variable: Risk Perception

50. It is reasonable to assume that industries working with nanomaterials will adapt or alter their safe-handling practices when new hazards are discovered.

Strongly agree	Agree	Disagree	Strongly disagree	Don't know
1	2	4	5	3

9 Missing

**There is a comment box here. Review and decide if you need to (a) change the way in which the response to 50 is recorded for the respondent, (b) create a new variable(s) based on the responses, or (c) report the response qualitatively.

51Benft

Variable Type: Ordinal

Measures Variable: Risk Perception

51. In the case of nanotechnologies, the benefits of advancements in science and technology outweigh the risks involved in research, development, and production.

Strongly agree	Agree	Disagree	Strongly disagree	Don't know
1	2	4	5	3

9 Missing

**There is a comment box here. Review and decide if you need to (a) change the way in which the response to 51 is recorded for the respondent, (b) create a new variable(s) based on the responses, or (c) report the response qualitatively.

52Deprive

Variable Type: Ordinal

Measures Variable: Risk Perception

52. Waiting until safety studies are complete to commercialize nanotechnology will deprive society of too many potential benefits.

Strongly agree	Agree	Disagree	Strongly disagree	Don't know
1	2	4	5	3

9 Missing

**There is a comment box here. Review and decide if you need to (a) change the way in which the response to 52 is recorded for the respondent, (b) create a new variable(s) based on the responses, or (c) report the response qualitatively.

53VolRept

Variable Type: Ordinal

Measures Variable: Risk Perception

53. Voluntary reporting approaches for risk management are effective for protecting human health and the environment.

Strongly agree	Agree	Disagree	Strongly disagree	Don't know
1	2	4	5	3

9 Missing

**There is a comment box here. Review and decide if you need to (a) change the way in which the response to 53 is recorded for the respondent, (b) create a new variable(s) based on the responses, or (c) report the response qualitatively.

54Citzn

Variable Type: Ordinal

Measures Variable: Risk Perception

54. Direct involvement of citizens in policy decisions about research and development of new technologies is beneficial.

Strongly agree	Agree	Disagree	Strongly disagree	Don't know
1	2	4	5	3

9 Missing

**There is a comment box here. Review and decide if you need to (a) change the way in which the response to 54 is recorded for the respondent, (b) create a new variable(s) based on the responses, or (c) report the response qualitatively.

55GM

Variable Type: Ordinal

Measures Variable: Risk Perception

55. In my company, we worry that nanotechnologies may encounter unwarranted public backlash such as that which accompanied genetically modified foods in Europe.

Strongly agree	Agree	Disagree	Strongly disagree	Don't know
1	2	4	5	3

9 Missing

**There is a comment box here. Review and decide if you need to (a) change the way in which the response to 55 is recorded for the respondent, (b) create a new variable(s) based on the responses, or (c) report the response qualitatively.

56BizBttr

Variable Type: Ordinal

Measures Variable: Risk Perception

56. Businesses are better informed about their own workplace safety needs than are government agencies.

Strongly agree	Agree	Disagree	Strongly disagree	Don't know
1	2	4	5	3

9 Missing

**There is a comment box here. Review and decide if you need to (a) change the way in which the response to 56 is recorded for the respondent, (b) create a new variable(s) based on the responses, or (c) report the response qualitatively.

57EeRspbl

Variable Type: Ordinal

Measures Variable: Risk Perception

57. Employees are ultimately responsible for their own safety at work.

Strongly agree	Agree	Disagree	Strongly disagree	Don't know
1	2	4	5	3

9 Missing

**There is a comment box here. Review and decide if you need to (a) change the way in which the response to 57 is recorded for the respondent, (b) create a new variable(s) based on the responses, or (c) report the response qualitatively.

58SftyPrty

Variable Type: Ordinal
Measures Variable: Risk Perception
58. Workplace safety should take priority over scientific and technological advances.

Strongly agree	Agree	Disagree	Strongly disagree	Don't know
1	2	4	5	3

9 Missing

**There is a comment box here. Review and decide if you need to (a) change the way in which the response to 58 is recorded for the respondent, (b) create a new variable(s) based on the responses, or (c) report the response qualitatively.

59NInsrnc
Variable Type: Ordinal
Measures Variable: Risk Perception
59. Insurers in my industry are increasingly concerned about nano-specific risks.

Strongly agree	Agree	Disagree	Strongly disagree	Don't know
1	2	4	5	3

9 Missing

**There is a comment box here. Review and decide if you need to (a) change the way in which the response to 59 is recorded for the respondent, (b) create a new variable(s) based on the responses, or (c) report the response qualitatively.

Variable Type: Ordinal
Measures Variable: Risk Perception
60. Please rate your level of trust in the following government agencies to effectively assess and manage nano-specific environmental health and safety risks:

IN THE US	No trust	Some trust	Trust	Much trust	Not familiar with agency
60EPA Environmental Protection Agency (EPA)	1	2	3	4	5
60FDA Food and Drug Administration	1	2	3	4	5

(FDA)					
60NIOSH National Institute of Occupational Safety and Health (NIOSH)	1	2	3	4	5
60USDA US Department of Agriculture (USDA)	1	2	3	4	5

9 Missing
-1 Skipped

If blank and respondent is not in the US (HQCtry does not = 1), code "-1"; If blank and respondent is from the US (HQCtry = 1), code as missing ("9").

IN CANADA	No trust	Some trust	Trust	Much trust	Not familiar with agency
60HCan Health Canada	1	2	3	4	5
60EnvCan Environment Canada	1	2	3	4	5

9 Missing
-1 Skipped

If blank and respondent is not in Canada (HQCtry does not = 2), code "-1"; If blank and respondent is from Canada (HQCtry = 2), code as missing ("9").

IN THE UK	No trust	Some trust	Trust	Much trust	Not familiar with agency
60DEFRA Department for Environment, Food & Rural Affairs (DEFRA)	1	2	3	4	5

60HSE Health & Safety Executive (HSE)	1	2	3	4	5

9 Missing
-1 Skipped

If blank and respondent is not in the UK (HQCtry does not = 13), code "-1"; If blank and respondent is from the UK (HQCtry = 13), code as missing ("9").

**There is a comment box here. Review and decide if you need to (a) change the way in which the response to 60 is recorded for the respondent, (b) create a new variable(s) based on the responses, or (c) report the response qualitatively.

Variable Type: Ordinal
Variable Measure: Risk Perception

61. Please rate your level of trust in the following international organizations to effectively assess and manage nano-specific environmental health and safety risks:

TRANSNATIONAL	No trust	Some trust	Trust	Much trust	Not familiar with agency
61REACH Regulation on Registration, Evaluation, Authorization & Restriction of Chemicals (REACH)	1	2	3	4	5
61ISO International Organization for Standardization (ISO)	1	2	3	4	5
61ASTM ASTM International	1	2	3	4	5

9 Missing

**There is a comment box here. Review and decide if you need to (a) change the way in which the response to 61 is recorded for the respondent, (b) create a new variable(s) based on the responses, or (c) report the response qualitatively.

Variable Type: Ordinal
Measures Variable: Risk Perception

62. Please indicate your level of trust in the following sources to adequately communicate the *benefits* of nanotechnology to the public:

	No trust	Some trust	Trust	Much trust
62Acad Academic Scientists	1	2	3	4
62Reg Government regulatory agencies	1	2	3	4
62Ind Industry (companies involved in nanotech)	1	2	3	4
62NGO Non-profits and non-governmental organizations	1	2	3	4
62Media Traditional Mass media (television, radio, newspapers)	1	2	3	4
62Net Internet media (web logs (blogs), web-based news)	1	2	3	4

9 Missing

**There is a comment box here. Review and decide if you need to (a) change the way in which the response to 62 is recorded for the respondent, (b) create a new variable(s) based on the responses, or (c) report the response qualitatively.

Section Nine: Closing Questions

In closing,

63. Can you recommend other companies and/or individuals that you think we should invite to participate in our survey?

**Exclude from database

Variable Type: Nominal
Measures Variable: Measures yet unknown variables

64. Is there anything that we haven't covered in this interview that you think is relevant and we need to understand and include in this survey?

**Create answer categories and code accordingly.

65. If we have additional questions or need to follow up with you, are you willing to be contacted?

**Exclude from database

Appendix H. P-values from Fisher's exact test for correlation between independent variables

Table 20. P-values from Fisher's exact test for correlation between independent variables for company characteristics and nanomaterial type.

		Independent Variables							
		Company Age	**Years Working with NM**	**HQ Location**	**Company Size**	**Nanomaterials Handled: CNT**	**Nanomaterials Handled: Nano-Silver**	**Nanomaterials Handled: Silica**	**Nanomaterials Handled: Clay**
Dependent Variables	**Company Age**	-	**0.000**	0.341	**0.000**	0.321	0.528	0.231	**0.031**
	Years Working with NM	**0.000**	-	0.534	**0.023**	0.541	0.541	0.534	**0.059**
	HQ Location	0.341	0.534	-	0.434	0.151	0.224	0.122	0.153
	Company Size	**0.000**	**0.023**	0.434	-	0.104	0.104	0.354	0.368
	Nanomaterials Handled: CNT	0.321	0.541	0.151	0.104	-	0.403	0.483	0.539
	Nanomaterials Handled: Nano-Silver	0.528	0.541	0.224	0.104	0.403	-	**0.000**	0.271
	Nanomaterials Handled: Silica	0.231	0.534	0.122	0.354	0.483	**0.000**	-	0.118
	Nanomaterials Handled: Clay	**0.031**	**0.059**	0.153	0.368	0.539	0.271	0.118	-

Table 21. P-values from Fisher's exact test for correlation between independent variables and EHS practices and views.

Dependent Variables	***Independent Variables***							
	Company Age	**Years Working with NM**	**HQ Location**	**Company Size**	**Nano Handled: CNT**	**Nano Handled: Nano-Silver**	**Nano Handled: Silica**	**Nano Handled: Clay**
18 General EHS	0.516	0.556	**0.021**	0.293	0.087	0.410	0.087	0.619
20 Nano EHS	**0.006**	0.071	0.457	0.215	**0.032**	0.313	0.407	**0.013**
21 EHS employees	**0.012**	0.231	0.200	0.450	0.101	**0.022**	0.217	0.193
25 Monitoring	0.334	0.344	0.526	**0.027**	**0.054**	**0.054**	0.083	0.396
34 Latex glove use	0.422	0.553	0.541	0.181	0.447	0.394	0.486	0.378
34 Dust Mask use	0.641	0.165	0.400	0.440	0.585	0.585	0.434	0.374
35 Respirator use	**0.035**	0.372	0.243	0.530	0.220	0.338	0.262	0.616
37 Budget impediments	0.466	**0.021**	0.405	0.555	0.555	0.327	0.445	0.492
38 Lack of info. Impediments	0.273	0.429	0.317	**0.026**	0.196	0.382	0.297	**0.058**
39 Lack of reg. impediments	0.389	0.354	0.568	0.584	0.364	**0.033**	0.154	0.150
40 Enforcement impediments	0.179	0.540	0.441	0.285	0.100	0.634	0.634	0.662
42 Nano Waste Program	0.243	0.500	0.586	0.540	**0.050**	**0.014**	0.256	0.581
43 Hazardous Waste	**0.001**	**0.042**	0.465	0.145	0.145	0.611	0.145	0.072
44 Separate Containers	0.321	0.215	0.085	0.338	0.247	0.356	0.166	**0.008**
45 List Separately	**0.033**	**0.032**	0.470	0.569	0.373	0.569	0.163	0.079
46 Advertise nano	**0.003**	0.406	**0.039**	**0.000**	0.337	0.395	0.605	0.603
47 Customer guidance	0.193	0.292	0.576	0.309	0.424	0.424	**0.018**	0.442

Table 22. P-values from Fisher's exact test for correlation between independent variables and views on risk.

		Independent Variables							
		Company Age	**Years Working with NM**	**HQ Location**	**Company Size**	**Nano Handled: CNT**	**Nano Handled: Nano-Silver**	**Nano Handled: Silica**	**Nano Handled: Clay**
Dependent Variables	***49Trust***	0.215	0.331	0.592	0.092	0.582	0.582	**0.024**	0.659
	50Adapt	0.143	0.649	0.527	**0.041**	0.584	0.623	0.584	0.206
	51Benft	0.340	0.643	0.174	0.563	0.591	0.201	0.409	0.086
	52Deprive	0.271	0.275	0.364	0.510	0.563	0.611	0.459	0.156
	53VolRept	0.488	0.237	0.221	0.308	0.115	0.219	0.414	0.242
	54Citzn	0.588	0.221	0.510	0.478	0.431	0.431	0.295	0.412
	55Gm	0.431	0.198	**0.038**	0.215	0.124	0.608	0.235	0.404
	56BizBtr	0.380	0.426	0.532	0.527	0.246	0.527	0.571	0.543
	57EeRspbl	0.441	0.116	0.149	0.256	0.205	0.077	0.256	0.291
	58SftyPrty	0.447	0.456	0.166	0.606	**0.006**	0.311	0.344	0.149
	59NIns	0.396	0.451	0.514	0.214	0.544	0.423	**0.046**	0.108

49Trust	Industries working with nanomaterials can be trusted to regulate the safe-handling of these materials.
50Adapt	It is reasonable to assume that industries working with nanomaterials will adapt or alter their safe-handling practices when new hazards are discovered.
51Benft	In the case of nanotechnologies, the benefits of advancements in science and technology outweigh the risks involved in research, development, and production.
52Deprive	Waiting until safety studies are complete to commercialize nanotechnology will deprive society of too many potential benefits.
53VolRept	Voluntary reporting approaches for risk management are effective for protecting human health and the environment.
54Citzn	Direct involvement of citizens in policy decisions about research and development of new technologies is beneficial.
55Gm	In my company, we worry that nanotechnologies may encounter unwarranted public backlash such as that which accompanied genetically modified foods in Europe.
56BizBtr	Businesses are better informed about their own workplace safety needs than are government agencies.
57EeRspbl	Employees are ultimately responsible for their own safety at work.
58SftyPrty	Workplace safety should take priority over scientific and technological advances.
59NIns	Insurers in my industry are increasingly concerned about nano-specific risks.

Table 23. P-values from Fisher's exact test for correlation between risk questions.

	Independent variables										
Dependent Variables	**49Trust**	**50Adapt**	**51Benft**	**52Deprive**	**53VolRept**	**54Citzn**	**55Gm**	**56BizBtr**	**57EeRspbl**	**58SftyPrty**	**59NIns**
49Trust	-	**0.003**	0.386	0.359	**0.001**	0.276	0.295	0.088	0.288	0.367	0.283
50Adapt	**0.003**	-	**0.040**	0.612	**0.014**	0.302	0.552	0.227	0.338	0.527	0.397
51Benft	0.386	**0.040**	-	0.278	0.305	0.372	0.396	0.283	0.591	0.514	0.089
52Deprive	0.359	0.612	0.278	-	0.570	0.585	0.511	0.412	0.490	0.445	0.555
53VolRept	**0.001**	**0.014**	0.305	0.570	-	0.529	0.416	0.081	**0.027**	0.680	0.620
54Citzn	0.276	0.302	0.372	0.585	0.529	-	0.284	0.338	0.335	0.629	0.195
55Gm	0.295	0.552	0.396	0.511	0.416	0.284	-	0.396	0.608	**0.061**	0.234
56BizBtr	0.088	0.227	0.283	0.412	0.081	0.338	0.396	-	0.373	0.196	0.631
57EeRspbl	0.288	0.338	0.591	0.490	**0.027**	0.335	0.608	0.373	-	0.360	0.577
58SftyPrty	0.367	0.527	0.514	0.445	0.680	0.629	**0.061**	0.196	0.360	-	0.581
59NIns	0.283	0.397	0.089	0.555	0.620	0.195	0.234	0.631	0.577	0.581	-

49Trust	Industries working with nanomaterials can be trusted to regulate the safe-handling of these materials.
50Adapt	It is reasonable to assume that industries working with nanomaterials will adapt or alter their safe-handling practices when new hazards are discovered.
51Benft	In the case of nanotechnologies, the benefits of advancements in science and technology outweigh the risks involved in research, development, and production.
52Deprive	Waiting until safety studies are complete to commercialize nanotechnology will deprive society of too many potential benefits.
53VolRept	Voluntary reporting approaches for risk management are effective for protecting human health and the environment.
54Citzn	Direct involvement of citizens in policy decisions about research and development of new technologies is beneficial.
55Gm	In my company, we worry that nanotechnologies may encounter unwarranted public backlash such as that which accompanied genetically modified foods in Europe.
56BizBtr	Businesses are better informed about their own workplace safety needs than are government agencies.
57EeRspbl	Employees are ultimately responsible for their own safety at work.
58SftyPrty	Workplace safety should take priority over scientific and technological advances.
59NIns	Insurers in my industry are increasingly concerned about nano-specific risks.

Table 24. P-values from Fisher's exact test for correlation between trust questions.

		Independent variables							
		60EPA	**60FDA**	**60NIOSH**	**60USDA**	**60Health Canada**	**60Environment Canada**	**60DEFRA**	**60HSE**
Dependent Variables	**60EPA**	-	**0.007**	**0.000**	**0.001**	0.269	0.269	0.490	0.296
	60FDA	**0.007**	-	**0.003**	**0.003**	**0.047**	**0.047**	0.178	0.093
	60NIOSH	**0.000**	**0.003**	-	**0.027**	0.070	0.070	**0.048**	0.090
	60USDA	**0.001**	**0.003**	**0.027**	-	0.479	0.267	0.400	0.256
	60Health Canada	0.269	**0.047**	0.070	0.479	-	**0.000**	**0.001**	**0.000**
	60Environment Canada	0.269	**0.047**	0.070	0.267	**0.000**	-	**0.000**	**0.000**
	60DEFRA	0.490	0.178	**0.048**	0.400	**0.001**	**0.000**	-	**0.000**
	60HSE	0.296	0.093	0.090	0.256	**0.000**	**0.000**	**0.000**	-

60. Please rate your level of trust in the following government agencies to effectively assess and manage nano-specific environmental health and safety risks.

Appendix I. Analysis of Respondent Job Titles

Many of the survey respondents (13) identified themselves as an EHS professional at the company, but other positions included CEO, CTO, and marketing or PR professionals. The respondents' company was considered the unit of analysis, and responses were treated the same regardless of participant job title. However, the position held by the participant was compared to company characteristics. The respondents were more likely to be an EHS professional at older companies (n=10, 34.5%, p=0.024) with 20 or more employees (n=13, 37.1%, p=0.000). The respondent was also more likely to be an EHS professional at a companies that handle CNTs (n=8, 38.1%, p=0.031; Table 25). In addition, EHS professionals held different beliefs regarding nano-specific EHS programming. EHS professionals were more likely to view lack of information as an impediment in implementing a nano-specific EHS program (n=10, 83.3%, p=0.021). However, EHS professionals were less likely to view budget as a barrier (n=1, 8.3%, p=0.053). EHS professionals were also more likely to have more trust in NIOSH to effectively assess and manage nano-specific EHS risks (n=8. 88.9%, p=0.015; Table 26). Another relationship identified that EHS professionals were more likely to report monitoring the workplace for nanomaterials (p=6, 69.2%, p=0.011) and less likely to report advertising or otherwise disclosing that their products contained nanomaterials (n=6, 50.0%, 0.024; Table 27).

As a result, these data indicate that larger, older companies may be more likely to employ an EHS professional, while start-up companies may have a CEO or scientist fulfilling this role. Furthermore, older, larger companies were less likely to report advertising that their products contain nanomaterials, and more likely to report monitoring. The relationship of company characteristics (Table 25) to EHS professional respondents may explain that monitoring and advertising had a significant relationship to the profession of the respondents.

Analysis also revealed that the respondents' views on some impediments are related to their position. An EHS professional may be less involved with a company’s budget, and this could be the reason for EHS professionals to not likely report budget constraints as a barrier. Also, while more than half of companies reported lack of knowledge as an impediment, more EHS professionals agreed with this statement. In conclusion, An EHS professional may be more familiar with the guidance available in other fields and notice the comparative lack of information in the nano-specific EHS field, but are less likely to be concerned with the financial cost of a nano-specific EHS program.

Table 25. Significant relationships between company characteristics and respondent job title.

	EHS Professional	Other	Chi-Square
Young Companies (<10 years)	3 (10.0%)	27 (90.0%)	**0.024**
Older companies (10 or more years)	10 (34.5%)	19 (65.5%)	
Small Companies (<20 employees)	0 (0.0%)	24 (100.0%)	**0.000**
Large Companies (20 or more Employees)	13 (37.1%)	22 (62.9%)	
Handles CNTs	8 (38.1%)	13 (61.9%)	**0.031**
Does Not Handle CNTs	5 (13.2%)	33 (86.8%)	

Table 26. Significant relationships between views on risks and respondent job title.

Budget is an impediment in implementing a nano-specific EHS program.	Agree	Disagree	Chi-Square	Lack of information is an impediment in implementing a nano-specific EHS program.	Agree	Disagree	Chi-Square	NIOSH: Less Trust	NIOSH: More Trust	Chi-Square
EHS Professional	1 (8.3%)	11 (91.7%)	**0.053**	**EHS Professional**	10 (83.3%)	2 (16.7%)	**0.021**	1 (11.1%)	8 (88.9%)	**0.015**
Other	16 (37.2%)	27 (62.8%)		**Other**	22 (48.9%)	23 (51.1%)		17 (58.6%)	12 (41.4%)	

Table 27. Significant relationships between reported practices and respondent job title.

	Monitor the Workplace for Nanomaterials	Do Not Monitor the Workplace for Nanomaterials	Chi-Square	Advertise that their products contain Nanomaterials	Do Not Advertise that their products contain Nanomaterials	Chi-Square
EHS Professional	9 (69.2%)	4 (30.8%)	**0.011**	6 (50.0%)	6 (50.0%)	**0.024**
Other	13 (28.9%)	32 (71.1%)		36 (83.7%)	7 (16.3%)	