2009 NCMS Study of Nanotechnology in the U.S. Manufacturing Industry

Final Report

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About NCMS

NCMS is a not-for-profit organization, based in Ann Arbor, MI, and a premier provider of collaborative research, information, knowledge and expertise to the North American manufacturing and defense community. Backed by over 350 corporate members, NCMS has spearheaded numerous advancements – in advanced materials, alternative energy, electronics, high performance computing, rapid prototyping/manufacturing, robotics, enterprise integration and sustainability – all focused on enhancing the nation's manufacturing competitiveness in the global economy.

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Acronyms and Abbreviations

2D	two-dimensional
3D	three-dimensional
ARRA	American Recovery and Reinvestment Act of 2009
BRIC	Brazil, Russia, India and China
CMOS	Complementary Metal-Oxide Semiconductor
DARPA	Defense Advanced Research Projects Agency
DoD	Department of Defense
DOE	Department of Energy
EPA	Environmental Protection Agency
FDA	Food and Drug Administration
IP	Intellectual Property
IPO	Initial Public Offering
NCI	National Cancer Institute
NCMS	National Center for Manufacturing Sciences
NHLBI	National Heart, Lung and Blood Institute
NIH	National Institute of Health
NIST	National Institute of Standards and Technology
NNCO	National Nanotechnology Coordination Office
NNI	National Nanotechnology Initiative
NNIN	National Nanotechnology Infrastructure Network
NSEC	Nanoscale Science and Engineering Centers
NSET	Nanoscale Science, Engineering and Technology
NSF	National Science Foundation
OEM	Original Equipment Manufacturer
PEN	Project on Emerging Nanotechnologies
R&D	Research and Development
SBIR	Small Business Innovative Research
SEC	Securities and Exchange Commission
STTR	Small Business Technology Transfer Research
TIP	Technology Innovation Program
TRL	Technology Readiness Level
U.S.	United States
VC	Venture Capital

1. Executive Summary

1.1 Background

Nanotechnology is a cross-disciplinary field of a variety of potentially disruptive technologies that involves the creation and application of novel materials, devices and systems by control and restructuring of matter at dimensions of roughly 1 – 100 nanometers in size.

The National Center for Manufacturing Sciences (NCMS) performed its third study of nanotechnology commercialization strategy during 2008-2010, under the sponsorship of the National Science Foundation (NSF). The methodology used was an industry survey on twenty contemporary issues addressing nanotechnology commercialization initiatives in U.S. research and manufacturing organizations. The main study objectives were to highlight aggregate trends in the transfer of nanotechnology from laboratory to industry, and to recommend approaches to accelerate product development and nanomanufacturing. A 20-question online survey questionnaire was delivered in mid-2009 to targeted industry executives with strategic- and technology-oversight, and followed up with selected cross-industry interviews. Datasets from 270 respondents were analyzed for assessing the viability, competitiveness and sustainability of U.S. Nanotechnology organizations. Over two-thirds of the respondents indicated their organizations were directly involved in nanomanufacturing value-chains.

Table 1-1 summarizes aggregate statistics and highlights of survey responses.

1.2 Geographically Speaking

California, Illinois, Massachusetts, Texas, New Jersey, Ohio, Pennsylvania, Michigan, New York, Arizona, Virginia, Washington, Florida, Maryland and Georgia lead the nation in cluster-formation around nanotechnology research and commercialization (Figure 1-1).

These study findings agree closely with rankings of leading states for venture capital (VC) investments as presented under the National Nanotechnology Initiative's (NNI)

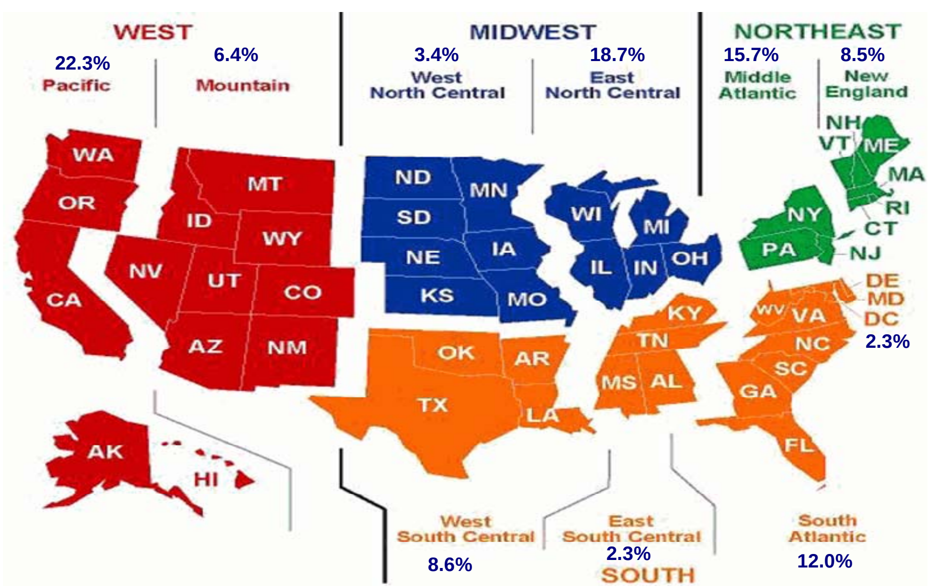

Figure 1-1. Geographical Distribution of 270 Respondents Mirrors the Locations of Nanotechnology Clusters

Second Assessment and Recommendations[1], and the recent Nano Metro[2] industry concentration study by the Woodrow Wilson Center's Project on Emerging Nanotechnologies (PEN), which found that California, Massachusetts, New York and Texas lead the nation in cluster-formation around nanotechnology research and commercialization. The PEN study reported 1,200 nanotechnology organizations in the U.S. in August 2009 of which 955 are for-profit companies. Based on this relative scale, the NCMS Survey response rate was over 22.5%.

1.3 Commonplace First Generation Nanotechnology Products

Nearly 30% of the respondents indicated their organizations are targeting two or more nanotechnology application markets. The consideration of nanoscale science and engineering technologies for product development and industrial uses has become routine in those corporations which have invested in enhancing the awareness and skill levels of scientific and engineering staff. First-generation nanotechnology is well past the "hype" phase in nearly all application sectors studied by NCMS. Nano-engineered material properties, near-atomically precise material or thin-film features and rapid processing methods are becoming commonplace in a broad range of manufactured components for consumer and durable goods. Nanotechnology is increasingly considered for enhancing and differentiating macro-scale components, and is regarded as an important source of innovations and competitive advantage in the development of new products, equipment and fabrication/synthesis processes.

The list of available or market-ready first-generation nanotechnology applications is very broad and growing rapidly. Aggregate results indicate that nearly 25% respondents' organizations are already marketing products and instruments incorporating nanotechnology, and about 85% expect to commercialize products by 2013. Current applications are dominated by nanomaterials (e.g. nano-structured catalysts, carbon nanotubes, quantum dots, nanowires and dopants), complementary metal-oxide semiconductor (CMOS)-based electronics/ semiconductor manufacturing processes, as well as other silicon-based energy conversion process industries that leverage similar large-scale fabrication equipment, thin-film coating processes, and closed-environment handling systems. Diverse nanotechnology-enabled, miniaturized biomedical and diagnostic devices, designer drugs and targeted therapies are also progressing, with early products such as nanoemulsions and viricides in advanced clinical trials.

The public's awareness and use of the term "*nano*" has become routine in 21st Century pop culture and vernacular, used as a colloquial descriptor for the branding of products exhibiting extremes of size, accuracy, precision and performance. These pervasive industrial and societal trends can be attributed to the decade-long infrastructure investments, thought leadership and educational/societal outreach by the NNI, which involves nearly all U.S. federal agencies leveraging research and development (R&D) programs via the National Nanotechnology Coordination Office (NNCO).

1.4 High Potential for Cross-Industry Transfer of Nanotechnology

Forty-six percent (46%) of the respondents reported interacting with NNI-spawned public-private ecosystems and networks of academia, (small and large) businesses and government laboratories – yet, only 5% respondents indicated their organizations had licensed

1 Table III-1 in the NNI's Second Assessment and Recommendation by the National Nanotechnology Advisory Panel, organized under PCAST, April 2008.

2 See http://www.nanotechproject.org/inventories/map/ – The PEN project defines *Nano Metros* as geographical areas containing more than 15 industry, government and academic organizations, and tracks clustering trends in nanotechnology.

nanotechnology from NNI projects. There is high potential for new collaborations evaluating the commercial viability of R&D advances.

As a result of the 2008-09 recession (affecting 80% of the surveyed organizations), nanotechnology commercialization efforts and industry resources are being more efficiently directed across both, civilian and defense applications, to define and address practical "pain-points" or problems with achieving significantly improved performance of existing systems. In the economic recovery phase, nanotechnology-based solutions that offer compelling properties and performance with affordability and low environmental risk in handling and processing, have the best chance of being selected in technology evaluations for mass production.

While a previous NSF-sponsored NCMS Survey of 600 executives in 2005[3] indicated a general state of exuberance, manifested in a proliferation of start-ups and nanotechnology development across many application sectors, the data from 270 executives in the 2009 Study showed a winnowed and narrower distribution of application markets for advanced nano-enabled products. This is primarily due to the contraction of VC investments in start-ups, and the rapid shift of U.S. industry focus to addressing near-term concerns in defense, energy efficiency and healthcare, where a clearer business case can be made, because the federal government is a co-investor through increased R&D and economic stimulus spending.

1.5 Nanomanufacturing Accelerates Clean Technologies

Nano-scale engineering advances enabled by leveraged public-private investments under the NNI have accelerated the development of "clean" technologies – i.e. emphasizing smaller environmental and energy footprint.

The latest applications of nanotechnology have resulted from a dramatically improved capability of U.S. semiconductor supply-chains to manufacture and utilize larger quantities of well-characterized nano-structured powders and nanoparticulate materials such as catalysts and coatings with increasing consistency, uniformity and reaction and deposition rates. Higher productivities and efficiencies have been demonstrated with processes and equipment for depositing these materials on substrates with greater precision in larger volumes, at corresponding economies of scale.

The end-user industries where such innovations are being implemented include photovoltaic and solar cell manufacturing, as well as other large area deposition and roll-to-roll technologies used in fabricating products with thin-films (such as electronic displays, fuel cell membranes, and battery electrodes), and three-dimensional (3D) semiconductor memory devices. Material transformation and energy efficiency breakthroughs enabled by nano-catalysts include biomass-to-energy, coal-to-liquid fuels, fuel cells, treatment of chemical waste streams, and conversion of cellulosic materials to energy compounds.

Thus, such increasingly complex nano-scale product forms and maturing nanomanufacturing competencies are laying the foundation for new, revolutionary self-assembly and converging technology products, that would have visionary implications for defense, energy, environmental, healthcare and consumer applications.

1.6 Nano-Biotechnology Spurs New Healthcare R&D Models

Eighty-five percent (85%) of the respondents from organizations targeting medical applications indicated they plan market introductions of new drugs or biomedical

[3] "2005 NCMS Survey of Nanotechnology in the U.S. Manufacturing Industry" is available at http://www.nsf.gov/crssprgm/nano/reports/survey06_2005_ncms_nanomanu_report_final.pdf.

products incorporating nanotechnology within the next five years, and 20% are involved in foreign collaborations or offshoring of R&D in this application sector.

Leading medical and pharmaceutical manufacturers are adopting “open-innovation” and co-creation strategies by contracting out the search for new uses of existing drug and device platforms to academic and contract research organizations. Should a resulting product win approval, the partners share intellectual property (IP) rights and negotiate preferential licensing agreements. With greater levels of awareness within the regulatory community, and improved communication with developers, the time from laboratory to market for new drugs and medical products is getting shorter, and a larger number of medical products incorporating nanotechnology advances are progressing through phased clinical trials, to reach commercial viability. Early products positioned for achieving regulatory approvals include diagnostic devices, nanoemulsions and nanoviricides; the opportunity for targeted drug-delivery and cancer therapies is also nearing the horizon, indicating new commercial potential.

However, these nascent R&D fields in the life sciences and synthetic biology remain fragile ecosystems, as the pathway for translating basic nano-bio-chemistry principles into approved medicines or therapies for widespread manufacturing and distribution is long and highly susceptible to numerous external factors. The high capital investments needed to underwrite these risky interdisciplinary endeavors as well as ongoing patent reform and reorganization within the Food and Drug Administration (FDA), combine to make it harder for entrepreneurs and established industry to pursue specialized or revolutionary treatments through lengthy trial phases.

Early involvement of all regulatory bodies evaluating the development of nanotechnology-based solutions is key to compressing the long product development cycles for medical and environmental applications of nanotechnology where human or ecological impact is a concern.

1.7 Growth in Offshoring and Foreign Competition

Nearly 30% of the executives indicated their organizations are involved to varying degrees in offshore development related to nanotechnology. Over two-thirds (70%) of the respondents indicated that the U.S. faces stiff competition in nanotechnology from countries in the Asia-Pacific and the European Union. The U.S. must continue its strong investments across the nanotechnology ecosystem, focusing on high-value R&D and innovation, while staying at the forefront of relevant technical education and workforce training.

The challenges to the continued leadership of the U.S. in nanotechnology arise from three main areas of concern:

1. Lack of a long-term domestic manufacturing policy which would incentivize and retain engineering, research and manufacturing operations in the U.S., and thereby drive new manufacturing investments in human capital and infrastructure.
2. Increase in environmental regulation which often drives decisions on location of new manufacturing facilities – it tends to raise the fixed costs of capital investment, compliance, and plant operations, making U.S. manufacturers less competitive. The net effect, when factoring domestic market saturation and the economic slowdown, is for manufacturers to move offshore to more profitable locations, or to regions promising lower break-even costs or large-growth markets as evidenced by U.S. semiconductor, transportation and machine tool manufacturers.
3. Rapid growth in the economic, intellectual and political power of emerging economies in Asia which is fueled by their high resource

consumption rates and market sophistication while setting new societal trends. This is impacting sustainability patterns globally by changing the balance of energy sources, skilled jobs, commodity and specialty raw materials, and vital manufacturing infrastructure. These high-growth markets are also providing early-mover advantages for U.S. manufacturers.

The faster rebound and growth of economic prosperity in Brazil, Russia, India and China (the BRIC nations) is incubating new business models and venture-backed ecosystems based on innovative technologies that will transform the competitive landscape of entire global industries, from financial and telecommunications services to consumer goods, health care, energy and transportation.

1.8 Weathering the "Perfect Storm"

The survey indicated that new businesses and spin-offs employing less than 10 staff comprised half (50%) of the U.S. organizations pursuing nanotechnology developments; 75% organizations have less than 20 employees. The majority of these organizations indicated they face significant viability and sustainability challenges that range from emergent technology issues, to raising capital for critical infrastructure investments, to attracting technical and business talent, to connecting with early adopters and end-users, to producing cost-effectively at pilot scales, to growing new market applications, or achieving higher yields or manufacturing volumes. IP management issues and the equitable sharing of knowledge are also areas of significant concern to these small businesses.

One in five (20%) respondents indicated the lack of clear regulatory policy and guidelines for environmental health and safety are impediments to nanotechnology, as well as the need for tort reform – these factors could result in adverse public reaction to new products.

Over 80% of the polled executives indicated their organizations were affected (to varying degrees) by the worldwide financial and credit crisis of 2008-09. The resulting contraction in VC funds accelerated the consolidation of start-up companies pursuing nanotechnology. It has forced many organizations to reduce staffing and scale back product development or launches, and impacted near-term R&D pathways and market entry strategies, as many such organizations have lost the ability to fully vet their IP portfolios for commercial relevance.

Resource-constrained early-stage, nanotechnology start-ups (many of them are university or national lab spin-offs) have been forced to merge or sell-out IP to larger competitors or customers, while established nanotechnology corporations were able to opportunistically acquire under-valued IP, or broker preferential collaborations with suppliers, academia and customers.

The largest manufacturing corporations active in nanotechnology developments such as aerospace and automotive original equipment manufacturers (OEMs) and materials suppliers were also forced to re-evaluate and rationalize their research and infrastructure investments, and to re-focus resources, in order to weather the downturn which resulted in decreased demand for pipeline materials and products. These organizations have focused R&D spending on seeding smaller but potentially faster-growth niche markets that could take on increasing prominence in coming years. This trend is evident across leading, diversified electronics/semiconductor, pharmaceutical, medical device and energy corporations. Larger OEMs and corporations have innovated agile partnering models by spinning off VC arms and subsidiaries that opportunistically establish open-innovation R&D partnerships, and direct targeted investments for the evaluation, sourcing or acquisition of technologies or corporations with complementary value to their pipeline products and strategic interests.

1.9 VC and Industry Consolidations Impact Nanotechnology Sectors

Access to capital was cited as a major barrier by 50% of the respondents. Venture financing institutions, a traditional source of investment in nascent science-based technologies underwent a major shakeout during the economic downturn, the effects of which are yet to be fully comprehended. The leading VCs managed risk by being highly selective, syndicating with more partners, adding leverage to mature Small Business Innovative Research (SBIR)/Small Business Technology Transfer Research (STTR) awardees, or by financing multiple small-rounds and series, and as well as moving to later-stage investments in corporations with higher maturity, or by combining IP portfolios. Angels and VCs who have chosen to invest in nanotechnology, directed the largest portions of their investments to "low-hanging fruit" nanotechnology products offering the greatest potential for faster exits and shareholder returns – e.g. by opting for technologies or products not requiring lengthy certification or regulatory approvals. The industry segments benefiting from these diminished but focused private capital infusions were high-value nanomaterials, tooling/nanometrology instrumentation, and "clean-tech" applications such as renewable energy conversion/storage systems, and photovoltaics aiming to meet the rapid growth of demand from selected domestic and foreign markets.

In the 2009 NCMS Study, respondents indicated slight increases over the 2005 Study in the staffing categories with 11-20 employees (19.3% of respondents) and 21-50 employees (15.6%). This trend indicates that stronger nanotechnology companies exploited the industry downturn by investing in or acquiring under-valued technology partners, and vertically integrating with material suppliers and intermediate processors, thereby increasing their control of the product/process value-chains. The near-term benefits of integration include lower development costs, accelerated commercial readiness of their products, and greater control over the process/value-chain, including variability of materials, processes and fabrication equipment, which are critical for reducing the processing cost of nanotechnology products.

In the long run, these extended nanotechnology "cluster" enterprises and ecosystems may achieve more rapid development, scale-up and implementation of nanotechnology solutions by incorporating functionality, standardization, safety and sustainability in their products. If successful in demonstrating compelling and differentiated nano-enabled solutions, or core competencies for developing high process capability at pilot or industrial scales, these consolidated organizations are more likely to be viable and sustainable in both, market growth and payback potential. They could be well-positioned for innovating new products and mass-production techniques for second generation nanotechnology devices and systems that rely on self-assembly fabrication techniques powered by chemical, electro-static or magnetic forces. At present, the traditional manufacturing approaches for envisioned second generation nanodevices are inconsistent, extremely slow, and therefore, unsuitable for commercialization.

Thirty percent (30%) of the respondents indicated the missing link is robust predictive technology – i.e. modeling tools and control algorithms for integrating self-assembly processes across multiple lengths of scale into visionary products.

1.10 Viability and Sustainability of U.S. Nanotechnology-Focused Businesses

Survey respondents indicated in aggregate that the distribution of nanotechnology developments is concentrated at the low Technology

Readiness Levels[4] (TRLs) 1-3 (38% in conceptual and early stages of applied R&D), and at high TRLs 8-9 (24% nearing implementation-readiness). Thirty percent (30%) of the organizations are working at mid-TRLs 4-7 which coincide with the "valley of death" stage in commercialization potential, where a large amount of resources are required to demonstrate a prototype product application, document performance, and pursue manufacturing pilot and scaling initiatives.

The near-term industry outlook for 2010-11, as predicted by a slight majority (57%) of surveyed strategic executives, is a cautious economic recovery in industrial and consumer demand in the U.S. NCMS believes this slow recovery will sustain as long as regulatory reforms made in the capital markets and the economic stimulus investments quickly equilibrate the financial value-chain, and translate to increased capital access, and consumer/industry confidence. If these events occur relatively early, then it is foreseeable that several nanotechnology-centered companies could file initial public offering (IPO) deals with the Securities and Exchange Commission (SEC) within the envisioned five-year commercialization timeline addressed in the study; only three survey respondents indicated their organizations may progress to IPOs in the 2010-2011 timeframe.

In the context of the stated 2009 NCMS-NSF Survey theme, one-third of responding U.S. Nanotechnology businesses indicated across the 20 strategy factors their business models are not presently viable. These 33% respondents have indicated their organizations may contract further in staffing, market share or profit, or they expect to sell-out or merge. Many depend on and will require substantial economic and technical support from federal and regional ecosystems if their intellectual capital in nanotechnology is to find market applications over the longer term. Nanotechnology-focused businesses are tenuously weathering the current turbulent times through consolidation, collaboration and vertical integration in attempting to remain viable, competitive and sustainable.

1.11 Government's Role in Expediting Recovery and Job Growth

Eighty-eight percent (88%) of executives polled by NCMS indicated their preference for a strong government role in facilitating the responsible development of nanotechnology.

Long-term government investments in the NNI are critical for:

a) Preserving the basic and pre-competitive research infrastructure and harnessing the innovation potential of U.S. industry

b) Facilitating collaborative understanding of complex material-process-property-impact phenomena

c) Disseminating information on detailed characterization of human and ecological risks across product lifecycles

d) Stimulating entrepreneurship and domestic job growth via start-ups and taking them across the "valley of death" so as to increase investor confidence

e) Scaling nanomanufacturing applications through market-driven leveraged co-investments.

The majority of survey respondents indicated that nanotechnology entrepreneurs require access to non-dilutive finance as they endeavor to raise funds for product development and job creation. In the current economic climate, the

[4] NCMS adapted the DoD's nine-point TRL rating scale for mapping the distribution of development stages of nanotechnology towards implementation; this data enables comparisons across sectors. Respondents were asked to self-assess the general readiness level of nanotechnology products in their organizations.

outlook for direct job creation from nanotechnology advances largely depends on the role government (federal and state) plays in mitigating technical risk, incentivizing industry investments and encouraging entrepreneurship.

States which consistently invest in strengthening entrepreneurship, research infrastructure, and innovative programs encouraging smart-leverage with private capital, stand the best chance to dominate the economic recovery, and will likely generate sustainable intellectual capital and skilled jobs in the long run. Larger job growth in nanotechnology can occur during the transition from lab- and pilot-scales to larger-scale manufacturing. The key to industry growth and the nation's competitiveness lies in the ability to innovate and implement cost-effective high-yield production methods.

Besides the ongoing targeted investments in mission-oriented nanotechnology developments by the Defense Advanced Research Projects Agency (DARPA), several government agencies involved with implementing the American Recovery and Reinvestment Act of 2009[5] (ARRA) have instituted initiatives in advanced infrastructure, renewable energy, energy efficiency and workforce training – all of which are linked to nanotechnology. While the returns may not be immediate, many of these programs can provide new impetus to entrepreneurship in nanotechnology and nanomanufacturing. DARPA Chief, Dr. Regina Dugan[6], recently lamented "the decline in our ability to make things," – a consensus opinion of many. It is imperative that the nation urgently formulate a long-term technology and manufacturing policy, and empower both, government and industry to take concerted steps addressing the dwindling domestic manufacturing base and the erosion of the innovation infrastructure.

Near-term efforts to spur industrial innovation and job creation based on nanotechnology need to center on the following three tactics:

1. Getting more non-dilutive capital and credit to fund technology transition and early product developments in small and midsize businesses
2. Improving the country's science education system so as to nurture the talent pool
3. Attracting and retaining high-skill foreign knowledge workers for staffing strategic R&D, and stimulating entrepreneurship.

The continued emphasis of the NNI on education of the public at large, and more specifically, proactive engagement of key government policy makers (state and federal), permitting bodies and legislative bodies regarding these issues will result in clearer product approval pathways, new industry standards and responsible handling practices, and thereby sustain U.S. dominance in the commercial deployment of nanotechnology.

1.12 Highlights of Aggregate Survey Responses

Table 1-1 summarizes aggregate statistics and highlights based on responses to 20 survey questions on the commercialization of nanotechnology.

[5] The economic stimulus package enacted by the U.S. Congress in February 2009, with the intent to create jobs, promote investment and consumer spending.

[6] Dr. Regina E. Dugan, Statement to the House Armed Services Committee, United States House of Representatives Subcommittee on Terrorism, Unconventional Threats and Capabilities, March 23, 2010, http://www.darpa.mil/Docs/DARPA2010CongressionalTestimonyHASC.PDF

Table 1-1. 2009 NCMS-NSF Nanotechnology Commercialization Study Highlights

Organization Role in Nanomanufacturing	The U.S. nanotechnology value-chain has diverse players and start-ups. Two-thirds respondents indicated direct involvement in development of products, raw materials, processes, equipment and instrumentation.
Profile of Respondents	50% of the respondents hold senior business or technical positions in nanotechnology organizations; a higher number of academic and research organizations are licensing IP to established corporations.
Dominant Nanomanufacturing Application Markets	Nanotechnology is being developed and applied in all major industry sectors, and driven by suppliers of nanomaterials, instrumentation and tools. Dominant applications include: Electronics and Semiconductors; Energy and Utilities; Pharmaceutical/Biomedical/Biotechnology; Aerospace; Chemicals and Processing; and Homeland Security/Defense.
Change Management in Nanotechnology Start-ups	75% of the respondents indicated organizations were coping adequately or well, while 25% were not. Senior business executives were more likely to state their organization was coping well with developing nanotechnology applications, whereas technology executives were more pragmatic.
Corporate Urgency for Nanotechnology	75% of the respondents indicated high or medium levels of urgency in commercialization of nanotechnology; senior business executives were more likely to state that nanotechnology receives a high priority in their organizations, whereas senior technical executives tended to state that nanotechnology receives low priority in their organizations.
Organization Capacity for Nanotechnology	Only 15% of the respondents stated their organizations have high capacity, whereas four in five (80%) respondents felt their organizations have low or medium levels of capacity for product development.
Available Infrastructure in Nanotechnology	15% of the respondents indicated having access to abundant infrastructure; one in three organizations stated they lacked infrastructure for nanotechnology research and product development.
Collaborative Development of Nanotechnology	The majority (80%) of organizations are involved in collaborations, ranging from single-company partnerships to co-creation in application-focused partnerships. The development of nanotechnology ecosystems is progressing with greater differentiation and product diversity.
Interactions with NNI Projects	Half the respondents (46%) stated their organizations had formal interactions with NNI projects or accessed specialized facilities in the government R&D networks; however, less than 5% indicated licensing IP.
Offshoring of Nanotechnology Developments	30% of the respondents indicated organizational involvement in offshore developments to varying degrees – those most active in offshoring are targeting applications in electronics/semiconductor, energy conversion/storage, aerospace and pharma/biomedical/biotechnology.
Staffing Trends in Nanotechnology Organizations	Early-stage start-ups with less than 10 staff form the single largest category (~50%) of businesses pursuing nanotechnology. The financial crisis has accelerated shifts in venture capital, resulting in widespread industry consolidation in pursuit of stable financial and IP positions.
Commercialization Timelines	A higher proportion of respondents (25%) indicated their organizations have launched commercial nanotechnology products. By 2013, nearly 80% respondents' organizations expect market-ready products.
Nanotechnology Products	A broad range of products incorporating nanotechnology are already commercialized or in varying stages of development. Early applications include: Nanomaterials for Functional Coatings, Structural Reinforcements, Energy Conversion, Displays, Drug Delivery, Diagnostics and Biomarkers.

Nanotechnology Readiness Levels	20% of the respondents indicated nanotechnology products with high market – readiness level (TRL 8-9), such as: Functionalized Nanomaterials for Coatings, Paints and Thin-Films; Semiconductor, Lithography and Print Products; Energy Conversion and Storage; and Electronic Devices, Displays and Optoelectronics. These products offer the highest potential for profitable venture exits, near-term job-creation and revenue-growth.
Government's Role in Nanomanufacturing	Majority (88%) respondents favor a strong government role in facilitating responsible development of nanotechnology, and favor the U.S. Government continue funding for R&D, and implement business-friendly policies that keep the nation unsurpassed in nanotechnology.
Barriers to Nanomanufacturing	Businesses commercializing nanotechnology face a number of technical, business, safety and regulatory challenges. The relative ranks of the top barriers were generally unchanged from the 2005 NCMS Industry Survey, with over 50% indicating the lack of investment capital as a key barrier.
U.S. Competitiveness in Nanotechnology	The U.S. presently leads the world in commercializing nanotechnology, but over two-thirds (70%) of polled executives indicated its leadership is threatened by foreign competition in nearly every application sector.
Impact of the Economic Recession	80% of the respondents indicated the economic recession of 2008-09 affected their organization's nanotechnology efforts to varying degrees; organizations involved in multiple partnerships appeared to weather the recession with lower levels of impact. The smallest organizations and startups with less than 10 employees were affected the most.
Near-Term Industry Outlook	57% of the respondents indicated cautious optimism in the near-term, anticipating improvements in the business climate and manufacturing. Nearly 40% expected to raise capital or increase employment, and 20% expected to contract in size, market-share or profit.
Demographic Information	The survey attracted a representative and geographically diverse sample of respondents from major states with strong R&D infrastructure in nanotechnology. The top 15 states are: California, Illinois, Massachusetts, Texas, New Jersey, Ohio, Pennsylvania, Michigan, New York, Arizona, Virginia, Washington, Florida, Maryland, and Georgia.

2. Introduction

Nanotechnology encompasses a vast range of envisioned multi-generational engineered materials and devices that are finding a fast-growing range of industrial and consumer applications. It is a recently recognized cross-disciplinary field of a variety of potentially disruptive technologies that involves the creation and application of novel materials, devices and systems by control and restructuring of matter at dimensions of roughly one to 100 nanometers in size. Nanomanufacturing is the repeatable building of materials, structures, components, devices and systems with nanoscale features to produce value-added materials, products and processes.

Dr. Mihail C. Roco[7] first advocated that four distinct chronological generations of nanotechnology would emerge over a span of two to three decades. The first generation consists of passive structures developed from nanoparticulates and two-dimensional (2D) coatings. The second marks the advent of active nanostructures with sensory attributes such as solar cells and targeted drugs. Three-dimensionally (3D) fabricated autonomous actuators, miniaturized robotic devices and systems of such nano-systems are predicted to constitute the third generation of nanotechnology, followed by a fourth generation of molecule-by-molecule design and bottom-up self-assembly systems. It is envisioned that these fourth-generation nanotechnologies will seamlessly converge or integrate with products of information technology, biology and cognitive sciences to produce disruptive devices for applications which are presently unimaginable.

The U.S. Government, under the decade-long NNI, is the largest catalyst, investor, and beneficiary of research in nanotechnology. NNI is widely regarded as the world leader in economic development and commercialization initiatives incorporating nanotechnology across myriad applications for responsible and potentially far-reaching societal benefit. There is not a stand-alone "nanotechnology industry[8]," but rather nanoscience and nanoengineering innovations are being incorporated into nano-enabled products and processes that are applied in almost every industry sector in the quest for breakthroughs in cost and/or performance. The evolutionary path of nanotechnology makes the assessment of its impact highly challenging.

2008 and 2009 have been unprecedented in recent memory as two years of worldwide economic turmoil, impacting virtually every sector of commerce and industry. They have resulted in increased pressure for virtually every company and organization pursuing the development of nanotechnology. With budgets tightening across the board, both research programs and industry investments have been affected. New economic opportunities also continued to arise and abound that could significantly benefit from new applications of nanotechnology or nano-enabled products.

With these national interests and long-term competitiveness concerns in mind, NCMS performed its third study of nanotechnology strategy of the U.S. Manufacturing Industry during 2008-09, under award from the NSF. The main objective was to identify key product development strategies and commercialization trends in nanotechnology and growth of nanomanufacturing, as well as to highlight the early application sectors and product development process aspects considered to be

[7] Senior Advisor for Nanotechnology to the NSF and founding chair of the National Science and Technology Council's subcommittee on Nanoscale Science, Engineering and Technology (NSET).

[8] Marburger, III, J. H., and Kvamme, E. F., "The National Nanotechnology Initiative: Second Assessment and Recommendations of the National Nanotechnology Advisory Panel," April 2008.

the basis of utmost need, opportunity or competitive benefit.

An extensive briefing summarizing the key nanotechnology trends and executive perceptions based on 20 strategic indicators was submitted to the NSF in March 2010. This final report has been prepared to document in more detail the NCMS Study methodology, data analyses and important findings.

2.1 Study Objectives and Value Proposition for Stakeholders

The main objective of the NCMS-led study was to develop and compile representative aggregate metrics and trends in strategic planning, technology development and commercialization observed in U.S.-based organizations involved in nanotechnology and nanomanufacturing, and to document the collective opinions and concerns of a broad cross-section of executives with leadership-, technology- or strategic- R&D responsibility. NCMS believes the survey process provides unique information that individual companies can use to elevate issues within their own organizations, and benchmark against their peers. This report endeavors to compare changes in executive opinions and assessments gathered in 2009 with the results of previous NCMS surveys in 2005[9] and 2003[10].

Another objective of this follow-up study was to develop a credible benchmark of entrepreneurship in nanomanufacturing across multiple parameters, innovation metrics and business strategy indicators – such as nanotechnology application markets, collaboration modes, interactions with NNI programs, offshoring patterns, product-/sector-/geography- specific industry profiles and trends. A new feature is the extensive correlation of challenges nanotechnology organizations face with the development stage or technology readiness of their product(s). Such information may be useful to venture financiers, mission-oriented agency planners, industry suppliers and service providers.

Federal and state agencies may find the information helpful in formulating and guiding government policies and economic development programs, as well as for planning the timing of competitive incentives and interventions for accelerating nanotechnology applications in a socially responsible manner. Policy planners, industry trade groups and other stakeholders often want to know what can be done to grow and retain nanotechnology-related activities, or generate high-skill jobs, and are often looking for data-driven answers to common questions such as:

- Where are nanotechnology organizations located?
- What type of work are companies doing with nanotechnology?
- What industry sectors are involved and poised for future growth?
- Where in the value-chain do those companies fall?
- Are there enough university/national laboratory facilities to support businesses?
- Is there well-developed infrastructure and mature entrepreneurial culture for promoting nanotechnology start-ups and economic development?

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9 The complete report "2005 NCMS Survey of Nanotechnology in the U.S. Manufacturing Industry" is available at http://www.nsf.gov/crssprgm/nano/reports/survey06_2005_ncms_nanomanu_report_final.pdf.
A concise summary is available in Nanomanufacturing Handbook (CRC Press Taylor & Francis Group, 2007, ISBN-10:0-8493-3326-1), in "Chapter 1: Introduction to Nanoscale Manufacturing and the State of the Nanomanufacturing Industry in the United States," co-authors: Ahmed Busnaina and Manish Mehta.

10 Mehta, M., "Industry Survey of Nanomanufacturing Trends and Commercialization Activities in the U.S." Final Report to NSF under NSF Award DMI-0305091, April 2004.

- What are the requirements for a well-prepared nanotechnology workforce?
- How can federal and state governments help overcome critical challenges identified by nanotechnology companies?

It is NCMS' intention to make widely available aggregate industry and sector intelligence information to the industry stakeholders, including policy makers, investors, consumers, end-users, technology developers and academia, and thereby, to offer a credible foundation for focusing attention, dialog and coordinated action.

3. Methodology

The methodology proposed by NCMS for identifying aggregate nanotechnology commercialization trends was an online industry survey consisting of 20 question screens for data capture; this information provided extensive datasets for analysis. Key identified trends and outliers in data were addressed through industry research. The preliminary findings were further amplified and augmented by interviews with selected executives from major sectors of the U.S. Manufacturing Industry.

3.1 Progressive Nanotechnology Study Themes

To develop the most relevant list of industry concerns and a theme (i.e. hypothesis) for structured query amongst industry stakeholders, NCMS initially conducted a brief literature search and held over a dozen interviews with selected senior executives representing major manufacturing and defense industry sectors as well as VC organizations pursuing nanomanufacturing developments. All interviewed executives cited the global economic slowdown which began in early 2008, and the resulting financial/credit crisis as a top-ranked concern and source of risk or uncertainty, in view of the high capital intensity of nanotechnology R&D.

While many early-stage start-ups in nanotechnology and established manufacturing organizations are recipients of government grants from various federal agencies – e.g. Departments of Commerce, Defense, Energy, NSF, National Institute of Health (NIH), Environmental Protection Agency (EPA), SBIR/STTR – the executives in small businesses expressed serious concern about their capacity to raise operating and growth capital. Executives in medium-size and larger corporations pursuing nanotechnology also shared concerns about the viability of their suppliers and customers in the current economic environment – during 2008, many were actively evaluating which R&D programs and product launches to postpone or cancel, while trying to remain profitable.

From these highly insightful interviews, the general 2009 Survey emerged, based on which 20 questions were formulated for the broader industry survey.

The progressive themes of three NCMS studies of the U.S. Nanotechnology Industry are:

- **2003 – Do U.S. manufacturers recognize the potential of nanotechnology?**
- **2005 – Do surveyed organizations view nanotechnology differently from other advanced science and technology?**
- **2009 – Are U.S. nanotechnology businesses viable, competitive and sustainable in current economically turbulent times?**

3.2 Strategic Issues for Survey Query

Questions and response options were designed around the 2009 Survey theme addressing the following 20 strategic indicators of the status of U.S. organizations engaged in nanotechnology innovation and nanomanufacturing:

1. Organization Role in Nano-Value Chain
2. Respondent’s Function in Organization
3. Nanotechnology Application Markets
4. Coping with Nano-Strategy
5. Corporate Priority
6. Overall Organization Capacity
7. Available Infrastructure
8. Level of Collaboration
9. Interactions with NNI Labs and Projects
10. Offshoring of Developments
11. Direct Staffing
12. Commercialization Timelines
13. Nano-Product Type(s)

14. Technology Readiness Level
15. Role of Government
16. Challenges & Barriers to Nanomanufacturing
17. U.S. Leadership/Competitiveness
18. Impact of 2008-09 Recession
19. Short-Term Business Outlook
20. Geographic Location.

3.3 Survey Launch and Industry Solicitation

The online survey was launched electronically on June 22, 2009 with the assistance of PennWell Corporation, publishers of Small Times, a well-known online trade publication of the micro- and nano- technology industry. Nearly 10,000 targeted senior executives in U.S.-based manufacturing and research organizations were solicited twice via PennWell's cleared (opt-in) industry database during June – October 2009. Authentication protection was designed in the online questionnaire to prevent duplicate inputs from the same respondent or submission of incomplete surveys to the NCMS database.

The NNI's definition of nanotechnology was used to qualify all respondents having a direct stake in nanotechnology or nanomanufacturing value-chains and ecosystems (Figure 3-1). Respondents were then encouraged to candidly answer an electronic survey form addressing these 20 precompetitive aspects regarding their organization's development and commercialization of nanotechnology.

3.4 Survey Response Rates and Metrics

The metric proposed by NSF for a successful study sample was 300 industry response datasets. The 2009 NCMS-NSF Nanotechnology Survey came close to this goal, securing 270 complete industry responses over a three-month period. This figure, while typical of blind surveys, was lower than anticipated due to three possible contributing factors:

- Timing of the NCMS survey over much of the 2009 Summer vacation period
- Busy executives experiencing "survey-fatigue"
- Indifference fuelled by a sense of uncertainty due to the ongoing recession.

3.5 Submission and Reporting of Survey Results

The survey was closed on October 31, 2009. A total of 270 unique responses were logged on the web-server hosting the survey, and captured in an Excel database for offline analysis.

The data analyses were completed using Nano Data Explorer Version 4.2, a custom business intelligence and graphical reporting software, developed under NCMS direction.

To protect the confidentiality of the respondents, all results are reported in aggregate numbers only. Results are not reported where a single respondent provided 50% or more of the data for any specific category or question.

The remainder of this report provides a summary of survey responses from the diverse organizations involved in the transition of nanotechnology to nanomanufacturing.

3.6 Geographically Speaking

Datasets of survey responses were first analyzed (see Question 20) by respondents' location aggregated into U.S. Geographical Regions, based on the U.S. Department of Commerce' Census Regions classification. The distribution of 270 respondents (Figure 3-2) closely mirrors the distribution of 594 respondents from the 2005 NCMS dataset (Figure 3-3).

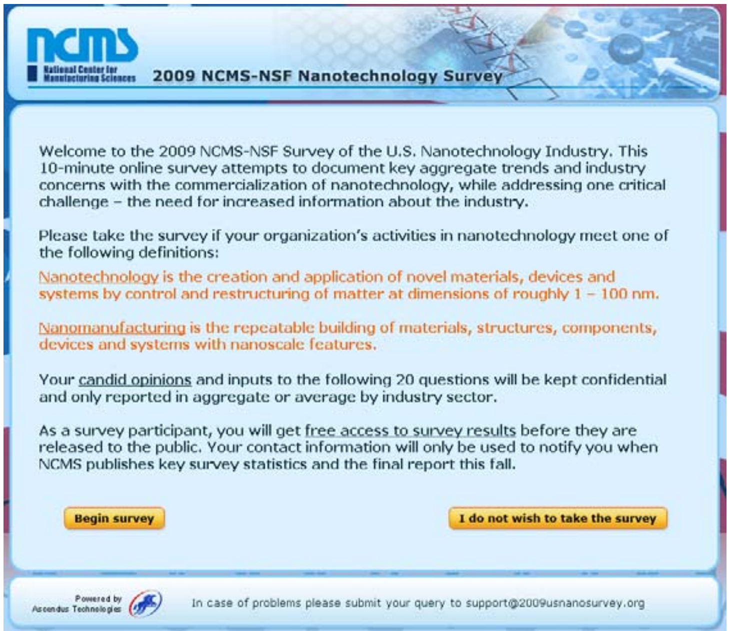

Figure 3-1. Screenshot of 2009 NCMS-NSF Nanotechnology Industry Survey Welcome Page Showing the Survey Solicitation and the NNI's Definition of Nanotechnology (in red font)

While survey responses were logged from nearly all states of the U.S. where nanotechnology is being developed, it is no surprise that the Pacific states represent the largest proportion of respondents (22.3%). The electronics and semiconductor industry of Silicon Valley, in particular, has been at the leading edge of commercializing nanoscale science, engineering and metrology advances for many years. Competitiveness pressures and technology evolution trends to meet Moore's Law[11] help assure that new CMOS-based semiconductor components and device developments will continue to help this region dominate in nanomanufacturing. Organizations in this region are also leading in the translation of semiconductor-like, high-volume production techniques to advance other fast-growing initiatives in alternative energy and energy efficiency – i.e. the "Clean Technology" markets such as energetic nanomaterials for fuel cells and batteries, green chemistry, environmentally friendly treatments, photovoltaics and smart-grid devices.

Other well-represented U.S. Regions are: East North Central States (18.7%), Mid-Atlantic States (15.7%), South Atlantic (12%), West South Central (8.6%), New England (8.5%).

The geographical distribution of 270 aggregate respondents correlates closely with the states receiving the highest levels of NNI funds and other private investments, as well as the top 10 states ranked by the number of patents awarded in 2007[12] – California, Texas, New York, Washington, Massachusetts, Illinois, Michigan, New Jersey, Florida and Ohio.

[11] Moore's Law (as retrospectively observed by Intel co-founder, Gordon E. Moore) states that the number of transistors that can be inexpensively placed on an integrated circuit has doubled approximately every two years. Correspondingly, driving forces of social and technological change have spurred exponential improvements in performance of digital computing hardware and technology, when measured in terms of size, cost, density, processing speed and memory capacity of components.

[12] Rogers, D.E. and Hartzer, A., "Business Success Through Innovation – An Insider's Guide to the World of United States Patents" published by IsoPatent LLC (2009), ISBN-10: 098190520X.

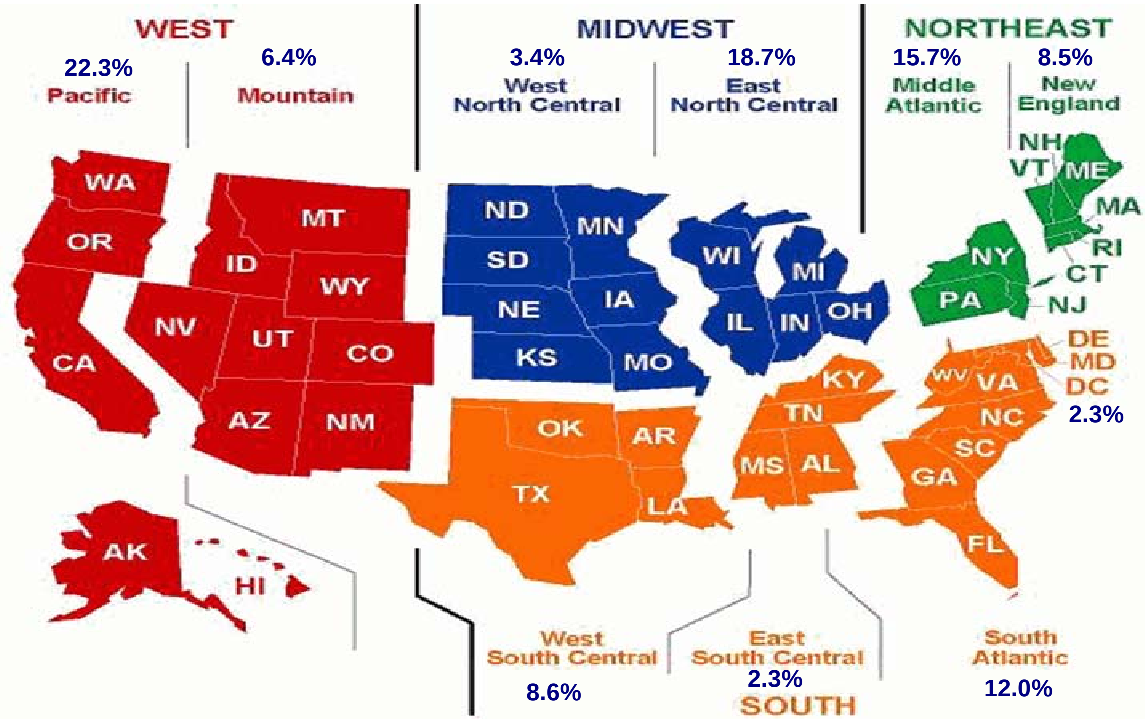

Figure 3-2. Geographical Distribution of 270 Respondents (2009) Mirrors the Distribution of 594 Respondents from the 2005 NCMS Survey Dataset

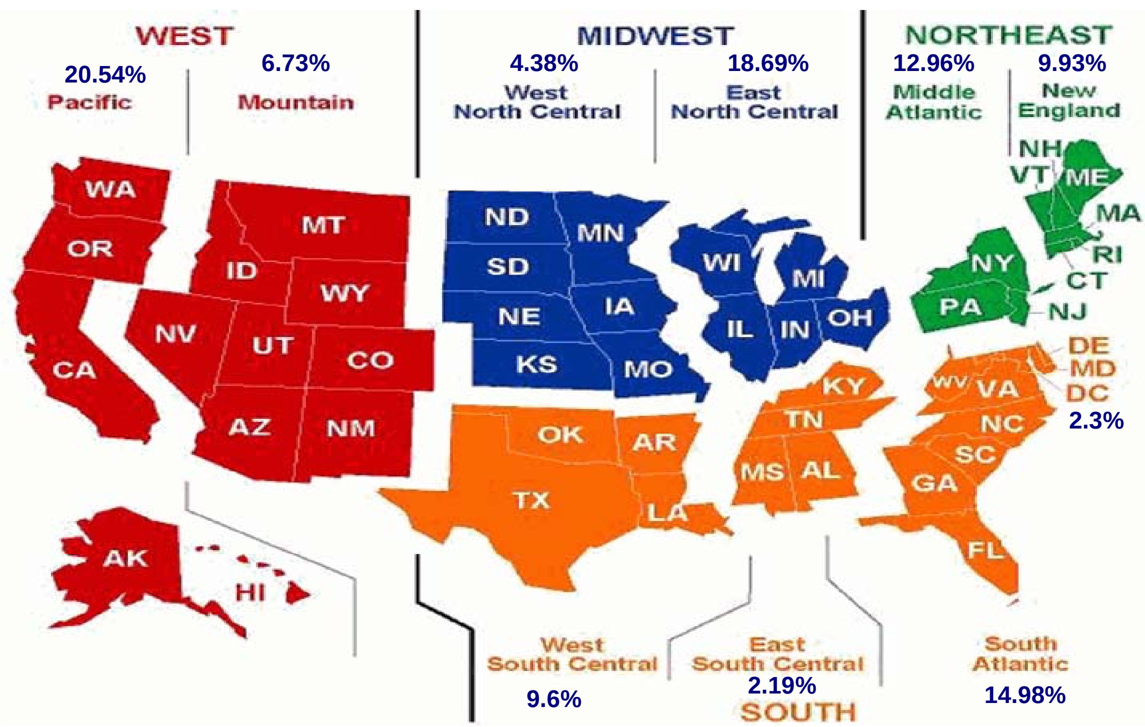

Figure 3-3. Geographical Distribution of 594 Respondents from the 2005 NCMS Survey Dataset

4. Complete Survey Highlights

The 20 survey questions, aggregated results and cross-correlation analyses of 270 respondents are discussed sequentially in the following sections.

4.1 Organization Role in Nanomanufacturing

A diverse value-chain of players is involved in the development and technology transfer of nanotechnology. Two-thirds of the respondents indicated involvement in nanomanufacturing developments related to materials, processes, tools, and specialized supporting industries.

As illustrated in Figure 4-1, respondents were asked to select from a tiered list their organization's primary or envisioned role in the nanomanufacturing value chain.

4.1.1 Aggregate Results

- Nearly two-thirds (66%) of the survey respondents indicated their organizations are directly involved in nanomanufacturing – this group was comprised of materials suppliers, component suppliers, tool and equipment vendors, and manufacturers-integrators-assemblers of products and equipment incorporating nanotechnology (Figure 4-2). In the 2005 NCMS Study, this group comprised about 50% of survey respondents.
- University-based respondents comprised 18%, of which a large number identified with university technology transfer and spin-off activities – the magnitudes were unchanged from the 19% academic respondents in the 2005 NCMS Study.
- Contract or non-profit R&D laboratories comprised nearly 9%.
- Government laboratories constituted 7% of respondents.

Since so many organizations and entities are involved directly in the U.S. in development and manufacturing/commercialization of nanotechnology, it is apparent that the industry is already experiencing significant economic impact.

The high numbers of respondents based in academic organizations may indicate that the transfer of nanotechnology advances for commercialization initiatives is largely being achieved by spin-off to start-ups and licensing of IP to established private organizations. In follow-up interviews, some executives indicated a growing realization that commercialization during challenging economic times requires both, strong business skills and management expertise, and entails a longer pathway. In the current tight investment climate, it is much harder to pursue scale-up strategy to penetrate near-term markets, and even more challenging to find patient angel/venture investors willing to make significant investments in early stage nanotechnology start-ups.

4.2 Profile of Respondents

Fifty percent (50%) of the respondents hold senior business or technical positions in nanotechnology organizations; a higher number of academic and research organizations are licensing IP to established professional organizations.

Respondents were asked to indicate their position in the organization, specifically, whether they were business or technical professionals (Figure 4-3). An option was also provided for respondents to specifically indicate whether they were entrepreneurs holding joint positions in academia.

4.2.1 Aggregate Results

Figure 4-4 provides a breakdown of the categories of respondents:

Figure 4-1. Survey Question #1

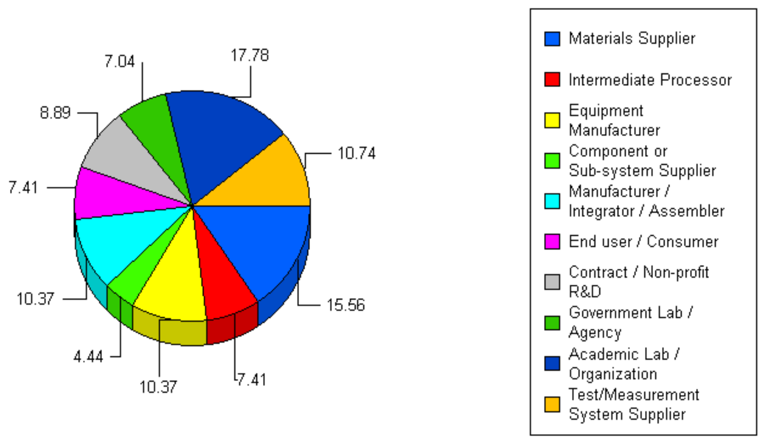

Figure 4-2. Breakdown of 270 Survey Respondents Indicates Diverse Players and Organizations Involved in U.S. Nanomanufacturing Value-Chain

- Half (50%) of the respondents hold senior-level business or scientific/technical positions in the responding organizations.
- 30% indicated they held mid-level scientific or engineering positions.
- Less than 5% respondents stated they are academic/laboratory entrepreneurs (compared to 19% in the 2005 NCMS Study).

The transfer of nanotechnology (i.e. formal intellectual property and know-how or ideas) from university or government research laboratories occurs primarily by spin-off collaboration or when students are hired by start-ups and existing firms.

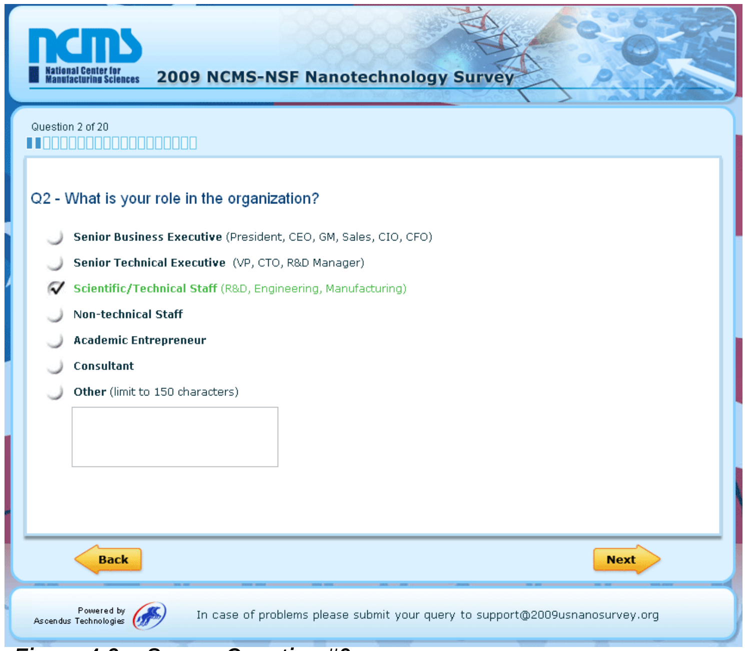

Figure 4-3. Survey Question #2

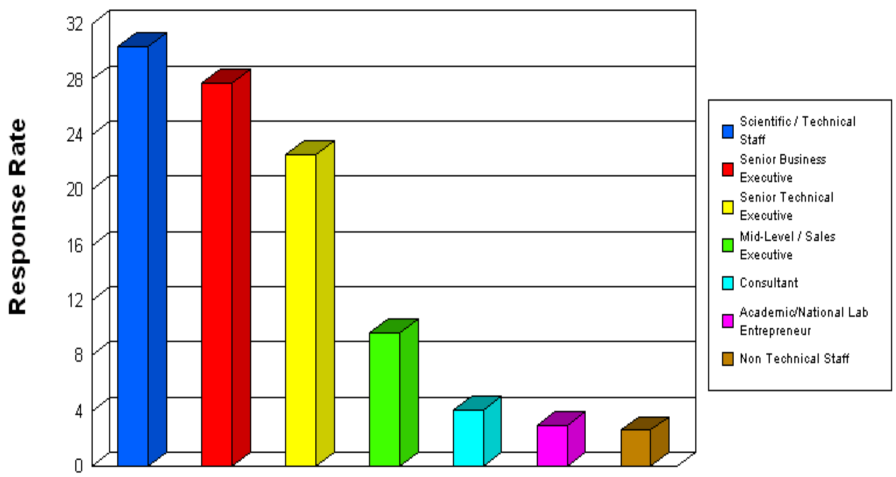

Figure 4-4. Breakdown of 270 Survey Respondents by Position Held in Their Organizations – Nearly 50% Senior Business or Technical Executives

4.3 Dominant Nanomanufacturing Application Markets

Nanotechnology is being developed and applied in almost every industry sector, driven by suppliers of nanomaterials, instrumentation and tooling. Dominant application markets include: Electronics and Semiconductors; Energy and Utilities; Pharmaceutical/Biomedical/Biotechnology; Aerospace; Chemicals and Processing; and Homeland Security/Defense.

Respondents were asked to indicate the dominant or primary industry sector their organization is targeting with new nanotechnology products (Figure 4-5). The list of 18 application sector options was consolidated as logically as possible so as to make it convenient to select industry categories. Respondents were also asked to list under “Other” what unlisted sectors their organizations are targeting.

4.3.1 Aggregate Results

Over 28% of all 270 respondents indicated nanotechnology developments were being targeted in their organizations for two or more application markets, which is shown by the blue bar in Figure 4-6. This is due to the fact that many nanotechnology companies have developed or specialized in the supply of platform nanomaterials and coatings, or nanoscale tooling/manipulation/fabrication/characterization equipment for making high-rate material depositions, inspections and measurements. These organizations are aggressively pursuing simultaneous commercialization pathways for penetrating multiple markets and end-uses for these products.

Leading individual nanotechnology application markets selected by the respondents are:

- Electronics and Semiconductors
- Pharmaceutical/Drug Delivery/Medicine and Biotechnology
- Aerospace
- Energy and Utilities
- Chemical and Process
- Homeland Security and Defense
- Sensing and Environment.

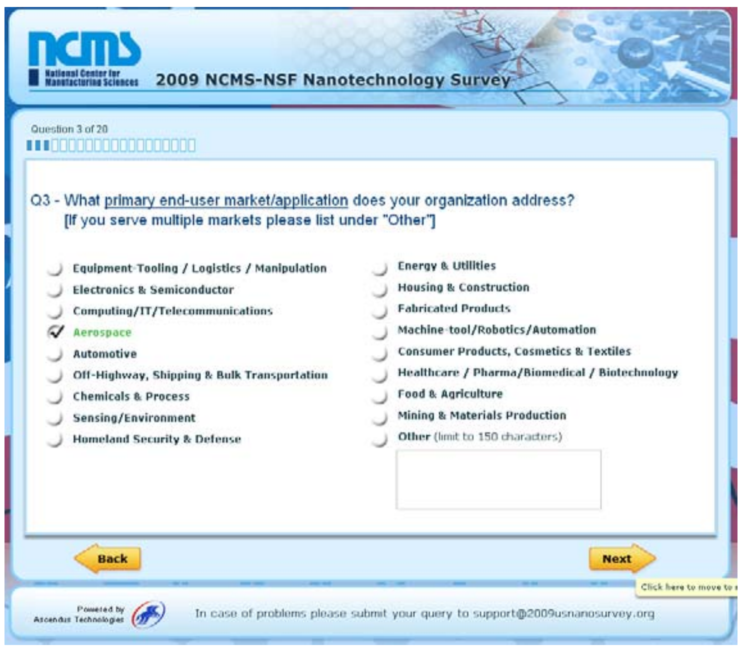

Figure 4-5. Survey Question #3

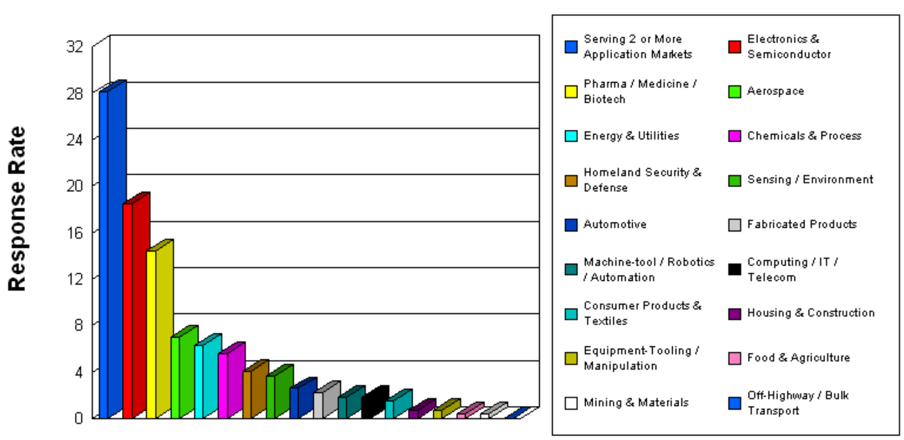

Figure 4-6. Top Application Markets for Nanotechnology Products as Ranked in the 2009 NCMS Study

The single largest individual application sector indicated was Electronics and Semiconductors. These markets continue to attract and dominate the majority of early innovations in nanotechnology. Competition to meet Moore's Law, and the rapid growth of global markets in computers, memory and storage devices, touch-screens for mobile and telecommunication devices, and active display applications are driving these industries to invest in advanced nanoscale engineering and manufacturing infrastructure. Exploiting the benefits of nanostructured semiconductor materials, these competitive and cost-sensitive markets drive innovations in applications such as higher-functionality CMOS chip designs, miniaturization and flat-screen display technologies, all of which rely on innovative nanomaterials and high-rate nanoscale processes. New memory devices are being tested in applications requiring very fast response or switching speeds and non-volatility at low power consumption. The dominant U.S. semiconductor corporations and their value-chains of suppliers thus, stand to be the prime movers and early beneficiaries of the nation's economic recovery and near-term market growth.

Pharmaceutical and nanomedicine product applications have moved up slightly higher in identified applications than was indicated in previous NCMS studies. Many new nano-bio products, lab-on-a-chip diagnostic systems, nano-enabled drug therapies and functionalized therapeutic technologies or devices have been introduced, or are progressing towards market entry. As these products mature in ongoing reviews with the FDA, and through phased clinical or market trials, the manufacturers are organizing their supply chains to meet anticipated demand from consumers and healthcare institutions.

Several aerospace industry and military applications of carbon nanotube-based structural nanocomposites are already commercialized, and await airworthiness certification. This sector was listed fourth highest by survey respondents as a specific market application for nanotechnology.

Applications of nanostructured materials, membranes and functionalized coatings are proliferating for energy-efficiency and environmentally "clean" technologies such as batteries, lightweight structures for transportation and wind-power, electric utilities (e.g. new sensors for smart grids) as well as portable/ military energy production and storage devices such as nano-structured fuel cell membranes.

Product development is underway in many U.S. corporations on integration of nanotechnology and green chemistry principles to simultaneously address the full range of environmental, energy-efficient and lean aspects of greener products, manufacturing and sustainable material recovery technologies. Many of these are being pursued in early- to mid- stage start-ups funded by leading venture financiers, and are tackling challenges such as energy efficiency, emissions, effluents, and the remediation of their impacts on ecosystems, energy use and renewables, material consumption, reuse, and waste.

The top six markets for nanotechnology products in the 2005 NCMS Industry Study were:

- Equipment, Tooling and Instrumentation
- Electronics and Semiconductors
- Computing, Information Technology and Telecommunications
- Aerospace
- Automotive
- Chemicals and Process.

In the 2003 NCMS Study, the top six application/end uses were:

- Electronics
- Advanced Coatings
- Devices and Sensors

- Automotive Applications
- Raw Materials Supply
- Biotechnology/Biomedical.

4.4 Change Management in Nanotechnology

Three-quarters of the respondents indicated organizations were coping adequately or well, while 25% were not. Senior business executives were more likely to state their organization was coping well or was on track with developing nanotechnology applications, whereas technology executives were more pragmatic.

This question was intended to assess the respondents' perception of how the organization was performing in advancing change and implementing corporate strategy for commercializing nanotechnology developments (Figure 4-7).

Selections provided ranged from
1 (Coping Poorly) to 5 (Coping Very Well).

4.4.1 Aggregate Results

Figure 4-8 illustrates the distribution of 270 survey responses. Half of the respondents stated their organization is coping adequately with implementing nanotechnology strategy, and about a quarter each indicated their firms were either Coping Well or Coping Poorly.

Senior business executives were slightly more likely to state their organization was Coping well. Technical executives were more likely to indicate their organization was Coping Poorly. A leading venture capitalist in the nanotech space explained these differences in perceptions during interview: "Executives in start-up companies tend to be more optimistic about market assumptions and growth strategies their organizations pursue."

4.5 Corporate Urgency

Higher proportions of senior business executives tended to state that nanotechnology receives a high priority in their organizations; a higher proportion of senior technical executives tended to state that nanotechnology receives low priority in their organizations.

This question was intended to assess the industry insiders' recognition and awareness of the changes in corporate attitudes towards nanomanufacturing (Figure 4-9). In other words, "Is the commercialization of nanotechnology important to your organization?" Selection options ranged from 1 (Low priority) to 5 (High priority).

For effectively commercializing nanotechnology and harnessing the many unique benefits it offers, it is widely recognized that all tiers and players in the nanotechnology product value-chains will have to get closely involved in sharing risks and payoffs. They would have to radically change management approaches, business models and corporate strategies for many current and visionary nano-enabled products.

4.5.1 Aggregate Results

Figure 4-10 shows that:

- 42% of the aggregate respondents stated nanomanufacturing is considered a High priority for development in their organizations
- 35% assigned Medium priority
- 18% indicated organizations placed a Low priority
- 4% chose not to answer this question.

Senior business executives were twice as likely to select High priority (42%) than were technical or engineering executives (20%). Of those 18% aggregate respondents who indicated Low priority for nanotechnology, two-thirds were either senior technical or business executives.

Raw materials suppliers (24%) were the most likely nanotechnology value-chain players to indicate High priority for nanotechnology,

Figure 4-7. Survey Question #4

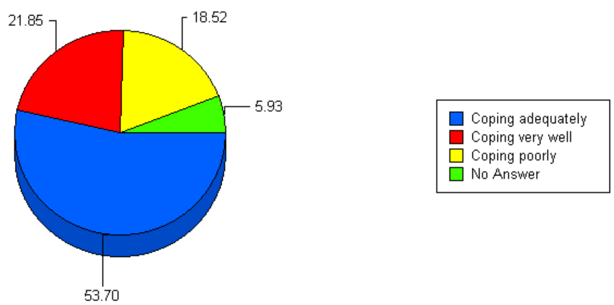

Figure 4-8. Majority of Respondents (~75%) Indicated Their Organizations Coping Adequately or Very Well with Developing Nanotechnology

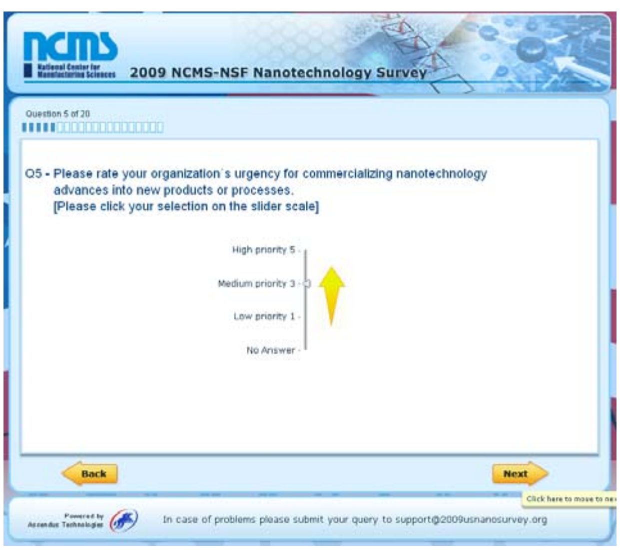

Figure 4-9. Survey Question #5

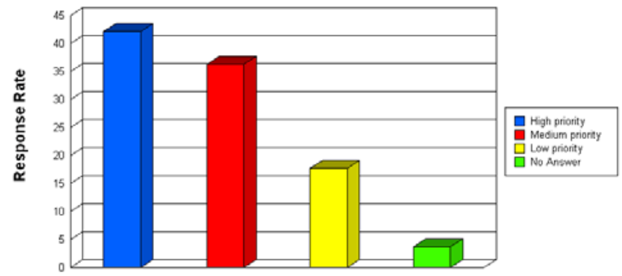

Figure 4-10. Over 75% Aggregate Respondents Indicated High or Medium Levels of Corporate Urgency for Commercialization of Nanotechnology

followed by intermediate processors of nanomaterials, test/instrumentation and equipment manufacturers. Respondents from academic organizations were more likely to indicate Low priority is being given to commercialization.

4.6 Organization Capacity for Nanotechnology

Only 15% of the respondents stated their organizations have high capacity, whereas four in five (80%) respondents felt their organizations have low or medium levels of capacity for pursuing nanotechnology developments.

This question and Question #8 on assessment of nanotechnology infrastructure were both intended to understand how well respondents' organizations are aligning their resources such as capital, R&D infrastructure, staffing and IP portfolios for the development of nanotechnology (Figure 4-11). In posing this question, NCMS attempted to appraise organizational and sectorial capacities for managing the commercialization of new nano-enabled products and systems.

4.6.1 Aggregate Results

Figure 4-12 illustrates that:

- Only about 15% of the responding executives indicated their organizations have High capacity – the granularity of respondents by organization size is shown in Figure 4-13.

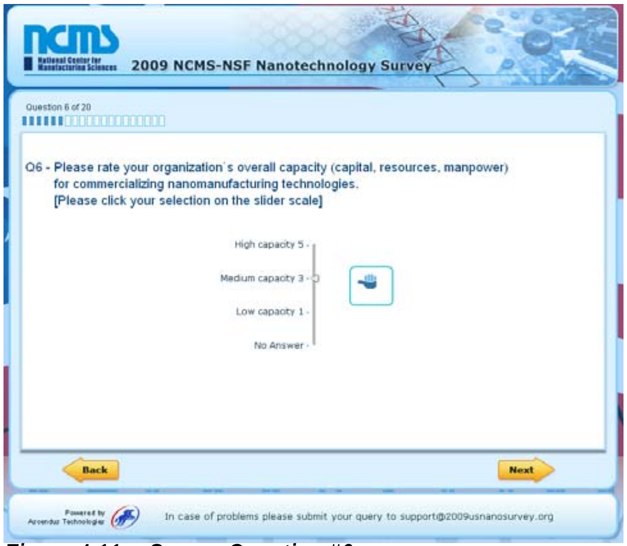

Figure 4-11. Survey Question #6

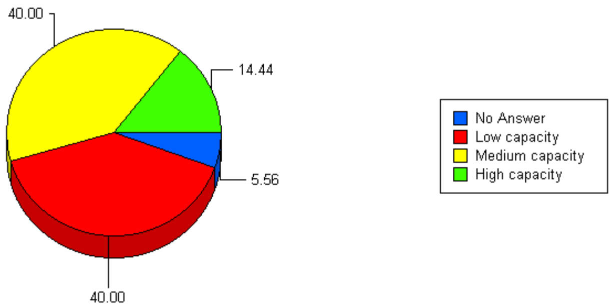

Figure 4-12. Aggregate Results for Respondents Assessment of Organization Capacity for Nanotechnology Development

- 40% indicated Medium (or adequate) capacity levels – this is a marked drop from the 2005 NCMS Study wherein nearly 70% respondents indicated Medium to High organizational capacity for nanotechnology developments.
- 40% respondents felt their organizations have Low capacity.
- About 5% of the executives did not select any option.

Figure 4-13 shows that respondents from organizations with staff size 21-50 in nanotechnology were more likely to indicate High capacity level for nanotechnology development. These findings may be due to the fact that the respondents in this category are mature start-ups (beyond three years since formation), that have progressed beyond Angel funding or Series A venture financing rounds which have helped establish their technology viability and resulted in a critical mass of staff, Series B or C financing and have access to the relevant infrastructure for the next phase of growth. A sampling investigation of the respondents' organizations corroborated by web searches and press releases helped confirm this assertion.

Expectedly, the smallest organizations expressed the greatest levels of concern about their internal capacity for nanomanufacturing (Figure 4-14).

It can be concluded that start-up companies that quickly develop strong alliances (e.g. with VCs, universities, suppliers, national labs or other value-adding partners) stand to fare better and can develop greater capacity for taking risks in nanotechnology-focused developments.

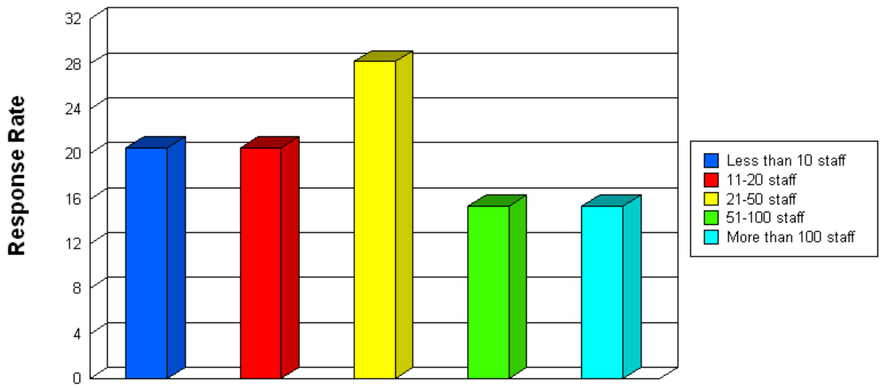

Figure 4-13. Organizations with 21-50 Staff Sizes Indicated High Organization Capacities

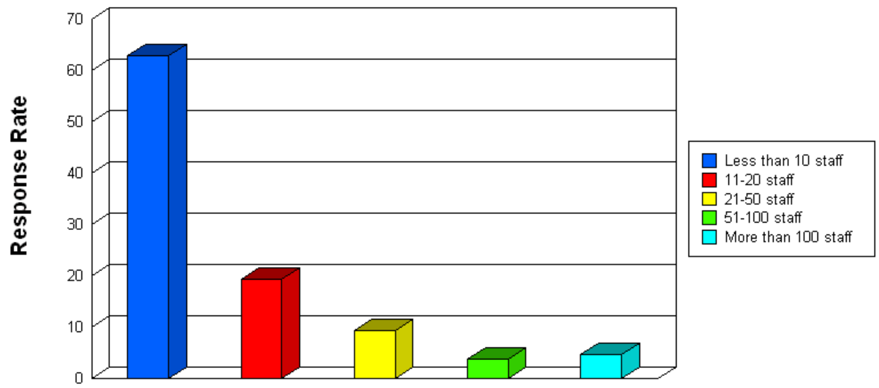

Figure 4-14. Of the 40% Respondents Selecting Low Capacity, the Vast Majority Have Less Than 10 Staff

4.7 Available Infrastructure for Nanotechnology

Only 15% of the respondents indicated having access to abundant infrastructure; one in three organizations stated they lacked infrastructure for nanotechnology developments.

Respondents were asked to provide assessments of their organization's infrastructure for nanotechnology development and nanomanufacturing, considering factors such as access to laboratory space and facilities, processing equipment, specialized test and diagnostics capabilities, etc. (Figure 4-15). This question was also intended to corroborate previous responses on the organization's priority, capacity, and coherence with critical internal hardware-related resources needed for nanotechnology developments.

For example, nanotechnology product developments for semiconductor and electronics applications are typically undertaken in capital-intensive, environmentally controlled clean rooms or foundries, requiring continuous raw material and consumable supplies, high-precision fabrication and metrology equipment, thereby impacting many different players in the supply-chain. Clean room facilities, once dominated by leading electronics manufacturers, have now become commonplace at academic and research laboratories across the nation, due in large part to infrastructure investments by the NNI.

4.7.1 Aggregate Results

Figure 4-16 shows that:

- About 5% respondents did not share information on their infrastructure
- 15% stated their organizations have abundant infrastructure
- One-third (31%) indicated inadequate infrastructure

Figure 4-15. Survey Question #7

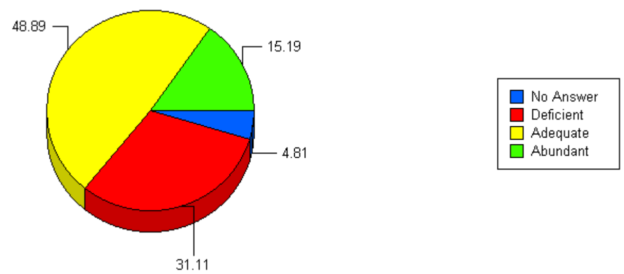

Figure 4-16. Aggregate Industry Response Indicate Significant Dissatisfaction with Nanotechnology Infrastructure

- Half (48%) of all respondents stated infrastructure was adequate.

Technical executives in the latest NCMS survey database were more likely to assess nanotechnology infrastructure as Deficient than were respondents who identified themselves as business executives. The larger the organization (in terms of disclosed staff size), the higher the proportion of respondents indicating Adequate or Abundant infrastructure for nanotechnology development.

These findings generally indicate an urgent need for further public-private investments and value-chain collaborations that could enable increased access to shared state-of-the art infrastructure user facilities for smaller nanotechnology organizations or developers. The resulting improvements in technologies and IP portfolios from a higher number of start-up organizations could facilitate stronger and more viable partners for vertical integration, mergers and other growth/exit opportunities, thereby accelerating the transition of nanotechnology advances to the marketplace.

Of the 15% respondents selecting the Abundant infrastructure option, the majority (26%) also stated they were involved with nanotechnology applications for multiple applications (e.g. manufacturers of nanomaterials and coatings), followed by electronics/semiconductor (16%) and pharma/biomedical/biotech (12%) and aerospace (8%). It is noteworthy that 40% of these respondents also indicated being involved in collaborations with multiple partners and laboratories.

The application markets of the 31% respondents who indicated Deficient infrastructure are similar but the data spread was more pronounced, i.e. nanomaterials/coatings, electronics/semiconductor, pharma/biomedical/biotech and aerospace. A higher percentage (38%) of these respondents indicated being in collaboration with only one other entity. Seventy percent (70%) of these respondents were from organizations with less than 10 employees.

In the 2005 NCMS Study, respondents were nearly equally divided in rating the adequacy of their available infrastructure for undertaking nanomanufacturing developments:

- 39% selected Plentiful
- 30% selected Adequate
- 31% selected Inadequate (with 9% selecting Significantly Lacking).

4.8 Collaborative Development

The majority (80%) of organizations are involved in varying levels of collaborations, ranging from single-company partnerships to co-creation in application-oriented value-chains. The development of large nanotechnology clusters and ecosystems is progressing steadily with greater differentiation and product diversity.

This question was framed to compare and assess the degree of technology-level partnering for commercialization of nanotechnology – i.e. alliances between end-users/customers, suppliers, academia, national labs, trade groups, and other associated entities (Figure 4-17). Organizations typically collaborate or join alliances to develop standards, or to leverage critical strengths so as to achieve specific business-related goals or technical outcomes that can advance their corporate strategy. The most common types are:

- Precompetitive research consortia and organizations evaluating emerging technologies from academic and national laboratories, and identifying opportunities for standardization
- Joint ventures and cooperation agreements for product development involving co-creation of innovations, transition and production scale-up
- Networks of mature supplier groups or vertically integrated teams driven by standard practices for more established high-volume manufactured products driven by leading OEMs.

Nanotechnology is inherently a multi-disciplinary field, involving the convergence of chemistry, physics, materials science and electricity (at the minimum) at the phenomenological level. These interdisciplinary aspects rapidly increase in complexity and often interact when considered at the hierarchical engineering and macro-scale manufacturing levels, requiring closer coordination and attention to safety and handling, regulatory and public outreach.

Figure 4-17. Survey Question #8

4.8.1 Aggregate Results

The economic recession of 2008-09 has put great pressure on early-stage nanotechnology start-ups as well as many established larger players, spurring them to seek new ways to accelerate product development and reduce development risk. Successful commercial exploitation of advanced nanotechnology products requires unprecedented levels of collaboration and information sharing across many different fields (including environmental health and safety) and realms in order to adequately address the inherent complexities associated with the lifecycles of nano-enabled products.

As shown in Figure 4-18, the vast majority (85%) of respondents indicated varying degrees of organizational involvement in collaborations and technology partnerships. This is a significantly higher number than 75% respondents who indicated participation in collaborations in the 2005 NCMS Study.

Of the subset of these 85% aggregate respondents, 28% indicated single entity partners (i.e. one-on-one, typically a small company-large company partnership); 11% indicated partnering with at least two entities; and over 34% indicated participating in partnerships with multiple players (such as academia, government laboratories and private corporations for development of nanotech-nology. It is encouraging to find that 11%

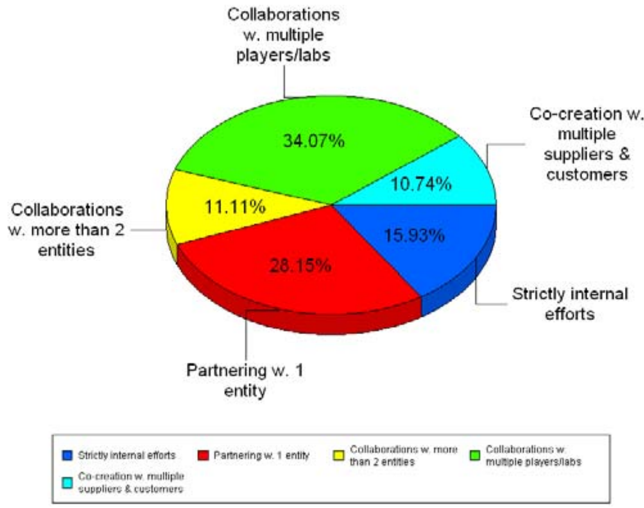

Figure 4-18. Majority (85%) of Respondents' Organizations Involved in Collaborative Nanotechnology Developments

respondents stated they are involved in nanotechnology developments through co-creation partnerships.[13] These are defined as application-specific joint ventures aimed at commercializing new, and highly differentiated products. Co-creation ventures are generally characterized by equitable sharing of costs-, profits- and intellectual property between entities for the focused leverage of complementary competencies in order to gain new competitive advantage.

Only 16% respondents indicated nanotechnology is being developed through strictly internal efforts. The main application markets such entities are pursuing include electronics/semiconductors, aerospace, pharma/biomedical/biotech.

4.9 Interactions with NNI Projects

Nearly half of all respondents (46%) stated their organizations have had formal interactions with NNI projects or accessed specialized facilities in the U.S. Government's vast network; Less than 5% indicated licensing IP from NNI centers.

In the 2005 NCMS Study, North American organizations developing products incorporating nanotechnology indicated three drivers for collaboration:

- To leverage limited resources/infrastructure and share development risks
- To assess customers/end-users' technical needs in order to co-develop focused products and solutions incorporating nanotechnology advances
- To access new (or established) markets through a partner's distribution channels.

For the 2009 NCMS Study, this question was modified and re-framed so as to develop a more granular profile of public-private technology-level partnering in nanotechnology (Figure 4-19). Survey executives were asked to indicate alliances and affiliations with leading federally-funded research programs under the NNI, such as academic, national and agency laboratories that have received substantial mission-oriented NNI investments, targeting improvements in healthcare, energy, defense, and standards. There are over 80 NNI-supported centers, networks, and user facilities for pursuit of nanotechnology R&D, education, and discourse.

[13] Prahalad, CK and Ramaswamy, V., "The Future of Competition: Co-Creating Unique Value With Customers," Harvard University Press, 2004.

Figure 4-19. Survey Question #9

4.9.1 Aggregate Results

In Figure 4-20, the aggregate bar chart illustrates respondents' selections from available six independent options (which explains why the percentages do not total 100%). The following summarizes the observed trends from responses:

- 54% (143) respondents stated they had no formal affiliations with NNI facilities and projects – this appears realistic, but it is also possible the magnitude is higher because some respondents (especially from larger organizations) may lack sufficient knowledge or breadth of their organization's connections with NNI-funded academic and federal research facilities.
- 46% (127) respondents stated their organizations had interacted with NNI laboratories and facilities. The following figures provide further detail based on data provided by these 127 respondents:
  - 50% (63) respondents' organizations had affiliations with NSF-funded National Nanotechnology Infrastructure Networks (NNINs) and Nanoscale Science and Engineering Centers (NSECs) established at university campuses across the nation (Figure 4-20).
    - These include early-stage research firms targeting multiple applications, followed by electronics/semiconductor, energy/utilities and pharma/bio-medical/biotech.
  - 45% (57) organizations had connections with Department of Energy (DOE)-sponsored Nanotechnology User Facilities (Figure 4-21)
    - This group was dominated by firms targeting multiple applications, as well as those focused on electronics/semi-conductor, energy/utilities, chemicals and process industries – they are

commercializing energy conversion and storage materials, nanoparticulates, coatings, paints and thin-films, displays and electronics, etc.

– 28% (36) organizations were linked with metrology or standardization programs with National Institute of Standards and Technology (NIST) (Figure 4-22).

  - Nanotechnology products in development for semiconductors and electronics, print and lithography applications; coatings, paints and thin-films; energy conversion and storage; electronic, displays, optoelectronics, nanowires, and nanoparticles.

– 21% (27) organizations had affiliations with NIH, National Cancer Institute (NCI) and National Heart, Lung and Blood Institute (NHLBI) networks (Figure 4-23).

  - Nanotechnology products for drug delivery, diagnostic and medical implants, as well as functionalized nanoparticles and coatings make up this profile.

– 9% (11) organizations stated they had either licensed technology or had project-level collaborations with one or more of these NNI facilities.

4.10 Offshoring of Nanotechnology Developments

Thirty percent (30%) of the respondents indicated their organizations are involved in offshore developments to varying degrees – the organizations most active in offshoring of nanotechnology developments are targeting applications in electronics/semiconductor, energy conversion/storage, aerospace and pharmaceutical/ biomedical/biotechnology

This query was included to assess the extent of offshoring and collaborative nanotechnology product development between U.S.-based and foreign organizations (Figure 4-24).

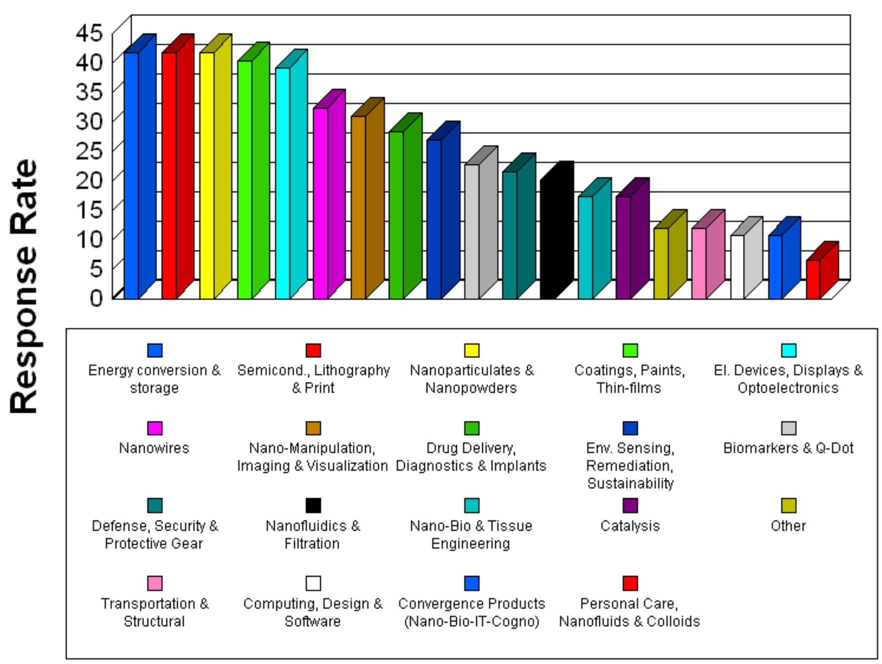

Figure 4-20. Nanotechnology Products of 27 Respondents Partnering with NSF Projects at NNIN/NSEC Facilities

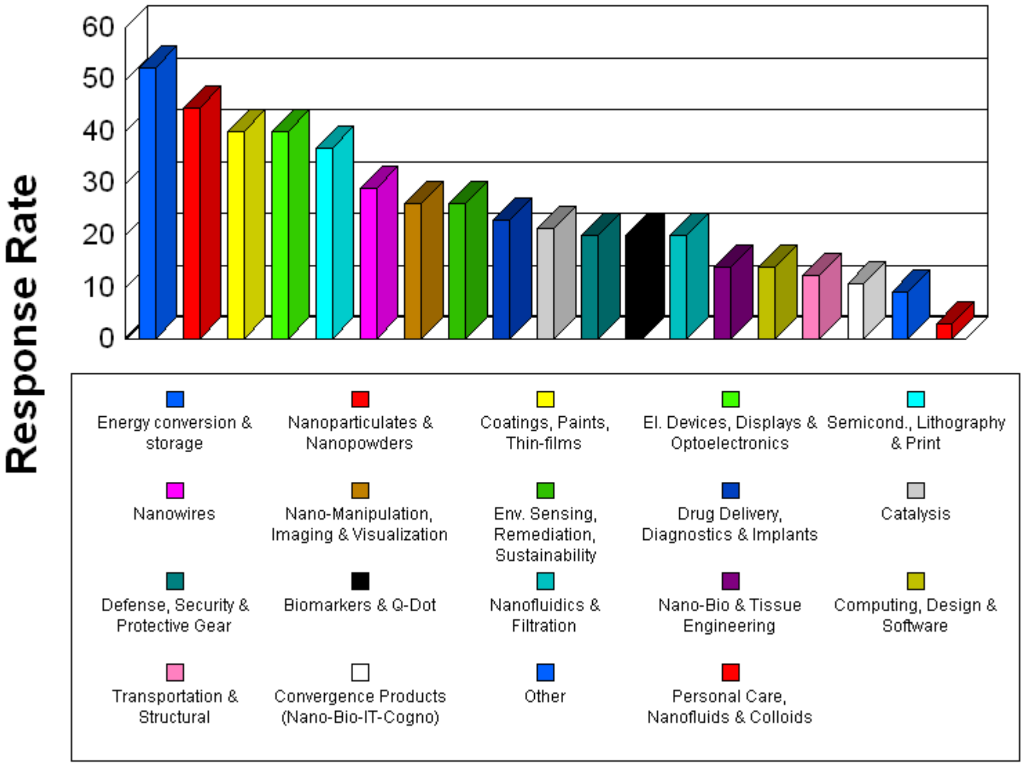

Figure 4-21. Nanotechnology Products of 57 Respondents Partnering with DOE Nanotech User Facilities

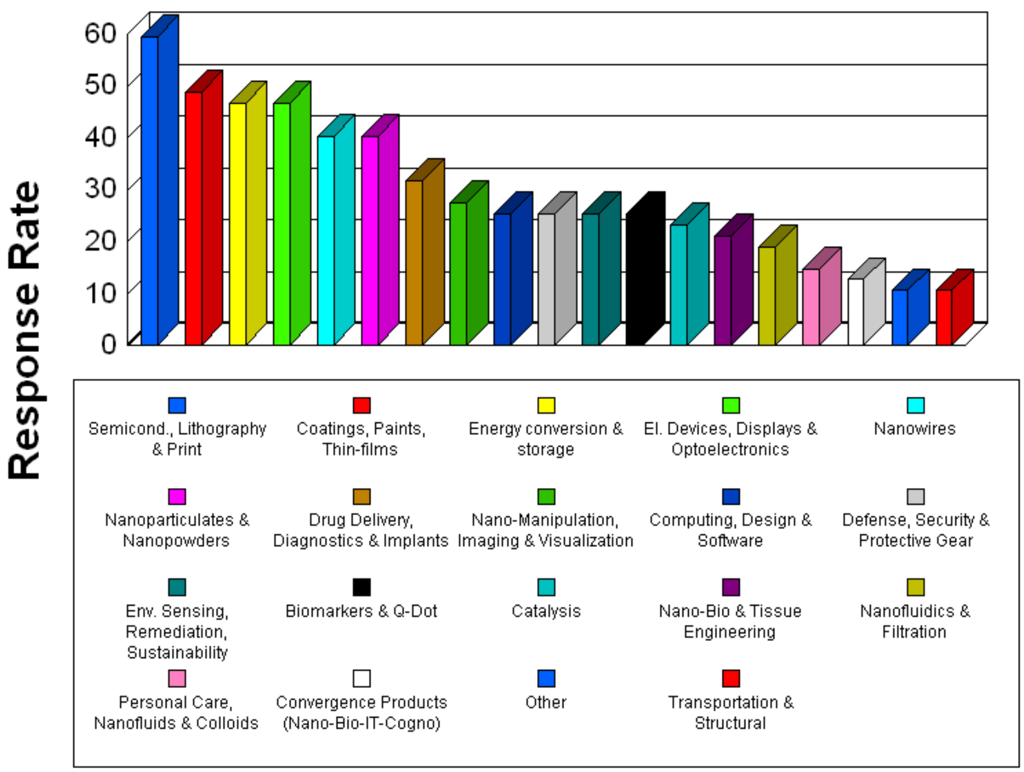

Figure 4-22. Nanotechnology Products of 36 Respondents Indicating Partnerships with NIST Facilities

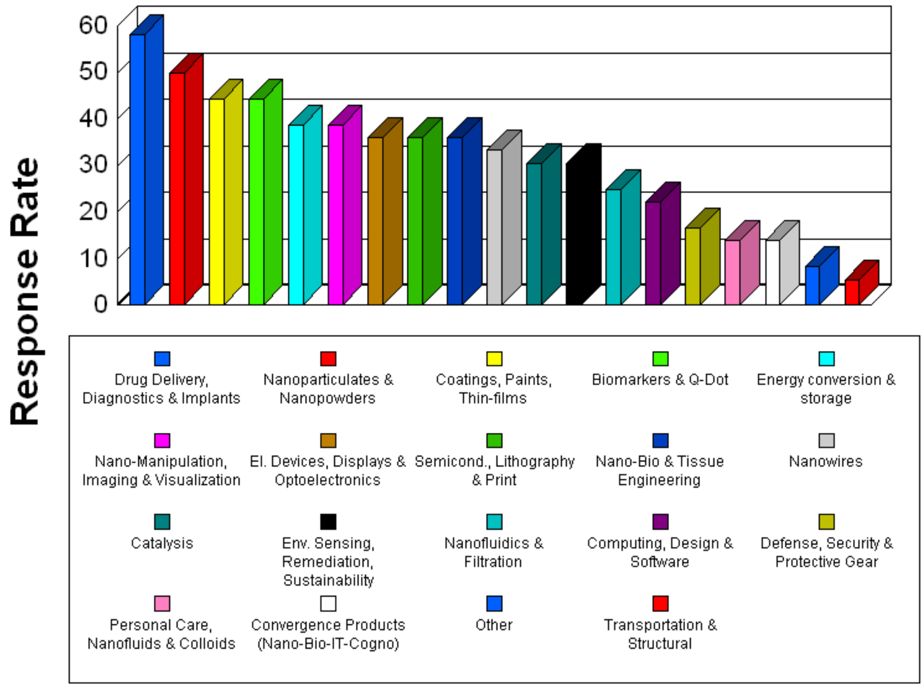

Figure 4-23. Nanotechnology Products of 27 Respondents Partnering with NIH/NCI/NHLBI Networks

Figure 4-24. Survey Question #10

4.10.1 Aggregate Results

Figure 4-25 illustrates that:

- 7% respondents indicated they are service providers with no tangible product
- About two-thirds (63%) of the respondents indicated their nanotechnology products are entirely developed in the U.S.
- Nearly 30% of the respondents stated their organizations were involved with varying levels of offshore product developments, of which:
  - 20% indicated their organizations are involved with some offshore development
  - 4% indicated significant offshore development
  - 5% stated substantial offshore development.

Mapping these data trends, the nanotechnology developers most active in offshore R&D relationships are those targeting application markets such as aerospace, energy conversion, electronics/semiconductors, and pharma/medicine/biotechnology (Figure 4-26). This finding also corroborates data from a 2009 NSF Survey of R&D in U.S. businesses conducted jointly with the U.S.

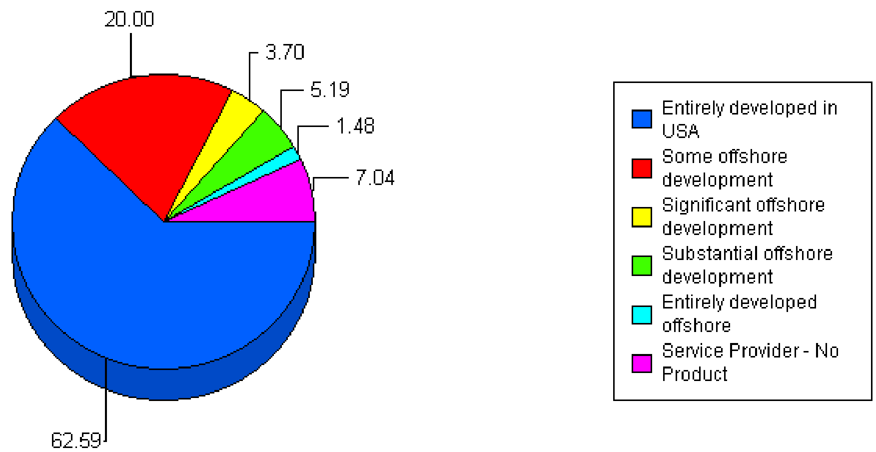

Figure 4-25. Offshore Development Profile of 270 U.S. Nanotechnology Organizations

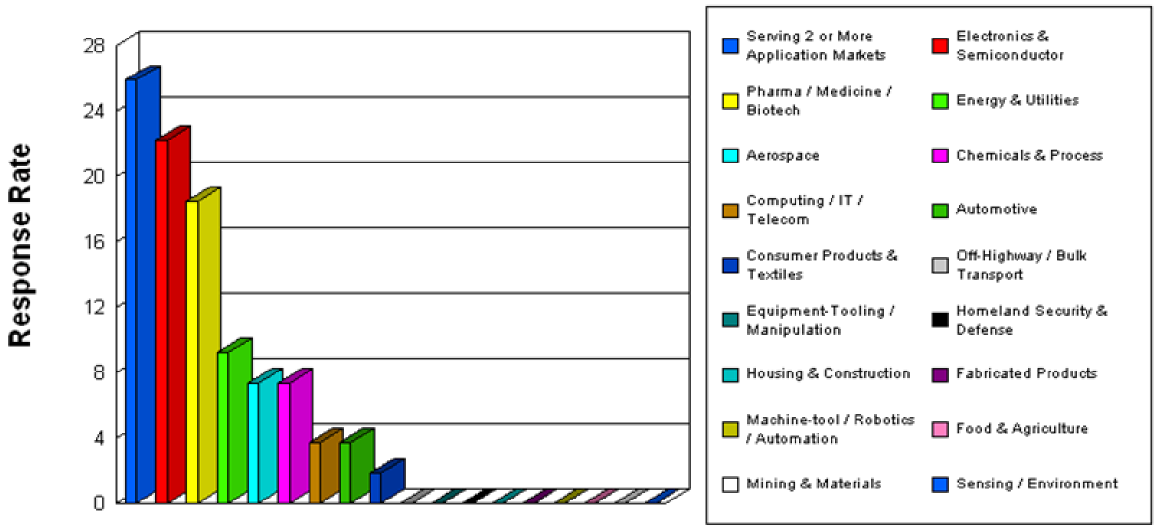

Figure 4-26. Nanotechnology Application Markets of Organizations Engaged in Offshore R&D

Census Bureau.[14] The report identifies a strong trend in the pharmaceutical industry and electronics/semiconductor manufacturers to conduct developments at offshore locations as their operations in the U.S. are challenged with high product development costs, long approval cycles and tough regulations. Thus, it appears that U.S. corporations pursuing nanotechnology in these sectors are similarly motivated to benefit from offshore partnerships in order to stay competitive or perhaps to enter new markets.

4.11 Staffing Profiles of Nanotechnology Organizations

Early-stage start-ups with less than 10 staff are the single largest category of businesses pursuing the commerciali-zation of nanotechnology. The financial crisis has accelerated shifts in VC, resulting in an industry consolidation.

Staffing trends in organizations provide key metrics for assessing the commercial impact of

[14] Wolfe, Raymond M. "U.S. Businesses Report 2008 Worldwide R&D Expense of $330 Billion: Findings from New NSF Survey," NSF, Directorate for Social, Behavioral and Economic Sciences, NSF 10-322, May 2010.

nanotechnology investments and their job creation potential (Figure 4-27).

4.11.1 Aggregate Results

In general, the staffing distribution of nanotechnology organizations follows similar trends seen in the 2005 NCMS Study with start-up technology businesses dominating the nanotechnology sector. The majority are small businesses[15] with less than 10 employees, have licensed technology from universities or federal laboratories, and leveraged government funding with other forms of risk capital – this is a pattern observed in other similar nascent industries such as biotechnology and life sciences. The 2009 NCMS database shows the following staffing trends:

- 50% reported having less than 10 staff (versus 57% in the 2005 NCMS Study)
- 19.3% have 11-20 staff (versus 18.5% in 2005)
- 15.6% have 21-50 staff (versus 12.3% in 2005)
- 7% have 51-100 staff (versus 6.7% in 2005)
- 8.2% have more than 100 staff (versus 5.2% in 2005).

Figures 4-28 and 4-29 illustrate the aggregate data from the 2009 and 2005 industry surveys, respectively.

One finding from the 2009 Study is that respondents in the category of “less than 10 staff” dropped significantly, while the 21-50 staff category recorded a measurable increase from 2005 levels, indicating that a consolidation is underway. This hypothesis was confirmed through interviews held with leading institutional/venture financiers, and nanotechnology entrepreneurs. The economic recession of 2008-09 and resulting credit crisis were cited as key factors which accelerated industry consolidation; the slow recovery continues to threaten the viability of many small (less than 10 staff) nanotechnology organizations. The other driver for consolidation concerns limitations in the internal capacity or stage of commercialization readiness achieved by a start-up in its technology lifecycle, necessitating mergers or other stronger leveraged partnerships for the next phases of growth.

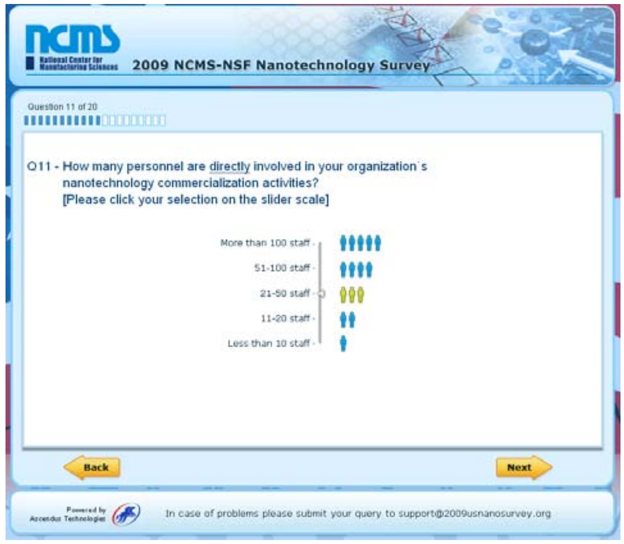

Figure 4-27. Survey Question #11

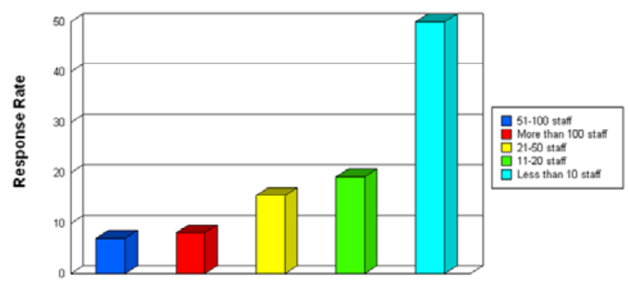

Figure 4-28. Fewer than 20 Staff at 75% of the Nanotechnology organizations with Industry Consolidation Underway Amongst Start-ups (2009)

[15] Per the U.S. Small Business Administration, a small business may have up to 499 employees.

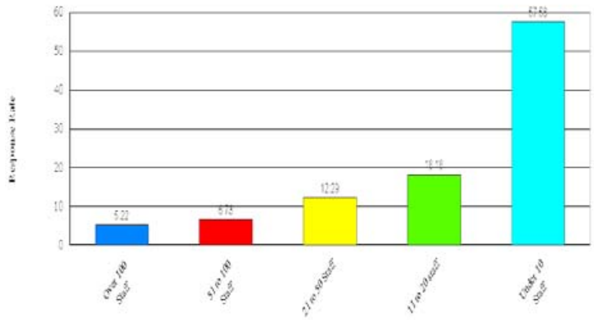

Figure 4-29. Nearly 75% of Nanomanufacturing Organizations With Less Than 20 Staff (2005)

Some larger and longer established manufacturing organizations have taken advantage of the market downturn and availability of under-valued nanotechnology patents from struggling start-ups by increasing their staffing in nanotechnology product development. These organizations, or their venture financiers, are strengthening their brands or differentiating their products for enhancing shareholder value, or to achieve economies of scale by acquisition of specialized capabilities, manpower and infrastructure. The application sectors exhibiting this trend include:

- Electronics/semiconductors
- Energy conversion and storage (mostly photovoltaic manufacturers)
- Nanomaterials
- Paints, coatings and thin-films.

Start-up nanotechnology businesses, by themselves, have limited potential for generating the significant numbers of jobs, as their innovation capability is generally narrow and limited for generating new IP. These organizations usually work on technology scale-up, and material characterization (e.g. for toxicity) or on building co-development alliances with larger corporations/customers. Such organizations require fewer, but higher skill level knowledge workers capable of inter-disciplinary work.

Industry shakeouts and consolidations accelerated by the recession of 2008-09 will continue over the next several years. The “winnowing” process is resulting in mergers of companies with weak asset positions or IP portfolios with larger competitors or customers. Venture firms are also affected by the credit crisis due to lackluster returns, virtually zero realized exits in nanotechnology through IPOs, fewer successful equity financing rounds, and the general attrition of high-net worth investors. Those VCs playing in the nanotechnology space are actively combining smaller companies working on similar or complementary technologies into larger firms that can eventually go public. It is anticipated that growth will be generated from healthy exits these firms make to recoup their investments – such as through profitable IPOs or by acquisitions or cross-licensing of nanotechnology advances and patents to larger players.

Job growth can occur during the transition from pilot to larger-scale nanomanufacturing when specialized top-down and bottom-up nanomanufacturing tools, logistics equipment and characterization/measurement systems are required in order to link macro-scale products with nanoscale components or properties. The key to this growth lies in the industry’s ability to innovate cost-effective high-yield production and self-assembly methods.

4.12 Commercial Timelines

A higher proportion of respondents (25%) indicated their organizations have launched commercial products incorporating nanotechnology; it is unclear whether the current recession has significantly impacted long-term product development timelines.

This question was intended to elicit generalized responses on timeline estimates, while recognizing that many organizations may have multiple products in the pipeline at various stages of commercial readiness, and hence may provide inaccurate timeline information (Figure 4-30). NCMS was looking for evidence that the

Figure 4-30. Survey Question #12

general development timelines or market introductions have been affected by the economic recession of 2008-09.

4.12.1 Aggregate Results

Aggregate cross-industry estimates of commercialization timelines reported by nearly 270 survey respondents are shown in the cumulative stacked bar chart in Figure 4-31. The general 2009 data trends are comparable with trends seen in the 2005 NCMS Study (Figure 4-32), and indicate that:

- Nanotechnology products are in various stages of development, and commercialization of emerging products could occur at an accelerated rate
- A higher percentage (25%) of aggregate respondents stated their organizations already have already launched products incorporating nanotechnology, whereas this figure was 18% in 2005
- A higher percentage of respondents (15%) indicating lead times over five years was correlated with large organizations (i.e. over 100 employees) involved in the more visionary nanotechnology developments
- Since the 2009 patterns appear similar to those observed in 2005, it is unclear whether the recession has significantly affected long-term product timelines.

Other near-term and mid-term commercialization timeline projections generally mirror the trends seen in the 2005 Study. In both studies, respondents understandably, tended to be more optimistic about introducing products over the mid-term (2-5 years) time-scales, and time-to-market projections were less certain about the longer term. This pattern is typical of venture-backed early stage start-ups where investors expect to exit in the 3-5 year timeframe.

Cross-correlations were also performed for time-to-market estimates with the types of end-use/applications and corresponding nanotechnology products in development. Summary results with dominant nano-enabled products are shown in Table 4-1.

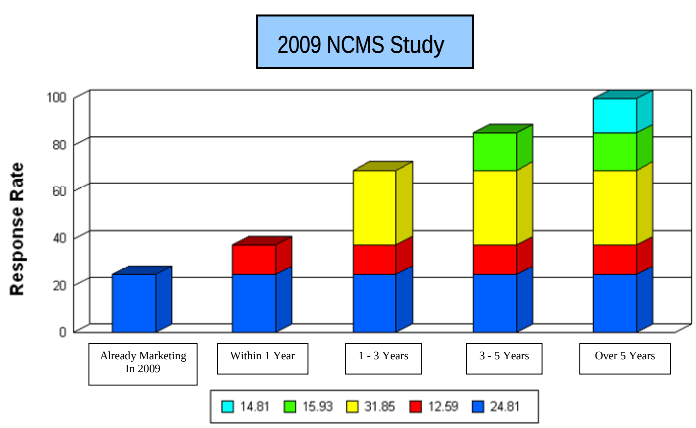

Figure 4-31. Commercialization Timelines Indicate Many Nanoproduct Introductions in 2011-2013

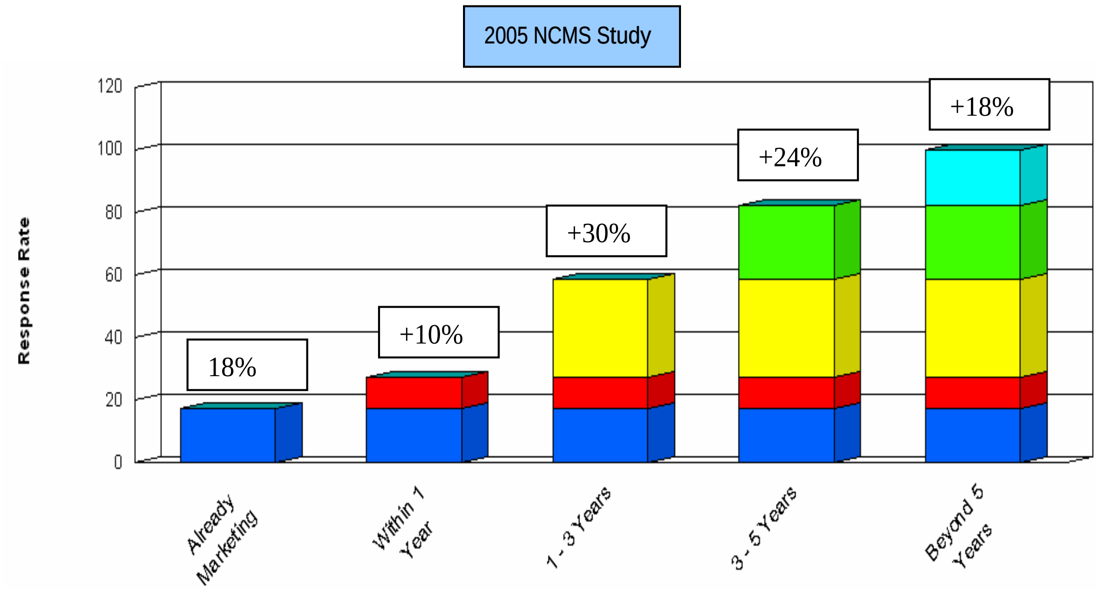

Figure 4-32. Commercialization Timeline from 2005 NCMS Study for Nanoproducts in 2007-2011

Table 4-1. Nanotechnology Markets and Commercialization Timelines for 2010-2015

% Respondents & Time-to-Market	Dominant End-uses/Applications	Nanotechnology Products
12.6% by 2011 (one year to launch)	- Electronics & semiconductors - Defense, structural and security gear - Energy & utility - Chemicals & process - Pharma/biomedical/biotech - Aerospace	- Coatings, paint, thin-films - Semiconductor, lithography & print products - Biomarkers, Q-dots - Nanotubes, nanopowders - Displays & optoelectronics
31.9% in 2011-13 (1-3 years to launch)	- Electronics & semiconductors - Energy & utility - Pharma/biomedical/biotech - Aerospace	- Coatings, paint, thin-films - Semiconductor, lithography & print products - Drug delivery, diagnostics, implants -Nanotubes & nanopowders - Displays & optoelectronics
15.9% in 2013-2015 (3-5 years to launch)	- Pharma/biomedical/biotech - Electronics & semiconductors - Energy & utility - Homeland security & defense - Environmental sensing	- Coatings, paint, thin-films - Semiconductor, lithography & print products - Nano-bio & tissue engineering products - Nanotubes & nanopowders - Displays & optoelectronics
14.8% - launch beyond 2015	- Electronics & semiconductors - Defense, structural and security gear - Energy & utility - Chemicals & process - Pharma/biomedical/biotech	- Coatings, paint, thin-films - Semiconductor, lithography & print products - Nano-bio & tissue engineering products - Nanotubes & nanopowders - Displays & optoelectronics - Metrology tools & instruments - Convergence products

4.13 Nanotechnology Products

A broad range of products incorporating nanotechnology are already commercialized or in varying stages of development. Early applications include: nanomaterials, functional coatings, energetics, optical materials, structural reinforcements, drug delivery and diagnostics, biomarkers.

Executives were asked to select from an abbreviated list of nanotechnology products, and also had the opportunity to enter their own description (Figure 4-33). Due to these multiple independent options, the percentages of responses do not add to 100%. Considering that nearly one-fifth (19%) industry executives chose not to provide nano-product information in the 2003 NCMS Survey, a greater level of openness was observed amongst industry executives in the latest 2009 Study.

Identified nanotechnology products were also correlated to key application markets and to the commercialization timelines indicated by respondents, as listed in Table 4-1.

4.13.1 Aggregate Results

A broad and growing range of products incorporating nanotechnology are commercialized or in varying stages of development in the U.S.

Figure 4-33. Survey Question #13

While the electronics and semiconductor industry has already commercialized advanced CMOS computer chips and memory devices by incorporating nanoscale dopants, processes and gate features, other commercially available products are in the form of nanostructured powders and integrated in compounds. These materials range in complexity from basic nanomaterials to particulates (e.g. catalysts, quantum dots, graphene platelets, nanowires, and nanoemulsions), to ultra-thin photovoltaic film coatings and thin-films, and to complex 3D semiconductor memories and miniature devices for embedded electronics that are just entering the market.

Figure 4-34 illustrates the aggregate results regarding the types of nanotechnology products and mix reported by executives in the 2009 Study. Readers are cautioned against reading absolute percentages, since respondents had multiple independent selection options.

The list of first-generation nanotechnology products already commercialized or soon to be commercialized over the five-year horizon comprises materials and coatings with higher precision for significantly enhanced manufactured macro-scale products. These product introductions are expected to result in greatly improved consumer and durable end-use goods, such as:

- Semiconductors, lithography and print products
- Transportation system structures incorporating nanostructured particulates and nanomaterials (including single and multi-wall nanotubes)
- Advanced, highly durable “smart” coatings, paints and thin-films for surface enhancement, energy conversion and conductivity/
storage applications (solar cells, lithium-ion batteries, fuel cells and ultra-capacitors)

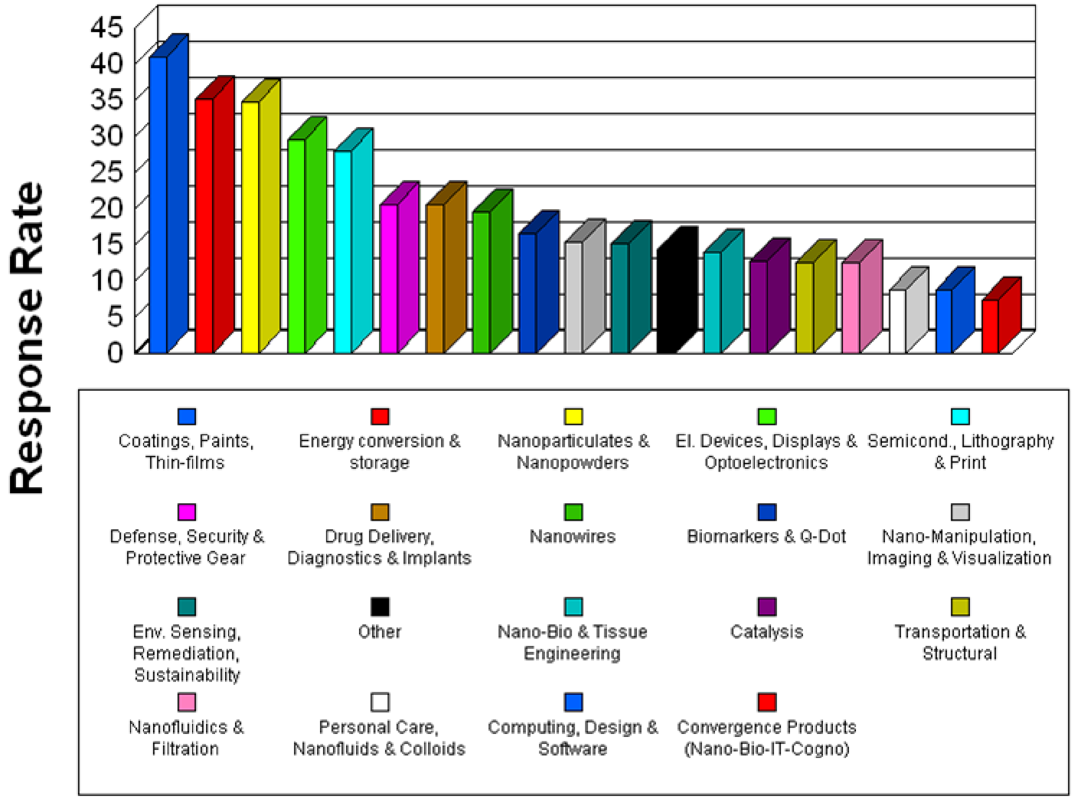

Figure 4-34. Nanotechnology Products Commercialized or In Development (Reported in 2009 NCMS Study)

- Nanoscale treatments assuring surfaces with significantly enhanced adhesion, erosion-, corrosion- and wear- resistance of components
- Computers/consumer electronics, mobile telecommunication equipment, displays and other optoelectronics products (e.g. touch-enabled screens).

With the advent of novel nanoscale biomaterials in recent years, the field of medical diagnostics and treatment is seeing the potential for significant impact on society. Efforts are now more widespread to achieve the specificity of outcomes, from the functionalization of nanomaterials to improve biocompatibility, increase efficiency and reduce toxicity. Several companies appear poised to demonstrate the successful implementation of diagnostic techniques, medical treatments, or improved fundamental biological understanding that could benefit both, researchers and the healthcare industry.

The 2009 Study responses also indicate higher commercialization rates of a new generation of nano-biomedical devices (such as lab- and system- on-a-chip) incorporating nano-biotechnology, as well as combination sensors, diagnostic/therapeutic materials and devices, and other novel hierarchically scaled/integrated systems for applications such as:

- Environmental, sensing and remediation products
- Drug delivery, medical diagnostics and implant systems
- Nano-biotechnology, nanofluidics and tissue engineering products
- Computational, design, visualization, Q-dots, biomarkers and imaging tools.

The following is a representative list of the types of new coatings, packaging, sensing, energetic and protection products approaching commercialization for early markets:

- Nanoparticulates and additives for improved catalysis and functionality (strength, water resistance, absorbance, gloss, barrier properties, conductivity)
- Nanotechnology-enabled photovoltaics printed directly onto building materials – an approach that simply is not possible with conventional crystalline silicon solar materials
- Nanocomposite magnetic materials for tag sensors
- Nanoclay/carbon nanotube/graphene nanoplatelet reinforcements for polymer and metal matrix nanocomposites
- Plastics for bottle applications with ultraviolet barrier properties
- Miniature nano radio frequency identification tags
- Nanoscale barcodes and taggants – to track, trace and provide brand protection (e.g. counterfeit/tamper-proof pharmaceutical and currency applications)
- Enhanced durability and reusability of plastic packaging materials
- Reinforcement coatings for polymer nanocomposites
- Paper and plastics with tailored sensing ability
- Nanocoded plastics and paper materials for authentication and identification applications
- Intelligent packaging systems indicating freshness or safety of contents.

These product introduction trends will continue well beyond the three to five year timeline (2009-2011), with even greater growth, complexity, and diversification of products and application markets.

The 2009 NCMS Study responses also indicate that visionary directed self-assembly and convergence nanotechnology products will be commercialized well beyond five years. These second and third generation products face complex challenges in risk-reward assessments, clinical trials, testing, certification and approvals which requires close coordination across multiple federal agencies, development of new industry safe practices and accountability paradigms, as well as through new regulation and education of stakeholders regarding products exploiting these potentially disruptive technologies.

4.14 Nanotechnology Readiness Levels

One in five respondents indicated nanotechnology products with high market – readiness level at TRL 9, such as: functionalized nanomaterials for coatings, paints and thin-films; semiconductor, lithography and print products; energy conversion and storage; and electronic devices, displays and optoelectronics. These have the highest potential for profitable venture exits, near-term job-creation and revenue-growth.

Military research projects in the U.S. are frequently assessed for their development stage or implementation-readiness using a nine-point rating scale known as TRLs which considers both, hardware and software developments and their validation. NCMS adapted this rating system in an attempt to more objectively assess the aggregate development state of nanotechnology products and compare across sectors (Figure 4-35).

Survey respondents were presented concise definitions of nine TRLs ranging from conceptual level (TRL = 1) to implementation-ready product (TRL = 9), and asked to select the option that best describes the maturity of their nanotechnology product.

Figure 4-35. Survey Question #14

TRLs 4 and 5 define a mid-level development stage of application-oriented technology intended to result in "product or components with breadboard validation performed in a laboratory and then in a relevant environment." They are regarded as the "valley of death" stages where a large amount of resources are required to demonstrate a product whose test performance shows agreement with analytical requirements, and whose scaling requirements are documented. They are also the typical "sweet-spots" for investments by the venture community in early-, mid- or late-stage entrepreneurial start-ups, or for larger corporations to begin collaborations and licensing of applications from the inventor.

Respondents with exceptions to the TRLs were encouraged to indicate in the Other field – this field captured 10% of responses, including service providers (who do not have tangible products), as well as several respondents indicating multiple nanotechnology products in development at various readiness levels. This information is shown by the grey bar at the extreme right hand side of the TRL chart in Figure 4-36.

4.14.1 Aggregate Results

The executives' aggregate responses to this question are summarized below and illustrated in Figure 4-36. The spread of percentages across TRL 1 – 9 ranged about 10%, indicating that the sample of nanotechnology organizations spans all development stages:

- 13.7% TRL 1 = Basic principles observed and reported in peer-reviewed publication
- 12.2% TRL 2 = Technology concept or application formulated and documented
- 11.9% TRL 3 = Analytical or experimental critical function/proof-of-concept shown
- 8.9% TRL 4 = Component or breadboard validation in laboratory
- 5.6% TRL 5 = Validation in a relevant environment
- 7.8% TRL 6 = Prototype demonstration in a relevant environment
- 6.3% TRL 7 = Test performance agrees with analytical predictions/design
- 7.4% TRL 8 = Actual system completed and qualified via test and demonstration
- 16.7% TRL 9 = Final product successfully operated in actual application.

This set of questions and responses addressing innovation stages can readily serve as the foundation for new sectorial studies of the U.S. Nanomanufacturing Industry.

Analyses as shown in Figure 4-37 were also performed to identify key market sectors and nanotechnology products correlated with the highest readiness level (i.e. based on 16.7% respondents for TRL = 9) – i.e. products that have been "successfully utilized or operated in an actual application or mission, and technology is documented with operational results." They are:

- Functionalized nanomaterials for coatings, paints and thin-films

- Semiconductor, lithography and print products
- Nanoparticulates and nanopowders
- Energy conversion and storage materials
- Electronic devices, displays and optoelectronics.

These commercialized or nearly market-ready nanotechnology products are indicative of the industry sectors where growth of viable and sustainable companies, infrastructure/ecosystems and supply-chains is currently occurring.

Other analyses were also performed to correlate typical barriers and commercialization challenges faced by the aggregate groups of organizations depending on whether they indicated nanotechnology products in Low, Medium or High levels of technology readiness and maturity. Respondent-selected barriers for each stage are graphically illustrated below – the reader is cautioned that in Figures 4-38 – 4-42, the bar colors in each plot correlate to the aggregate rank of barriers listed in each adjacent color legend box.

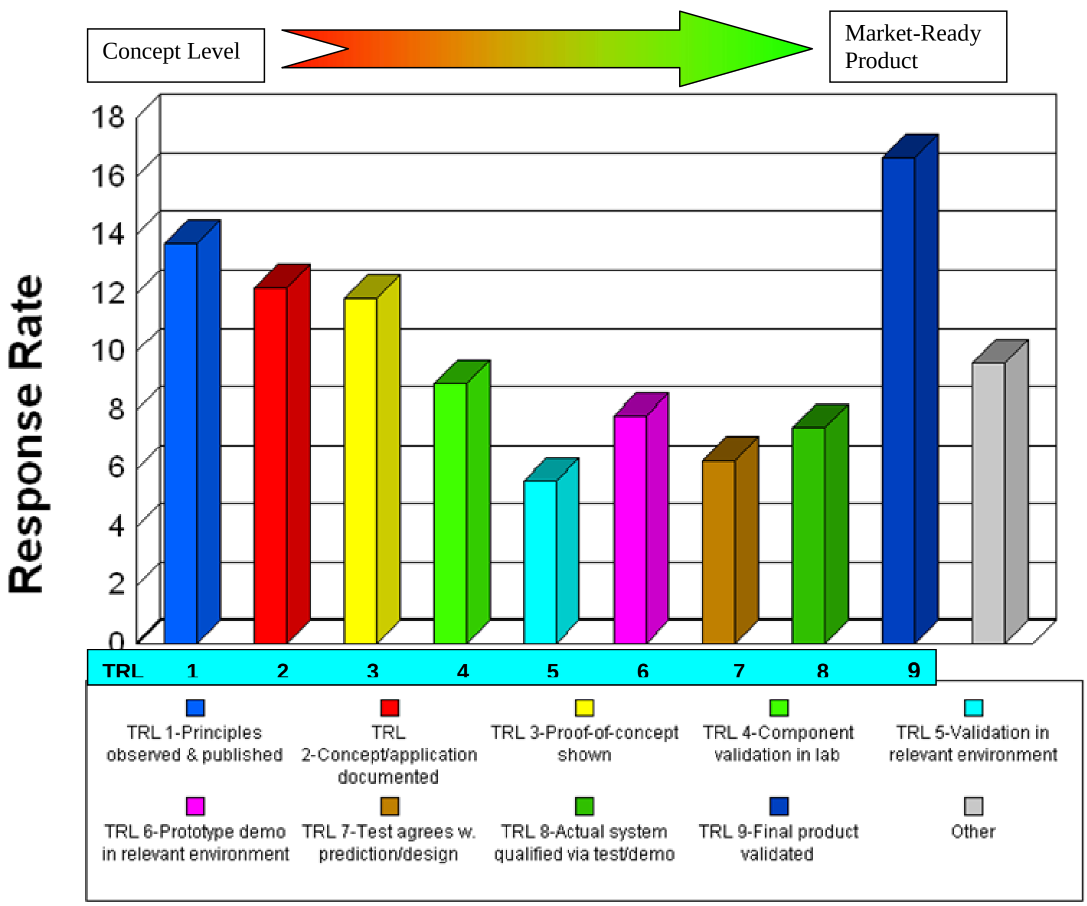

Figure 4-36. Distribution of 270 Responses Across Nine Technology Readiness Levels 1 – 9

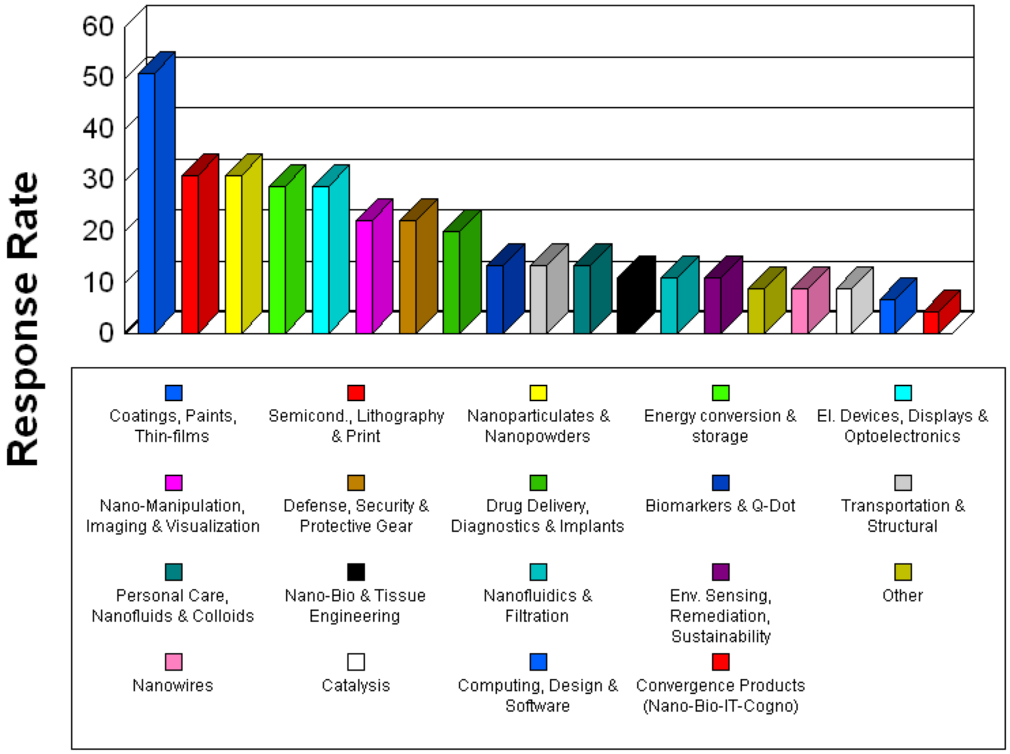

Figure 4-37. Nanotechnology Products with High Technology Readiness Level (9)

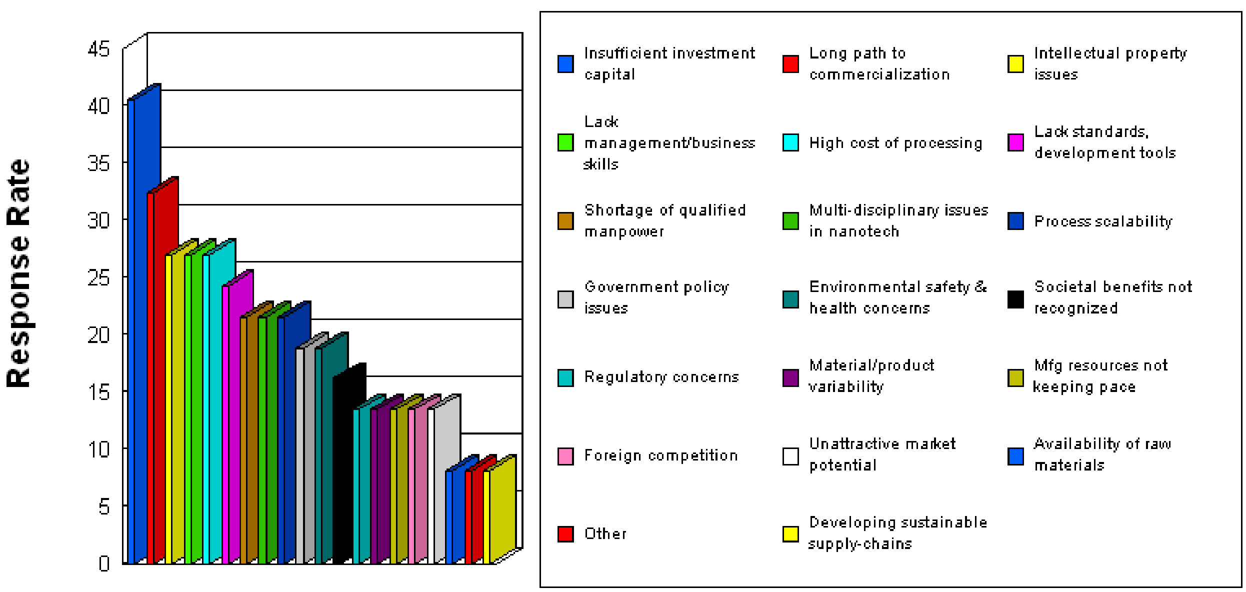

Figure 4-38. Profile of Commercialization Barriers in Organizations at Low TRL (TRL 1 = Basic Principles Published)

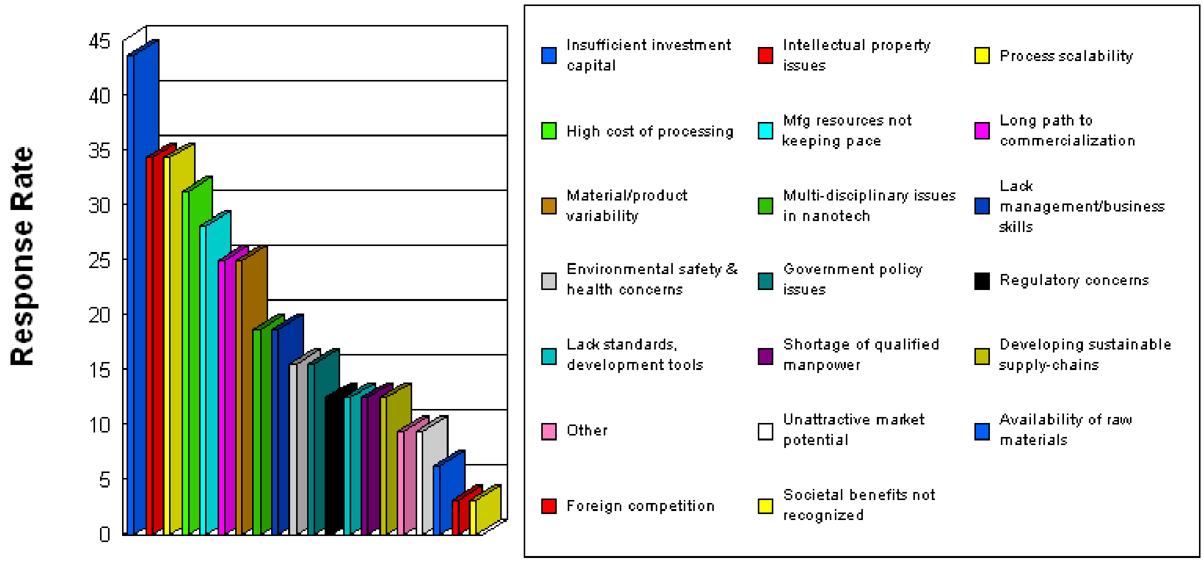

Figure 4-39. Profile of Commercialization Barriers in Organizations at Low-Medium TRL (TRL 3 = Proof-of-Concept Shown)

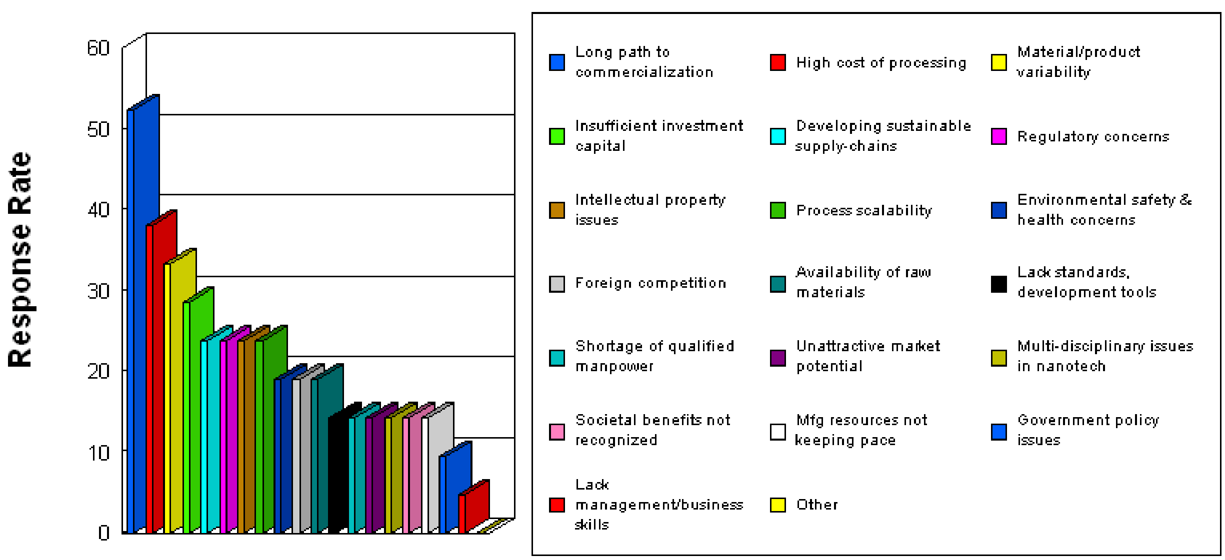

Figure 4-40. Profile of Commercialization Barriers in Organizations at Medium-High TRL (TR L6 = Prototype Demonstrated in Relevant Environment)

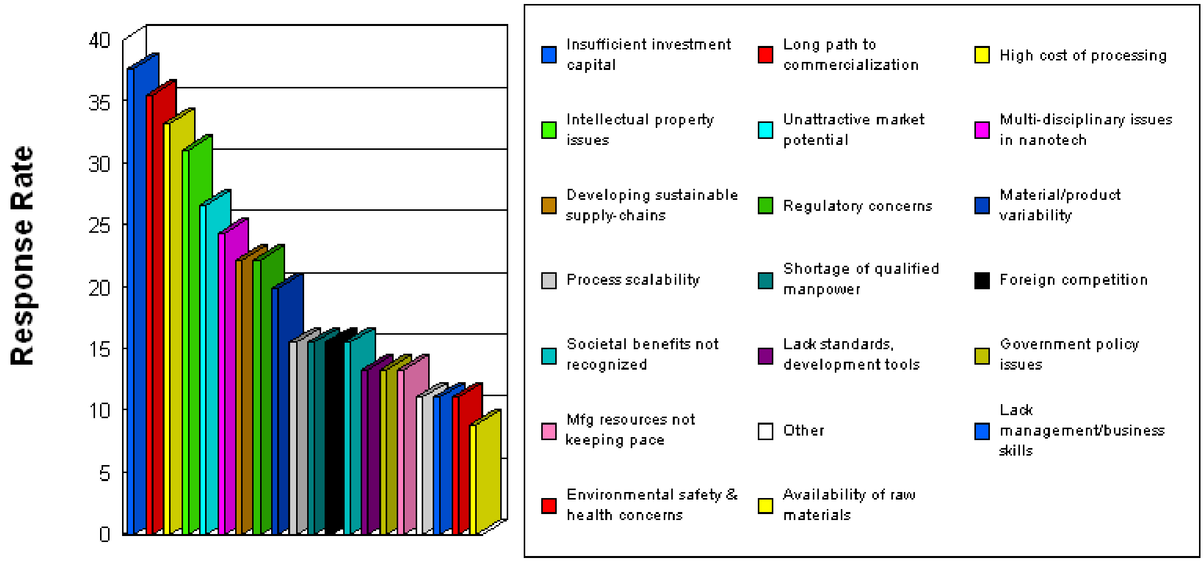

Figure 4-41. Profile of Commercialization Barriers in Organization at High TRL (TRL 9 = Final Product Validated in Production Environment)

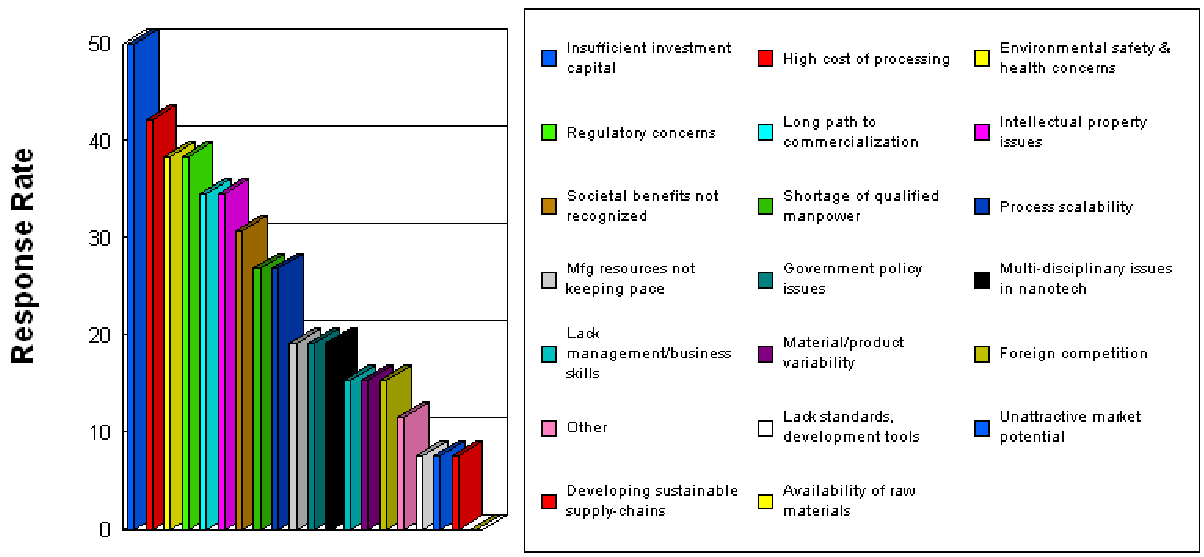

Figure 4-42. Profile of Commercialization Barriers in Organizations with Multiple Nanotechnology Products in Varying Development Stages and TRLs

4.15 Government's Role in Nanomanufacturing

The vast majority (88%) of respondents favor a strong government role in facilitating responsible development of nanotechnology. It is imperative that the U.S. government continue to fund cutting-edge R&D, as well as implement business-friendly policies that keep the nation unsurpassed in nanotechnology.

The successful commercial exploitation of nanotechnology is regarded as an enabler of immense techno-economic opportunity for U.S. industry, and is key to sustaining our technological leadership position. Nanotechnology innovations generated from knowledge spillovers and interactions with multiple sectors have high potential to create new economic opportunity, generate higher skill-level jobs and innovative products. To these ends, consistent public policies and long-term national strategies supporting responsible developments have a central role in facilitating a national environment conducive to a vibrant nanotechnology ecosystem.

Survey respondents were presented five different mutually exclusive scenarios describing an increasing role of the government in nanotechnology, and were asked to select the one best suited to their organizational goals and personal beliefs (Figure 4-43).

4.15.1 Aggregate Results

Figure 4-44 illustrates a pattern similar to trends seen in the 2003 and 2005 NCMS Industry Studies. The majority of respondents (over 80%) supported a significant government role in nanotechnology that consists of co-investments with private industry and strong incentives for entrepreneurship. This view was most preferentially indicated by executives in organizations addressing nanotechnology applications for multiple markets such as electronics/semiconductors, pharmaceutical/medical/biotechnology and energy and utilities.

A larger segment of respondents (11.5% vs. 5.56% in the 2005 Study) indicated they saw no significant role for government in nanotechnology. They were traced primarily to respondents in organizations pursuing nanotechnology for the electronics/semiconductor markets. This opinion can be attributed to the fact that well-capitalized large manufacturers of electronics and semiconductor industry are already working (often collaboratively) with world-leading nanofabrication technologies and established closed-loop processes – hence, they do not regard government involvement as being critical.

Of the 6% respondents favoring the government taking a greater leadership role in nanotechnology investments, the majority were from firms with staff sizes of 21-50 persons. Nanotechnology companies in this category are generally considered as established corporations, beyond early stage start-up, that have achieved viability and are seeking resources for the next phases of growth and development of advanced products. It is possible the respondents were reacting to the trend of reduced venture funds.

NCMS corroborated in executive interviews that this trend favoring an increasing government role as investor is indicative of industry's heightened concerns with erosion of competitive advantage and internal capacity for commercializing nanotechnology innovations during recessionary times. Other factors feeding this assertion include the growth of offshoring and decentralization of research, design, engineering and manufacturing operations in large corporations in favor of "open innovation" and globalization. McKinsey and Company[16] reported that organizations tried to weather the downturn and constrained resources by turning to shorter-term, lower risk projects, or by focusing on minor changes to existing products. The role of government is even more important during recessionary times, as it is possible that many companies may be overlooking longer-term opportunities to innovate.

Figure 4-43. Survey Question #15

[16] "Global Survey on R&D in the Downturn", McKinsey Online Journal, April 2009.

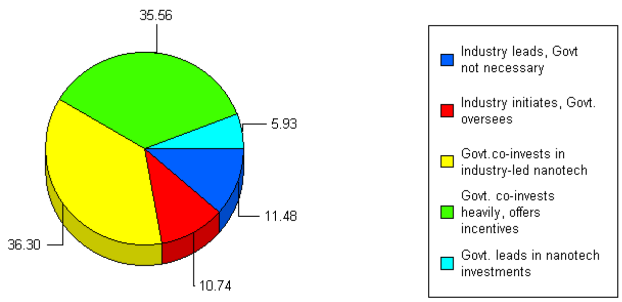

Figure 4-44. Aggregate Trends of Responses to Government's Role in Advancing Nanotechnology

Respondents were unanimous that government has a critical role in encouraging technology transfer and entrepreneurship to maximize the public benefit of massive NNI investments. The importance of federal programs such as SBIR, STTR, NIST-TIP and other federal agency initiatives cannot be overemphasized in view of uncertainties in the scope of pending financial legislation which may further stifle venture capital investments due to the increased financial reporting and accountability burdens.

Other contributing factors include the industry's urgent need for government leadership in formulating robust policies addressing nanotoxicity and environmental impact. Presently, the knowledgebase on potential interactions of nanomaterials and living systems are inconclusive and ambiguous. These issues merit the government's proactive role in neutrally facilitating "good science" studies by trusted organizations, and would help instill a high level of public confidence that this important industry is bringing products to the marketplace in a responsible manner.

Another critical area for expanded government leadership lies in expedited approval of new nanotechnology-enabled drug therapies, medical devices and pharmaceuticals – this can be accomplished by improved early communication and collaboration between developers and regulators to identify and mitigate product risks.

Promoting the development and adoption of standards for material systems, equipment, processing platforms and new measurement/characterization technologies is a critical function that the government can play in accelerating innovation and commercialization of nanotechnology, as these sustained efforts require long-term investments, dedicated manpower and extensive infrastructure.

Executives also favor the government's role in dissemination and educational programs that enhance the public's understanding and acceptance of nanotechnology. These can attract a steady supply of the nation's brightest students and yield a skilled workforce for the industry.

4.16 Barriers to Nanomanufacturing

Businesses commercializing nanotechnology face a number of technical, business, safety and regulatory challenges. The relative ranks of the top barriers were unchanged from previous NCMS industry surveys.

The successful commercialization of nanotechnology out of the laboratory and into the marketplace requires that corporations address many technical, business, regulatory and market challenges. The barriers faced by players in the nanotechnology and nanomanufacturing industry are unique, as the properties of matter at the nanoscale uniquely dictate specific behaviors and modalities in how the constituent raw materials, processing equipment, handling systems, and resulting enhanced products interact in order to achieve economies of scale for societal benefit.

The NCMS survey questionnaire listed 20 identified generic challenges (majority options were retained from the 2003 and 2005 NCMS Surveys). Respondents were asked to select the top five challenges specific to their industry sector (Figure 4-45).

Figure 4-45. Survey Question #16

4.16.1 Aggregate Results

In aggregate, the 270 respondents indicated key challenges which cluster at four distinct tiers or levels as shown in Figure 4-46.

The consensus top 10 industry barriers are:

1. Insufficient investment capital to finance nanotechnology developments for the marketplace
2. Long path to commercialization requiring patient capital
3. High cost of processing of nano-materials
4. Lack of process scalability to achieve economical high-volume manufacturing
5. IP issues
6. Regulatory concerns & uncertainty of federal policies inhibit supplier investments
7. Environmental, health and safety (EHS) issues are unresolved
8. Material/process variability result in poor reliability
9. Shortage of qualified manpower in nanotechnology
10. Multi-disciplinary issues and complexity of resources needed.

These general categories of barriers are consistent with recent NNI program assessments by the National Nanotechnology Assessment Panels, and the results of previous two NCMS

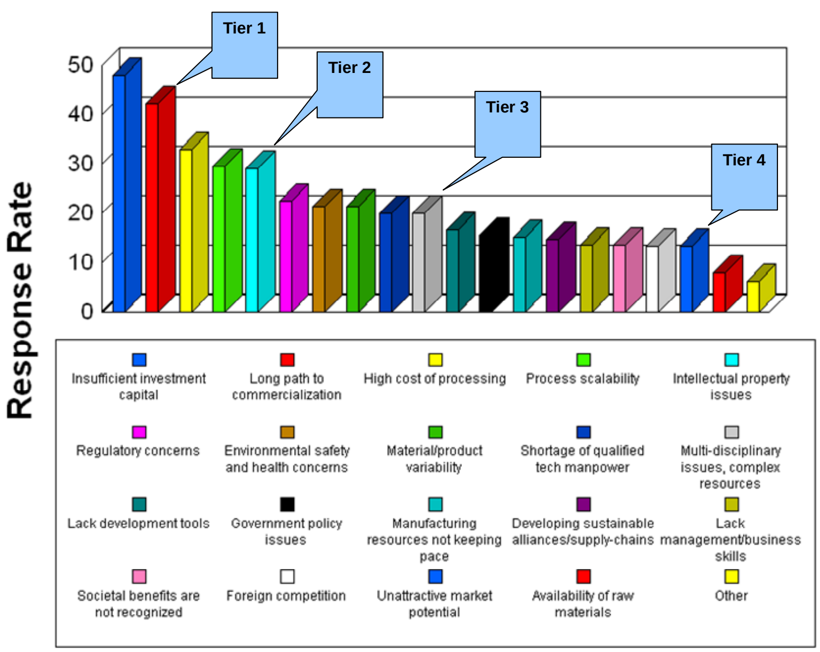

Figure 4-46. U.S. Nanotechnology Industry Faces Four Distinct Tiers or Groups of Barriers in Developing Market-Ready Nanotechnology Products

industry surveys. In the NCMS' latest rankings, the highest ranked aggregate barrier was insufficient investment capital for financing the development of nanotechnology-enabled products. The global financial and credit crisis triggering the recession of 2008-09 have been devastating to venture-financed entrepreneurship and spin-off of new nanotechnology companies, as reported by many other industry monitoring organizations. The economic slowdown also significantly impacted larger businesses, delaying commercial launch decisions due to the resulting credit crunch across the nanotechnology value-chains.

It was observed that regulatory concerns and environmental health and safety were slightly elevated in the ranking of top barriers over the 2005 NCMS Study results, indicating that (in aggregate), nanomanufacturing advances and higher readiness levels have prompted organizations to address issues related to production scale-up, safe handling practices and regulatory issues beyond the laboratory.

Industry sector differences were better accentuated when barrier selections were correlated by application markets, as summarized below:

- Organizations pursuing the nanotechnology equipment/tooling/manipulation developments tended to rank technology barriers higher than business concerns – i.e. factors such as shortage of qualified manpower, IP issues, EHS, process scalability and material/process variability.
- Aggregate players in the electronics/ semiconductors space cited the lack of investment capital, long commercialization timelines, high processing costs and IP issues.
- Aerospace industry organizations listed key barriers as: high processing costs, lack of capital, the shortage of qualified manpower, process scalability, material/process variability and supply-chain concerns.
- Organizations targeting the chemicals and process industry ranked regulatory concerns, multi-disciplinary challenges of nanotechnology and government policy as key barriers to commercialization.
- Organizations operating in the homeland security and defense industry applications ranked lack of investment capital, process scalability issues and lack of standards and predictive tools as important barriers.
- Energy conversion application developers ranked the lack of investment capital highest, followed by long commercialization timelines (due to involved approvals and certification cycles for transportation applications), IP issues, high processing costs, process yields/scalability and lack of sustainable supply-chains.
- Aggregate respondents pursuing pharma/medicine/biotechnology applications cited the lack of capital, long lead times and IP issues as key barriers, followed by high cost of processing, process scalability and regulatory concerns as secondary impediments. This order of ranking indicates that pharmaceutical and biomedical applications of nanotechnology are advancing but not yet market-ready.

4.17 U.S. Competitiveness in Nanotechnology

The U.S. presently leads the world in advancing nanotechnology, but over two-thirds (70%) of polled executives indicated the U.S. leadership is threatened by foreign competition in nearly every application sector.

This question was formulated to assess the U.S. Nanotechnology Industry's collective perceptions of its competitiveness on a global scale, and to facilitate analyses of application markets and nanotechnology product trends (Figure 4-47).

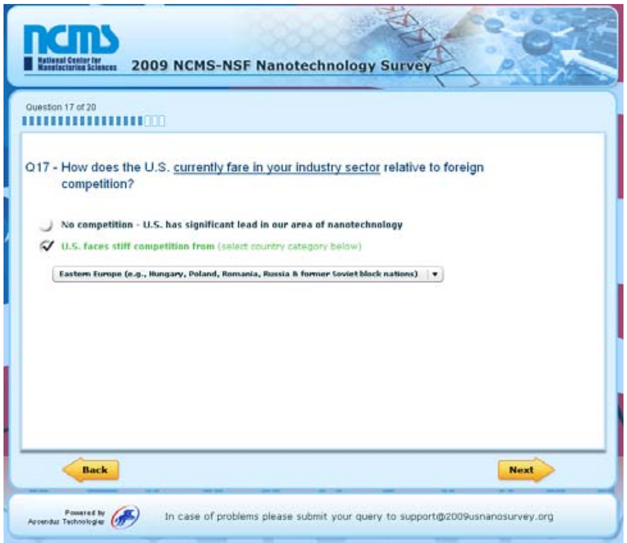

Figure 4-47. Survey Question #17

Respondents were initially asked to indicate whether or not the U.S. faces significant foreign competition in their respective sector of nanotechnology product and applications. Those indicating that significant foreign competition exists in their sector were then asked to select from a drop-down menu of seven world regions regarded as significant sources of competition to the U.S.

4.17.1 Aggregate Results

The distribution of 270 responses is shown in Figure 4-48, which illustrates that in aggregate, over two-thirds (189 respondents or 70% shown in the red bar graph) of polled executives indicated U.S. manufacturers face competition in their respective nanotechnology markets, while about 30% (81 respondents counted in the blue bar graph) feel the U.S. leads in their sector of nanotechnology applications. The competition was indicated primarily in nanomaterials/nanopowders, electronics/semiconductors and pharma/biomedical/biotechnology markets.

Further breakdown of data on two-third of the respondents (the red bar in Figure 4-48) is shown below:

- 39% indicated Developed Asia-Pacific (i.e. Japan, South Korea, Taiwan, Australia, Singapore) competes with the U.S. in products such as energy conversion/storage materials, coatings and thin-films, electronics, optics and displays incorporating nanotechnology or nanomaterials.
- 23% indicated Western Europe (e.g. Germany, United Kingdom, France, Spain, Switzerland) is competitive in products such as coatings and thin-films, energy conversion/storage materials, electronics and displays.
- 6% indicated Developing Asian Nations (e.g. China and India).
- 1.5% selected Eastern Europe (e.g. former Soviet block nations).

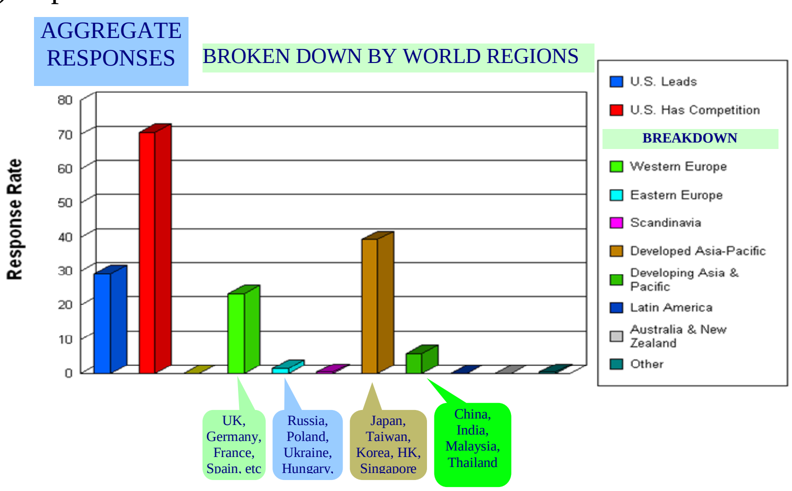

Figure 4-48. Sources of Foreign Competition in Nanotechnology as Indicated by Two-Thirds of All Respondents

A recent report by Lux Research[17] also corroborates these findings, stating that the U.S. faces stiff competition from industries based in these technologically strong nations whose governments have formulated progressive policies in energy efficiency and sustainability, and made aggressive investments in nanotechnology R&D, public education and workforce development.

4.18 Impact of Economic Recession

Four of five (80%) respondents indicated the economic recession of 2008-09 affected their organization's nanotechnology efforts to varying degrees; organizations that were involved in multiple partnerships appeared to weather the recession with lower levels of impact. The smallest organizations such as start-ups were affected the most.

This question was developed to determine if the severe business impact of the 2008-09 recessions extends across the nascent nanotechnology industry (Figure 4-49). Four impact categories were provided by NCMS in order to ascertain their relative assessments.

4.18.1 Aggregate Results

Figure 4-49 shows that at least four out of five respondents indicated the economic recession of 2008-09 affected their organization in some way. The impacts ranged from delayed product launches, to downsizing and cancellation of R&D programs. Less than 10% respondents felt their organizations had not been affected. The breakdowns by severity of impact are:

- 31% indicated Slight impact from the recession (i.e. organizations pursuing multiple end-uses/applications of nanotechnology, and aerospace)
- 32% indicated Significant impact on their organizations
- 26% indicated Substantial impact on their organizations (dominated by nanomaterials companies pursuing energy conversion and storage products, coatings/thin-films and electronics/semiconductors)
- 8.9% stated there was No impact experienced by their organizations (e.g. certain specialty nanomaterials producers, tool/equipment manufacturers, aerospace and pharma/medicine/biotechnology
- 2.2% listed Other types of impacts on their organizations.

While no specific nanotechnology application market was more affected by the ongoing recession over any other end-use market, the data trends show that organizations which had successfully reached out and collaborated with multiple partners appeared to be less impacted

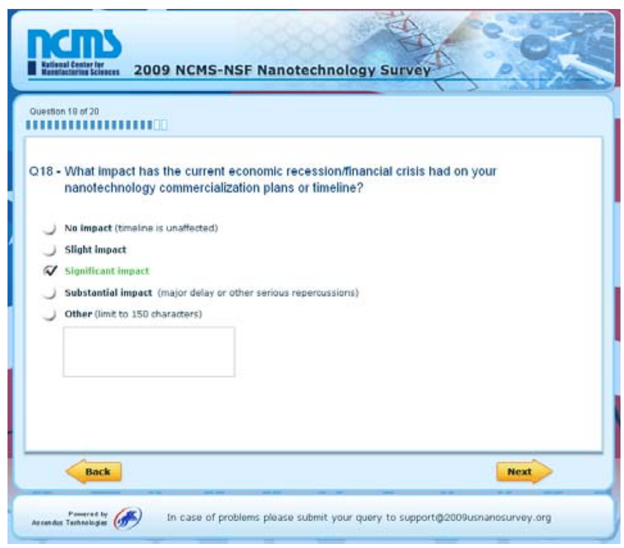

Figure 4-49. Survey Question #18

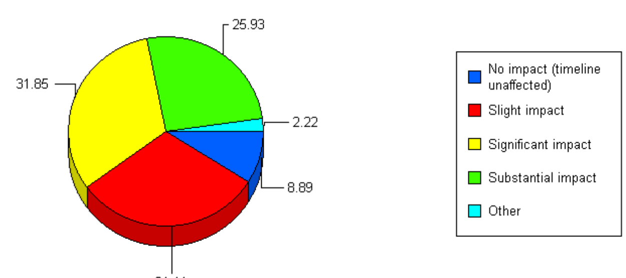

Figure 4-50. Aggregate Trends in Impact of Economic Recession on Nanotechnology Businesses

[17] Holman, M.W., "Nanotechnology: State of the Market Q1 2009," Section 4.2, Lux Research.

by the downturn, while those organizations which used strictly internal efforts or had partnered with a single entity tended to report higher levels of impact on their commercialization efforts. Aggregate trends are shown in Figures 4-51 and 4-52. Partnering with multiple value-adding entities helps an organization to both diversify and mitigate nanotechnology development and market risk.

Organization size had significant affect on the severity of impact due to the recession – the correlations between organization size and impact of recession were even more pronounced as seen in Figures 4-53 and 4-54. The resulting combination of pullbacks in institutional lending, business spending and VC investing have winnowed down the numbers and activities of start-ups in nanotechnology.

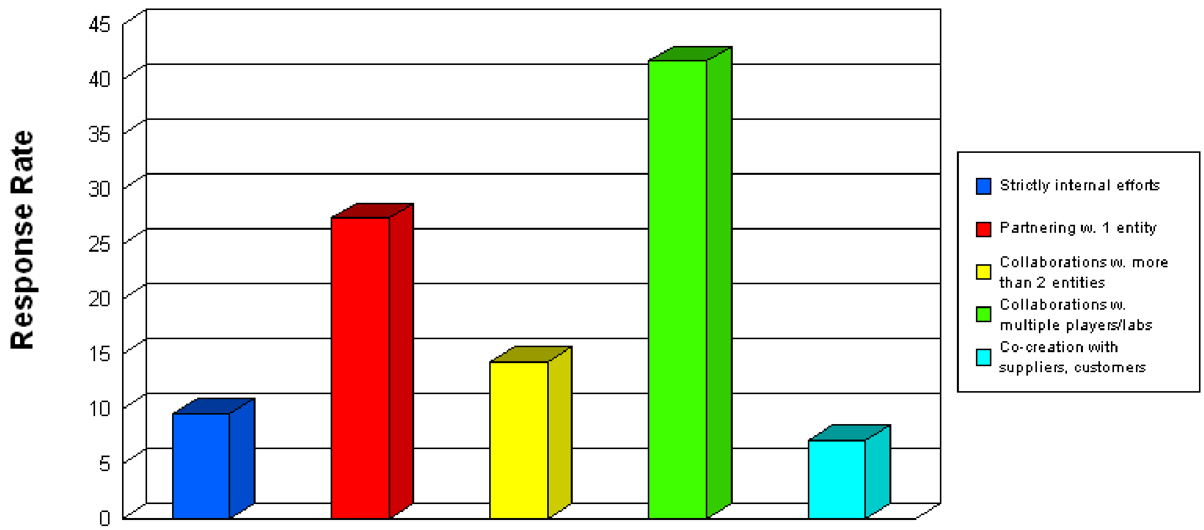

Figure 4-51. Collaboration Trends in Organizations Reporting Low Impact of Economic Recession on Nanotechnology Commercialization Programs

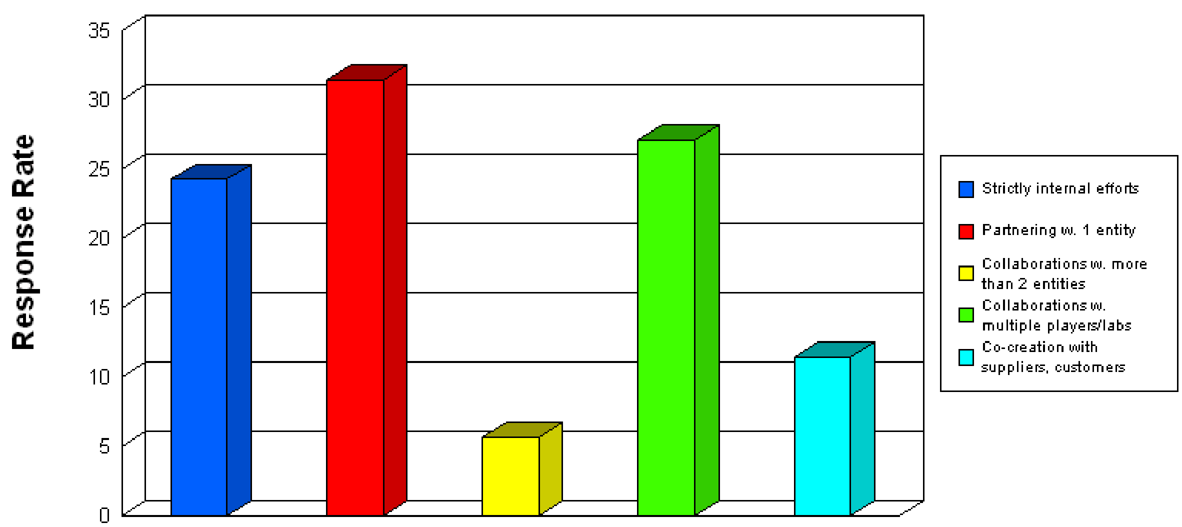

Figure 4-52. Organizations Reporting Collaborations with Fewer Entities Experienced Greater Impact from Economic Recession on Nanotechnology Commercialization Efforts

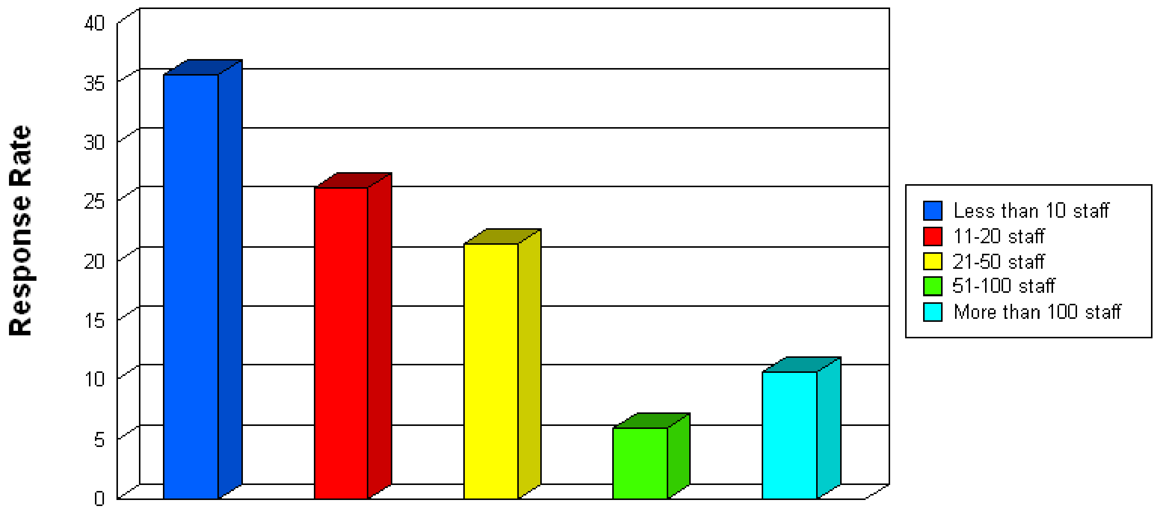

Figure 4-53. Breakdown of Staffing Trends in Organizations Reporting Slight Recession Impact on Nanotechnology Commercialization

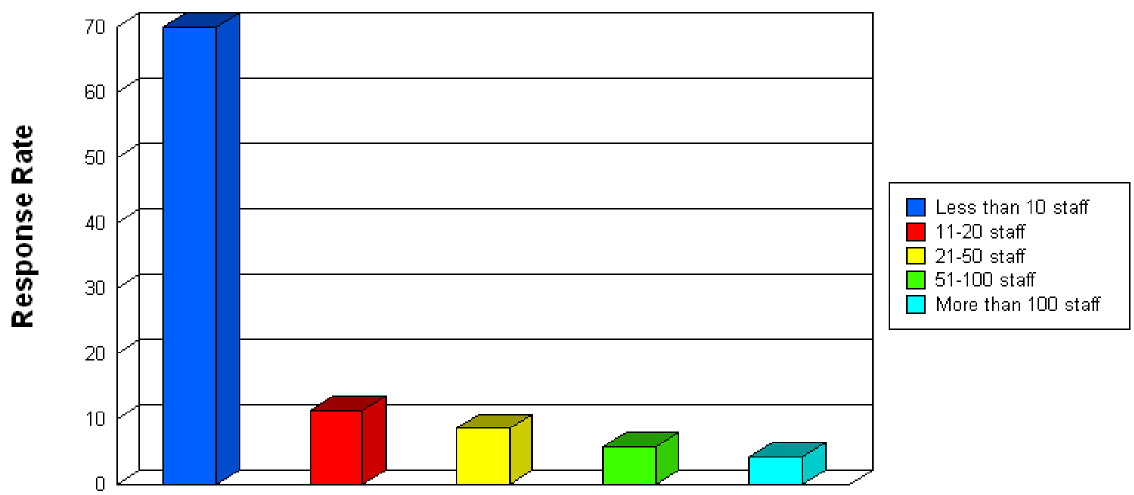

Figure 4-54. High Percentage of Start-ups Report Substantial Impact of the Economic Recession on Nanotechnology Commercialization Efforts

4.19 Near-Term Industry Outlook

Over half of the respondents (57%) indicated cautious optimism for the near-term outlook, anticipating improvements in the business climate and manufacturing. Nearly 40% expected to raise capital or increase employment in nanotechnology, while 20% respondents expected their organizations to contract in size, market-share or profit.

In the penultimate survey question, respondents were asked to predict up to three near-term scenarios (from a list of nine) they felt their respective organizations were most likely to experience in 2010 (Figure 4-55). The independent selection options ranged from optimism about potential improvements in their nanotechnology businesses, to pessimistic outcomes involving downsizing or closure of the business.

4.19.1 Aggregate Results

The pool of 270 respondents expressed cautious optimism about the near-term economic outlook over the one-year horizon for the U.S. economy and the growth scenarios for their organizations.

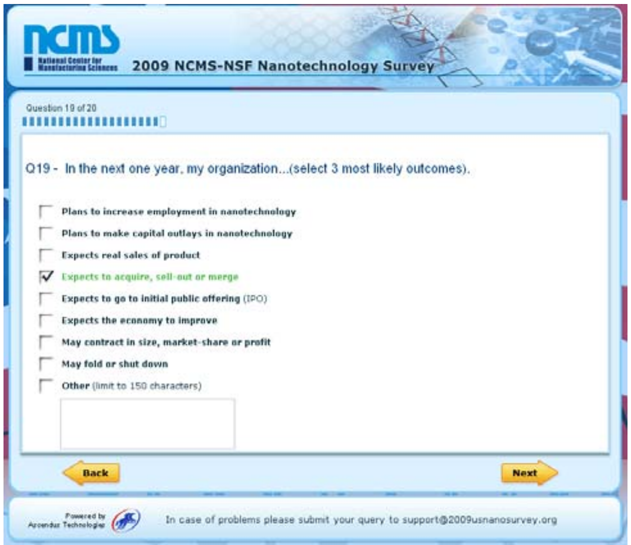

Figure 4-55. Survey Question #19

The aggregate results are shown in Figure 4-56 and discussed below:

- 57% expected the U.S. economy to improve
- 43% expected to increase employment in nanotechnology (responses were dominated by materials suppliers and research organizations aiming production-ready nanomaterials and technologies for the electronics/semiconductor, energy/utilities, pharma/medicine/biotechnology, aerospace and chemicals/process application markets)
- 38% expected to invest or raise capital in nanotechnology (i.e. the electronics/semiconductor, energy/utilities, pharma/medicine/biotechnology, aerospace, chemicals/process and homeland security/defense application markets for nanotechnology)
- 36% expected to achieve real sales of nanotechnology products (dominated by respondents from materials suppliers, manufacturers/integrators/assemblers and tool/equipment suppliers in nanotechnology)
- 20% respondents felt less optimistic about the economy and their businesses, indicating their organizations may contract in size, market-share or profit (respondents selecting this option were from organizations involved with test/measurement and raw materials supply in nanotechnology as well as academic groups anticipating R&D budget reductions)
- 11% expected to consolidate businesses by acquiring, selling-out or merging (primarily in test/measurement equipment supply, raw materials, intermediate processing and academic organizations)
- 7.4% selected Other
- 1% (3 respondents) indicated their organizations expected to achieve IPO status in 2010 (these were from the electronics/semiconductors, energy and automotive sectors).

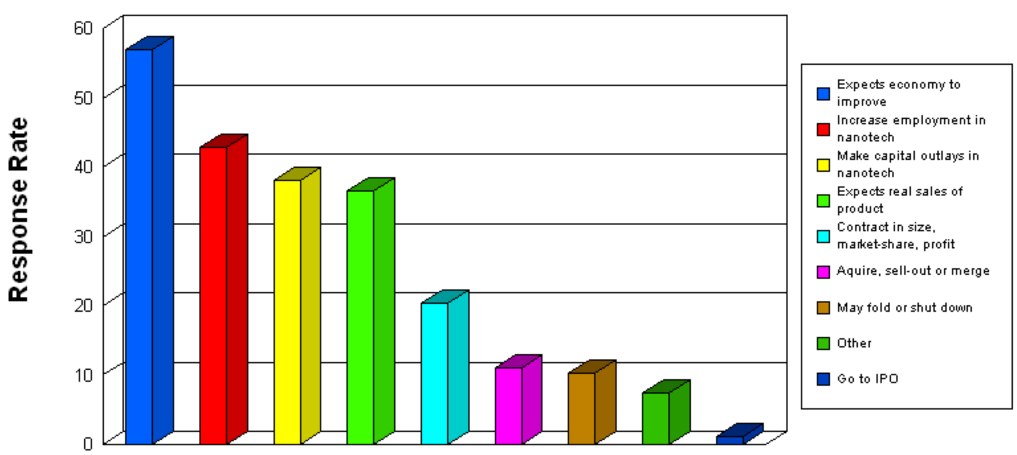

Figure 4-56. Range of Respondents' Predictions on Near-Term Outlook for Nanotechnology Organizations

4.20 Demographic Information

The 2009 NCMS Study attracted a representative and geographically diverse sample of respondents from all major states that have strong entrepreneurial infrastructure and are regarded as hub-locations for nanotechnology industry clusters.

In this final survey data collection screen (Figure 4-57), respondents were asked to indicate their location in the U.S., and also encouraged to provide their contact information and affiliation (primarily intended for notification of survey results and random authentication of responses).

4.20.1 Aggregate Results

The numerical list of 270 respondents broken down by states is shown below. Not surprisingly, California-based respondents were the highest single contributor to the NCMS nanotechnology industry database.

The top 15 states (i.e. states which contributed six or more respondents) include:

1. California (16.7%)
2. Illinois (7.8%)
3. Massachusetts (6.7%)
4. Texas (6.6%)
5. New Jersey (5.6%)
6. Ohio (5.2%)
7. Pennsylvania (4.8%)
8. Michigan (4.8%)
9. New York (3.7%)
10. Arizona (3.0%)
11. Virginia (3.0%)
12. Washington (2.6%)
13. Florida (2.6%)
14. Maryland (2.2%)
15. Georgia (2.2%).

Fewer than five executives (i.e. less than 2%) participated from nanotechnology organizations in 25 other states and the District of Columbia. There were no respondents from the following 10 states: Delaware, Idaho, Kansas, Maine, Nebraska, North Dakota, Tennessee, Vermont, West Virginia and Wyoming.

These survey findings agree closely with rankings of leading states for VC investments as presented under the NNI's Second Assessment and Recommendations[18], and the recent Nano Metro[19] Industry Concentration Study by the Woodrow Wilson Center's PEN, which found that California, Massachusetts, New York and Texas lead the nation in cluster-formation around nanotechnology research and commercialization. The PEN Study reported 1,200 nanotechnology organizations in the U.S. in August 2009 of which 955 are for-profit companies. Based on this relative scale, the 270 NCMS Survey responses on strategic nanotechnology commercialization issues indicate a 22.5% response rate.

Figure 4-57. Survey Question #20

[18] Table III-1in the NNI's Second Assessment and Recommendation by the National Nanotechnology Advisory Panel, organized under PCAST, April 2008.

[19] See http://www.nanotechproject.org/inventories/map/ - The PEN project defines *Nano Metros* as geographical areas containing more than fifteen industry, government and academic organizations, and tracks clustering trends in nanotechnology.

5. Conclusion

The 2009 NCMS Study of Nanotechnology in the U.S. Manufacturing Industry has concluded that nanotechnology is no longer a technology in waiting – a great breadth and diversity of nanotechnology products and application markets are being pursued with the potential for disruptive economic, social, environmental and military advantage. New product applications are being developed for the semiconductor, consumer electronics, energy generation/storage, chemical catalysis and pharma/biomedical/biotechnology application sectors that would eventually mature into nanotechnology-enabled products with greater sensory sophistication, predictive certainty, and autonomous functionality, advancing toward visionary applications and large-scale economic and societal impact.

The U.S. Nanomanufacturing Industry is innovating and cautiously introducing increasingly complex, integrated products incorporating nanotechnology in the form of functionalized nanomaterials and systems with greater uniformity. The path to achieve visionary products on large scales using directed self-assembly remains long and laden with many challenges. In addition to significant application-specific technology challenges, other critical commercialization factors such as funding, capital market uncertainties, legislative, safety and regulatory concerns, and a variety of business strategy and partnering issues greatly influence the long-term sustainability and viability of U.S. manufacturing organizations harnessing nanotechnology for competitive advantage. Therefore, the near-term impact of nanotechnology advances will continue to be fragmented and evolutionary rather than widespread and disruptive, partly due to the economic downturn, as well as longer-term concerns about unresolved safety, regulatory, and societal acceptance of nanotechnology.

Organizations pursuing nanotechnology increasingly recognize the benefits of collaboration beyond exploratory partnering, including co-development of nano-enabled macro-scale products. New online networks, social media channels and precompetitive R&D alliances are proliferating for pooling knowledge and encouraging best practices in nanotechnology.

These strategies will accelerate the introduction of these nanotechnology applications which are able to demonstrate differentiated superior performance over existing macro-scale products and systems at affordable cost. To achieve these goals with compressed lead times, nanotechnology entrepreneurs and business executives need to be constantly looking at new technologies, regulatory issues, economic forecasts and market trends to make the best judgments on collaboration and payoff on longer-term developments of complex nanotechnology products.

The NCMS Study indicates that the economic downturn and credit crunch put increased pressure on nanotechnology development programs, affecting nearly all players, large and small in North America. The recession has expedited consolidation in both, the start-up and venture financing communities involved with commercialization of nanotechnology. Weaker players have been weeded out, leaving stronger companies with more sustainable intellectual property and product portfolios, and hence greater viability for competing over the longer term in the global marketplace.

Appendix A – List of 2009 NCMS Survey Questions

2009 Survey Theme: Are U.S. nanotechnology businesses viable, competitive and sustainable in current economically turbulent times?

Q1 – What is your organization's primary role in commercializing nanotechnology?

- Materials Supplier (supplier of either nanoscale engineered or bulk materials)
- Intermediate Processor (convert nanomaterials into value-adding products or forms)
- Equipment Manufacturer (for handling/processing at the nanoscale)
- Component or Sub-system Supplier (of products incorporating nanotechnology)
- Manufacturer/Integrator/Assembler (of components or systems)
- End-user/Consumer (e.g. durable goods for aerospace, automotive, healthcare, energy, capital equipment, agriculture, machine-tools, military)
- Contract or Non-profit R&D organization
- Government Lab/Agency
- Academic Lab/Organization
- Other _________(limit to 25 words)

Q2 – Which title best describes your role in the organization?

- Senior Business Executive (President, CEO, GM, Sales, CIO, CFO)
- Senior Technical Executive (VP, CTO, R&D Manager)
- Scientific/Technical Staff (R&D, Engineering, Manufacturing)
- Non-technical Staff
- Consultant
- Other _________(limit to 25 words)

Q3 – What primary end-user markets/applications does your organization address?

- Equipment-Tooling/Logistics/Manipulation
- Electronics & Semiconductor
- Computing/IT/Telecommunications
- Aerospace
- Automotive
- Off-Highway, Shipping & Bulk Transportation
- Chemicals & Process
- Sensing/Environment
- Homeland Security & Defense
- Energy & Utilities
- Fabricated Products, Housing & Construction
- Machine-tool/Robotics/Automation
- Consumer Products, Cosmetics & Textiles
- Healthcare/Pharma/Biomedical/Biotechnology

- Food & Agriculture
- Mining & Materials Production
- Other ___________(limit to 25 words)

Q4 – How is your company/organization changing its strategy to commercialize, transition or incorporate nanotechnology(s)?

- 1 = Coping poorly
- 2
- 3
- 4
- 5 = Coping very well
- Don’t know

Q5 – Please rate your company’s urgency for commercializing nanotechnology advances into new products or processes.

- 1 = Low priority
- 2
- 3
- 4
- 5 = High priority
- Don’t know

Q6 – Please rate your company/organization’s overall capacity (capital, resources, manpower) for integrating nanomanufacturing technologies.

- 1 = Low capacity
- 2
- 3 = Just right
- 4
- 5 = High capacity
- Don’t know

Q7 – Please rate your company/organization’s infrastructure facilities for developing new nanomanufacturing technologies

- 1 = Deficient
- 2
- 3 = Adequate
- 4
- 5 = Abundant
- Don’t know

Q8 – Is your company/organization developing nanotechnology products internally or by partnering with external organizations? Please select the option that best describes your situation.

- 1 = Strictly internal efforts
- 2 = Partnering is usually with one entity at a time
- 3 = Collaborations involve more than two entities sharing costs and technology
- 4 = Collaborations often involve multiple players
- 5 = Co-creation is the norm, involving multiple suppliers and customer(s)

Q9 – Does your organization presently collaborate with any of the NNI's research centers, infrastructure networks and user facilities? Select from list of 6 options.

- NSF academic R&D centers
- DOE's nanotechnology centers and user facilities at national labs
- NIH networks/laboratories
- NIST user facilities/laboratories
- We have licensed technology from an NNI project/facility
- We have no interactions with any NNI facilities

Q10 – Is your nanotechnology product being developed in the U.S. or offshore?

- 1 = Designed and developed entirely in the U.S.
- 2 = Some development in offshore location(s)
- 3 = Significant development in offshore location
- 4 = Substantial development in offshore location
- 5 = Entirely developed in offshore location

Q11 – How many personnel are directly involved in your organization's nanotechnology commercialization activities?

- 1 = Less than 10 staff
- 2 = 11-20 staff
- 3 = 21-50 staff
- 4 = 51-100 staff
- 5 = More than 100 staff

Q12 – When does your company/organization expect to introduce nanotechnology products or processes on a commercial scale?

- 1 = Already deploying nanotech products/processes
- 2 = Within 1 year
- 3 = Between 1-3 years
- 4 = Between 3-5 years

- 5 = More than 5 years to market

Q13 – What types of products incorporating nanotechnology have been commercialized or are being developed in your organization?

- Nanoparticulates & Nanopowders
- Coatings, Paints & Thin-films
- Biomarkers & Q-Dots
- Semiconductors, Nanowires, Lithography & Print Products
- Drug Delivery, Diagnostic Systems & Medical Implants
- Nano-Bio & Tissue Engineering Products
- Personal Care, Nanofluids & Colloids
- Catalysis, Battery, Fuel Cell & Energetics
- Nanofluidics & Filtration Products
- Transportation & Structural Products
- Environmental Sensing & Remediation Products
- Defense, Security & Protective Gear
- Electronic Devices, Displays & Optoelectronics
- Nano-Manipulation, Imaging & Visualization Tools
- Computing, Design & Software Tools
- Convergence Products (Nano-Bio-IT-Cognitive)
- Other_______ (limit to 25 words)

Q14 – Select the Technology Readiness (TRL) Level that best describes your organization's nanotechnology product/process developments:

- TRL 1 = Basic principles observed and reported in peer-reviewed publication
- TRL 2 = Technology concept or application formulated and documented
- TRL 3 = Analytical and/or experimental critical function or proof-of-concept shown
- TRL 4 = Component or breadboard validation in laboratory
- TRL 5 = Validation in a relevant environment
- TRL 6 = Prototype demonstration in a relevant environment
- TRL 7 = Test performance agrees with analytical predictions/design
- TRL 8 = Actual system completed and qualified via test and demonstration
- TRL 9 = Final product successfully operated in actual application
- Other ________(limit to 25 words)

Q15 – What is your opinion regarding the government's role in development of nanotechnologies? Select <u>one</u> option.

- 1 = Industry leads developments, Government involvement is not necessary
- 2 = Industry takes the initiative and Govt. oversees the nanotech industry
- 3 = Govt. should co-invest in industry-led nanotechnology developments
- 4 = Govt. should co-invest heavily & offer strong incentives to industry

- 5 = Govt. should assume majority of risk in nanotechnology investments

Q16 – What are the key challenges facing organizations in <u>your sector</u> of the nanomanufacturing industry? Rank your top 5 challenges, 1 being highest priority.

- High cost of processing
- Insufficient investment capital
- Environmental safety and health concerns
- Regulatory concerns
- Process scalability
- Material/product variability
- Availability of raw materials
- Lack of development tools
- Manufacturing resources not in pace with developments
- Developing sustainable alliances/supply-chains
- Shortage of qualified technical manpower
- Lack of qualified management/business skills
- Foreign competition
- Government policy issues
- Intellectual property issues
- Unattractive market potential
- Multi-disciplinary aspects impose complex resource needs
- Long path to commercialization
- Societal benefits of nanotechnology are not recognized
- Other ________(limit to 25 words)

Q17 – How does the U.S. <u>fare in your industry sector</u> relative to the competition?

- No competition – U.S. has significant lead in our area of nanotechnology
- U.S. faces stiff competition from < __________> (pick from list of 8 world regions)

Q18 – What impact has the current economic recession/financial crisis had on your nanotechnology commercialization plans or timeline?

- 1 = No impact (timeline is unaffected)
- 2 = Slight impact (up to 1 year delay)
- 3 = Significant impact (1-3 year delay)
- 4 = Substantial impact (major delay or other serious repercussions)
- Other __________(limit to 25 words)

Q19 – In the next one year, my organization…(select and rank 1-3 most likely outcomes from the following statements):

- Plans to increase employment in nanotechnology

- Plans to make capital outlays in nanotechnology
- Expects *real* sales of product
- Expects to acquire, sell-out or merge
- Expects to go to initial public offering (IPO)
- Expects the economy to improve
- May contract in size, market-share or profit
- May fold or shut down
- Other __________(limit to 25 words)

Q20 – For notification of the survey results and to download the 2006 NCMS Survey Report, please provide your contact information below. Your comments and feedback on this survey project are welcomed – please type them in the box (less than 50 words); Asterisk * indicates mandatory data field.

*Your Location (U.S. State):

Your Name: _______________
Organization: ______________
E-mail: _____________Comments/Feedback: _______________(limit to 50 words).