2005 NCMS Survey of Nanotechnology in the U.S. Manufacturing Industry

(Sponsored by NSF)

Abstract

March 6, 2006

NSF Award DMI -0450666/Prepared by:

National Center for Manufacturing Sciences
3025 Boardwalk
Ann Arbor, MI 48108-3230

www.ncms.org

National Center for Manufacturing Sciences

Acknowledgments

The NCMS gratefully acknowledges the sponsorship of the National Science Foundation (Award # DMI-0450666), as well as the guidance received from Dr. Mike Roco, Senior Advisor for Nanotechnology, and Mr. Kevin Lyons, Program Director, Nanomanufacturing. Our thanks are also due to Ascendus Technologies for survey design, Small Times Media LLC, and all organizations associated with dissemination of the survey, as well as to the nearly 600 survey respondents and interviewees for their time and valuable insights.

Definition of Nanomanufacturing

Nanomanufacturing is defined as the controllable, large-scale manipulation of matter at the nanoscale (0.1 to 100 nanometers), to produce identical value-added components and devices. When the dimensional scales of materials and molecular systems approach the nanoscale, the conventional rules governing their behavior change significantly. The rapidly improving capability to manipulate matter at the atomic and molecular scales has already resulted in several first generation nanotechnology (popularly referred to as passive nanotechnology) applications and product enhancements. Research and development efforts are underway internationally to develop active (second generation nanotechnology) sensors, actuators and communications devices with more complex, engineered three-dimensional nanostructures, including the capability to link across biological interfaces. Over the next decade or two, these products are expected to be able to selectively sense, integrate and self-assemble at the nanoscale with other revolutionary atomic and molecular sub-assemblies to form third and fourth generation nanotechnology systems with visionary societal implications.

About NCMS

The National Center for Manufacturing Sciences (NCMS) is a not-for-profit organization, based in Ann Arbor, MI, and is a premier provider of collaborative research, information, knowledge and expertise to the North American manufacturing and defense community. Now in its 20th year, NCMS has spearheaded numerous advancements – in advanced materials, alternative energy, electronics, high-performance machining, process control, rapid prototyping, lean manufacturing, enterprise integration, information technology, and environmental conscientiousness – all focused on enhancing the nation's manufacturing competitiveness in the global economy,

Contact Information:

Manish Mehta, Ph.D.
Principal Investigator, NCMS Survey of Nanotechnology
Executive Director, Industry Forums
NCMS
3025 Boardwalk Drive
Ann Arbor, MI 48108
Tel: (734) 995-4938
Fax: (734) 995-1150
E-mail: manishm@ncms.org
http://www.ncms.org.

1. Nanomanufacturing Industry Survey

1.1 Background

In 2005, the National Science Foundation (NSF) awarded a grant to the National Center for Manufacturing Sciences (NCMS) to poll over 6,000 senior-level executives in leading U.S. organizations with leadership, technology or strategic research and development (R&D) responsibility to assess the outcome of growing private and public investments made in nanotechnology under the National Nanotechnology Initiative (NNI). The overarching objective in conducting this largest known cross-industry benchmark study was to determine whether surveyed organizations treat nanotechnology differently from any other generation of advanced science and technology. The metric established by NSF was 300 survey responses to develop a credible profile – the survey netted 594 completed responses, representing a response rate of 10%.

1.2 Aggregate Observations

The NCMS survey of nearly 600 industry executives indicates that the state of the U.S. Nanomanufacturing Industry is generally vital, innovative and competitive for demonstrated passive nanotechnology products with many two-dimensional product applications growing rapidly for end-uses across diverse industry sectors. The survey confirms that the U.S. has the best-developed and mature research facilities, entrepreneurial culture and governance infrastructure for promoting new nanotechnology-driven economic development.

Besides the numerous entrepreneurial startups and small businesses (often led by researchers with academic or government laboratory connections), many larger manufacturers of conventional industrial materials and products as well as OEMs and end users, have begun to pursue internal research, actively seek new technologies, and partner in order to evaluate the potential for incorporating nanotechnology in differentiating their current product lines. Some of the world's largest manufacturing organizations are actively developing their own pipelines and strategies for future products by adopting the specialized techniques to leverage risks and penetrate new markets with nanotechnology. Corporate partnering is critical for embryonic nanotechnology businesses to attain growth and viability; it begins anywhere from peer relationships to technology co-development and co-marketing, to culmination in merger and acquisition.

The survey found that organizations are proceeding cautiously in the development and commercialization of innovations such as active three-dimensional nanotechnology products that involve more direct human, societal and environmental impact. The nanomanufacturing industry for second generation (potentially disruptive) nanotechnology products is still in its infancy – there are as yet no commercial devices based on true nanotechnology. The challenges facing the industry are not limited to the technology itself – rather, factors such as funding, commercialization strategies, regulation and a variety of socio-business issues will affect the long-term success of organizations entering this domain.

Due to the cross-disciplinary nature and broad societal implications of nanotechnology, few organizations possess the vertical integration needed to rapidly commercialize the envisioned second generation nanoproducts from conception to consumption. While there is much exploratory partnering and co-development within the industry, it will accelerate when the early nanotechnology applications crossing the "valley-of-death" are able to demonstrate unquestionably superior performance of existing macro-scale products and systems at affordable cost, improved margins and higher reliability.

Large-scale, market-driven investments have been somewhat inhibited due to the lack of broader, in-depth understanding of nanotechnology's complex material-process-property phenomena and its interactions with humans and the environment. These issues uphold the perception of uncertainty and long lead times in the industry. Therefore, the near-term impact of nanotechnology is likely to be fragmented, product-specific and evolutionary rather than revolutionary. The distillation of survey trends and executive attitudes indicates that while new applications will grow in the near-term largely by entrepreneurial means (e.g. technology push to seek niche applications), the longer-term growth of a nanomanufacturing venture would depend on the organization's core competency to vertically integrate and partner with end users on the basis of platform nanotechnologies as well as its ability to meet defined performance objectives (i.e. market pull factors) that help meet the customers' bottom-line.

1.2.1 Diverse Nanotechnology Products in Development

Aggregate survey responses indicated that the U.S. Pacific region leads the nation in development of diverse nanotechnology products and application markets that are being pursued for potentially disruptive economic, social, environmental and military advantage (Figure 1). The U.S. leads the world in the generation and commercialization of nanoscale materials, manipulation tools and measurement innovations being applied to initially benefit the consumer products, digital storage, photovoltaic and semiconductor manufacturing industries. Myriad new applications of advanced nanocoatings, nanofilms and nanoparticles are being developed for introduction in the near-term (3-5 years) on a broader range of durable goods, consumer electronics and medical products (Figure 2). Nanoproduct applications are also being developed for the next generation semiconductor, energy, chemical catalysis and pharmaceutical/biomedical products. These would eventually mature into convergence products with higher sensory complexity, self-assembly and autonomous functionality, offering greater potentials for achieving the envisioned economic and societal impact.

1.2.2 Increased Corporate and Public Awareness

Traditional manufacturing organizations, while interested in adopting nanotechnology, tend to be preoccupied with issues of short-term profitability and other approaches that prioritize returns and revenues over long-term growth (such as innovation and skills development). Recent pronouncements of the importance of nanotechnology herald a significant change in corporate and National attitudes. For prepared organizations, these trends represent new opportunity for paradigm shifts in change management to drive innovations for superior product lines, and realize improved investment returns on a global scale.

These positive trends are attributed in large part to the substantial seed investments, leadership and outreach efforts made by the NNI through R&D undertaken across academia, small and large businesses and the National Laboratory infrastructure. Concurrently, the increased branding of leading-edge consumer products and coining of science fiction terms with "nano" have also raised societal awareness, albeit with mixed results. They have the longer-term impact of preparing both, a new generation of knowledge workers and informed consumers.

Survey respondents unanimously indicated that sustained government sponsorship is essential to attract the attention of senior manufacturing industry executives, investors, media and the public. Government support will expedite improved fundamental understanding of nanotechnology and further clarify its potential, while fostering both, early markets and entrepreneurship towards the more advanced generation product applications.

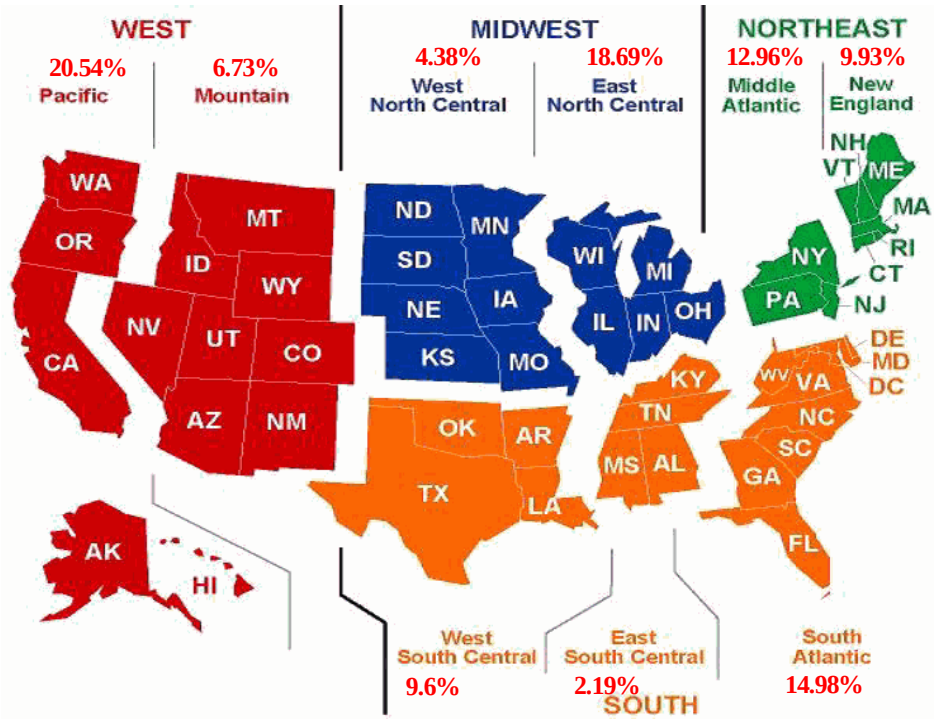

Figure 1. Geographical Distribution of 594 Respondents Corresponds Closely with Major Public Investments in Nanotechnology

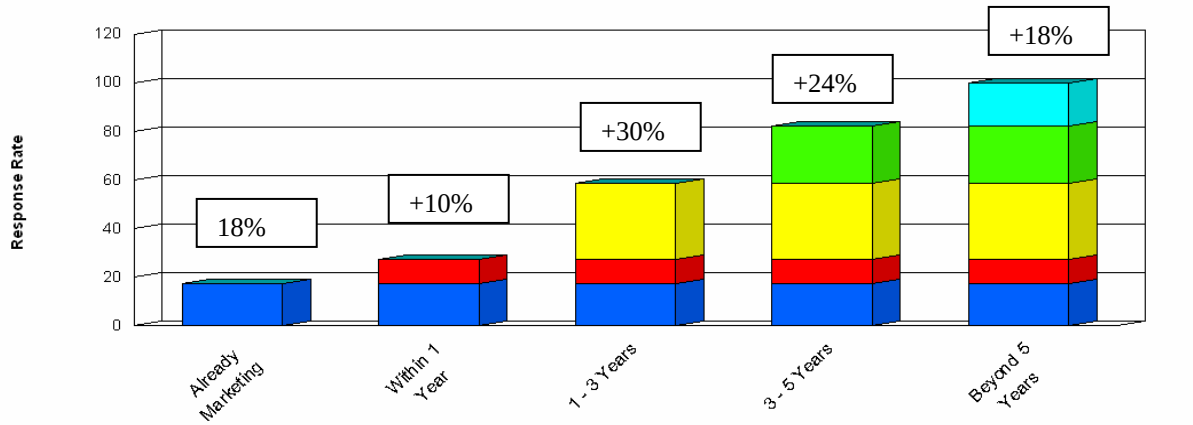

Figure 2. Commercialization Timelines Indicate Many New Nanoproducts Introductions in 2007-2011

1.3 Key Industry Barriers

The majority of the surveyed executives indicated their organizations faced considerable difficulty in nanomanufacturing, ranging from emergent technology issues, to raising capital for critical infrastructure investments, attracting the technical and business talent, connecting with early end-users, and producing competitively to meet new market applications and volumes.

Intellectual property issues and the sharing of knowledge were identified as areas of signifi-

cant concern, as well as the lack of clear regulatory policy, which could impede industry, and impact the public's reaction to future product developments. The continued education of the public and the key policy makers (State and Federal), government agencies and legislative bodies regarding these issues will result in clearer product approval pathways, robust standards and responsible practices, and thereby help ensure the continued dominance of the U.S.

While the nanomanufacturing industry faces unique challenges, similarities do exist with other recent technology waves such as the Internet and biotechnology, offering many lessons learned for formulation of sound anticipatory approaches. The answers to addressing the top-ranked challenges lie in continuing the aggressive National R&D policies for pursuing targeted investigations in fundamental nanoscale science, engineering and manufacturing technology. NCMS recommends several approaches for addressing the technology and business needs of the U.S. Nanomanufacturing Industry, while responsibly accelerating the benefits of new or enhanced products for societal benefit. NCMS further recommends the reclassification of the conventional definition of "small" business, as many of the largest organizations working with nanotechnologies would be considered small businesses by traditional industry standards. The following three broad re-classifications are suggested in addressing the unique needs of current generation of nanotechnology businesses:

- Small nanotechnology businesses (less than 20 staff)
- Medium nanotechnology businesses (21 – 100 staff)
- Large nanotechnology businesses (over 100 staff).

Table 1 lists several approaches and National strategies for addressing clusters of identified barriers to the nanomanufacturing industry.

Table 1. Strategies to Address Critical Identified Barriers Faced by the U.S. Nanomanufacturing Industry

INDUSTRY BARRIER(S)	RECOMMENDATION(S)
High cost of processing/ Process scalability issues/ Lack of development tools	▪ Collaborative R&D in value-chains ▪ R&D to reduce/combine process steps ▪ R&D in new equipment and to improve product yields
Long time-to-market/ Unclear societal benefits	▪ Government incentives for private R&D investments ▪ Raise public awareness of benefits via successes ▪ Promote supplier-end user partnerships
Insufficient investment capital	▪ Government investment in pre-competitive R&D ▪ Stimulate market pull via end users ▪ Mentor startups for attracting investment
Intellectual property issues	▪ New business models for nanotech value-chains ▪ Legal reform, train legal and judicial professionals ▪ Streamline partnering with academia and National Labs ▪ Facilitate supplier-end user partnerships
Shortage of qualified manpower/ Multi-disciplinary aspects	▪ Retrain tech workforce in basic science/testing/quality ▪ Attract students to science and engineering careers
Regulatory and safety concerns/ Environmental and toxicity issues	▪ Streamline permit/product approvals at agencies ▪ Increase government-sponsored R&D ▪ Broader dissemination of findings ▪ Balanced legislation and regulatory practices

2. Recommended National Priorities for the Near Term

2.1 Accelerating Nanotechnology Developments

Critical investment-, business- and regulation-related issues need to be addressed concurrently and collaboratively by State and Federal policy-makers in order to maintain the current high momentum of innovation in nanotechnology advances. Long-term policies for National investment and the stimulation of public-private-academic partnerships are imperative for developing the fundamental science base, facilitating technology transition to applied research, and demonstrating credible nanotechnology-enabled applications that are perceived as meaningful to our quality of life. The potential risks and hazards associated with the more revolutionary envisioned nanotechnology applications need to be assessed and disseminated by trusted sources to raise the public's awareness, and thereby gain societal confidence. Strong incentives will help resulting innovations become swiftly translated into industry-led technology demonstrations that enhance the public's awareness and acceptance. This will require dramatic changes in business strategy and unprecedented levels of public-private regulatory collaborations to responsibly commercialize future nanoproduct applications. Such levels of integration do not presently exist.

2.2 Government-Led Public-Private Collaborations

It is unlikely that the vast field of nanotechnology would reach the levels of maturity (like other traditional physical science-based industries did) within our lifetimes. This justifies the case for greater government investment in nanotechnology. Private and institutional investments can grow faster when some of the fundamental technical issues of process scalability and cost of production of new nano-components as well as associated risks have been more comprehensively addressed. Collaborative R&D and targeted technology demonstrations would also help scope the potential economic returns across nanotechnology value-chains.

Government can lead by defining and funding National priorities, and creating meaningful incentives for early industrial adopters of nanotechnology, in order to accelerate the broad-based translation of nanotechnology advances across multiple industry sectors. Public-private collaborations in applied nanotechnology will hasten societal support when targeted towards nearer-term National concerns such as:

- Increasing productivity and profitability in manufacturing
- Improving energy resources and utilization
- Reducing environmental impact
- Enhancing healthcare with better pharmaceuticals
- Improving agriculture and food production
- Expanding the capabilities of computational and information technologies.

Areas where government involvement in nanotechnology can have high National impact while leveraging substantially larger private investments include:

1. Incentives favoring longer-term investments (e.g. tax-free bonds for financing, tax credits for capital investments, reduced capital gains tax rates, investment-specific loan guarantees, etc.)
2. Promoting and streamlining strategic alliances for businesses and researchers with larger players or end users
3. Providing mentorship and business planning assistance to small businesses to identify key technology benefits and attract private capital

4. Underwriting and disseminating “good science” research and public education into the long-term issues related to waste disposal, safety and regulations
5. Undertaking tort and legal reform which will provide developers greater immunity and protection once their products are Federally approved.

State governments and economic development bodies could assist small and large businesses link up in neutral environments by promoting leverage of nano-incubator and user facilities. By working with university and National Laboratory technology transfer organizations, they could facilitate simpler access to nano-technology resources and training available in educational institutions, thereby stimulating new partnerships with entrepreneurs. Offering matching funds and other seed incentives to organizations pursuing Federal nanotechnology programs would provide further impetus for businesses and researchers to partner in commercialization ventures. Several progressive U.S. states have already initiated these next-generation technology partnerships.

3. Strategic U.S. Industry Indicators and Summary Trends

3.1 Geographical Profile

The geographical distribution of 594 respondents, illustrated by U.S. Census regions, generally correlated well with the U.S. regions receiving the highest infusion of NNI funds[1] and other private investments, and agreed with the Small Times annual ranking[2] of leading U.S. regions reporting the highest levels of commercial activity in nanotechnology (Figure 1). Predictably, the Pacific regions represented the largest proportion (20.5%), considering that the electronics and semiconductor industry has been at the cutting edge of nanoscale science and engineering for several years, and the region is the single largest adopter of nanomanufacturing techniques. This was followed by respondents in the East North Central regions (18.7%), South Atlantic (15%), Mid-Atlantic (13%), New England (9.9%) and West South Central (9.6%).

3.2 Major Players in Nanomanufacturing

Over half of the 594 respondents indicated their organizations were directly involved in nanomanufacturing developments, either as end-users (OEMs), manufacturer-integrators or component suppliers.

- A high proportion of educational and R&D facilities are involved in the development of nanomanufacturing technologies (Figure 3).

3.3 Nanotechnology Products

Diverse products incorporating nanotechnology are in varying stages of development and commercialization.

- The top passive nanotechnology products already commercialized or soon-to-be commercialized in the foreseeable future (up to three years out), comprise higher precision materials, tools and devices for enhanced manufactured goods, equipment and sub-components such as:
  - Semiconductors, nanowires, lithography and print products
  - Nanostructured particulates and nanotubes
  - Coatings, paints, thin films, and nanoparticles
  - Defense, security and protection gear
  - Telecommunications, displays and optoelectronics products.
- A greater diversity of nanotechnology products are in development in organizations in the Pacific, New England, Mid-Atlantic and South Atlantic regions.

3.4 Nanomanufacturing Application Markets

Nanotechnology developments are being targeted for use in diverse industry sectors – the top application markets for nanotechnology products are:

- 52% Equipment, Logistics and Distribution
- 46% Electronics and Semiconductors
- 46% Computing, Information Technology and Telecommunications
- 38% Aerospace
- 34% Automotive
- 33 % Chemicals and Process Industries

Figure 4 provides a graphic representation.

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[1] Roco, M.C., "Nanoscale Science and Engineering at NSF," Proceedings of 2005 NSF Nanoscale Science and Engineering Grantees Conference, December 12-15, 2005, Arlington, VA.

[2] Stuart, C., "Annual Ranking of Small Tech: Only One First Place But Many Winners," Small Times, March 14, 2005.

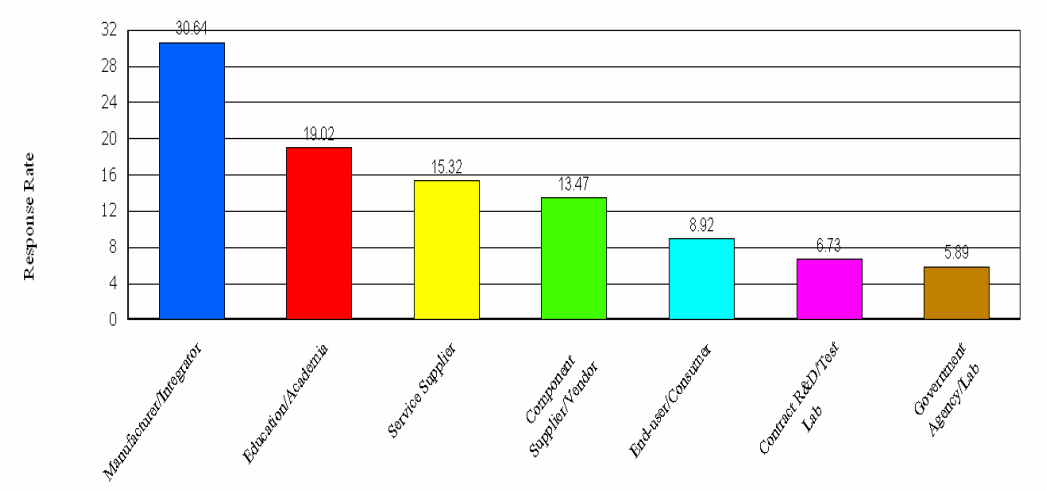

Figure 3. Respondents' Roles in the U.S. Nanomanufacturing Value-Chain

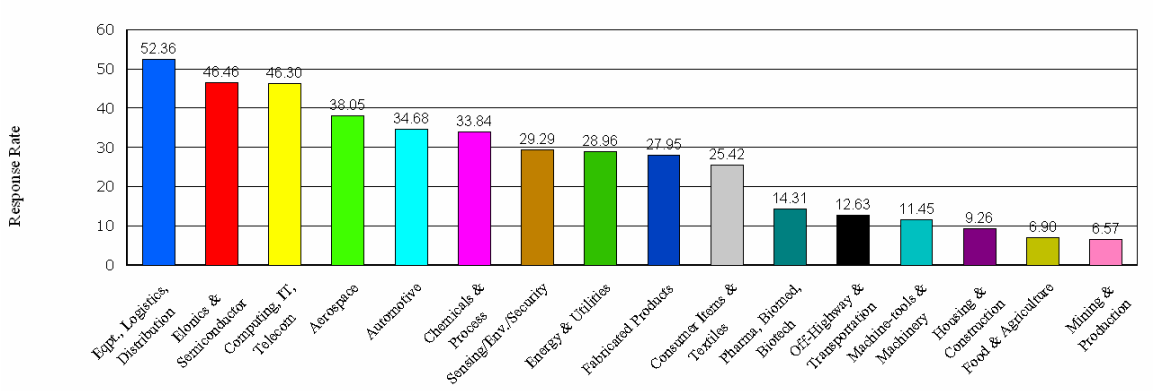

Figure 4. Nanotechnology Developments Being Targeted for Use in Diverse Industry Sectors

3.5 Corporate Urgency

Management attitudes are changing – medium and large organizations (50 or more staff) place a higher priority on commercialization of nanotechnology.

- 52% of the aggregate respondents stated nanomanufacturing is considered a High priority for development in their organizations, while about 20% indicated Low priority (dominated from East North Central and New England regions).

3.6 Change Management

Majority of medium and large nanotechnology organizations (50 staff or higher) were coping relatively well with adopting new commercialization strategies and technology management approaches, but smaller organizations reported greater difficulty in coping with market and business changes.

- Nearly one-fifth of the respondents indicated serious concerns. About 25% of the respondents from the East North Central region and 19% from the West North Central region stated their organizations were coping poorly.

3.7 Organization Capacity

Increasing numbers of senior executives in the conventional U.S. Manufacturing Industry have begun examining the potential of nanotechnology to take their organizations into new growth phases, product directions and markets, and translating this interest into R&D partnerships, procurement or acquisition of new nanotechnology development resources.

- About 70% of aggregate respondents reported Medium to High levels of organizational capacity to pursue nanomanufacturing.

3.8 Internal Infrastructure

Nanotechnology infrastructure is unevenly distributed across the U.S. and in its utilization by various industry sectors – additional specialty tools and targeted facility investments are needed in the private sector.

- Aggregate respondents were equally divided in rating the adequacy of their available infrastructure (ultra-clean rooms, laboratory space and facilities, processing equipment, test and diagnostics capability, etc) for undertaking nanomanufacturing developments – 39% selected Plentiful, 30% selected Adequate, and 31% selected Inadequate (with 9% selecting Significantly Lacking).

3.9 Collaborative Development

Collaborative developments, while on an increasing trend, are highly product specific in the U.S. Nanotechnology Industry.

- Over three-quarters of aggregate survey respondents indicated their organizations are involved in collaborative arrangements with external organizations, while about 20% were working largely internally on nanotechnology developments – the highest percentages of these respondents are in the Mountain (34%), West South Central (29%) and Pacific (26%) regions.

3.10 Drivers for Partnering

Nanotechnology organizations were motivated to partner and collaborate for three main goals: to gain access to new markets and/or distribution channels; to better assess end users' needs in order to co-develop focused products and solutions incorporating nanotechnology advances; or (in the case of longer-term nanotechnology research) to leverage resources and reduce development risks.

- Respondents expressed nearly equal preferences on what motivated their organizations to collaborate in nanotechnology. Smaller nanotech organizations were more likely to partner for gaining access to capital equipment, while larger organizations were driven to pursue global markets with their nanoproducts.

3.11 Staffing for Nanomanufacturing

Over 80% of nanotechnology businesses are smaller (< 20 staff), entrepreneurial, technology-heavy entities comprised of startups and spin-off organizations; only 5% employ over 100 staff – a rational re-categorization of business entities by size is recommended to better address the unique needs of the nanotechnology industry.

- Many organizations involved with first generation (passive) nanotechnology developments are poised to profit through licensing of patents. They have limited potential for large-scale growth of jobs and the commoditization of raw materials that occurred in traditional manufacturing.

3.12 Commercialization Timelines

60% of the respondents expected to market nanotechnology products by 2009. Organizations in the Pacific region appear to have a steady stream of new product introductions across all timeline categories. Medium-sized (21-100 staff) nanotechnology organizations are best poised for growth, partnering or acquisition.

- The proportion of respondents indicating market entry within one year with nanotechnology products was the highest in the Mountain (25%) and the East North Central (17%) regions. Regions indicating the highest proportions of product introductions within three years were West North Central (42%), New England (40%) and Mid-Atlantic (36%) regions.

3.13 Government's Role in Nanomanufacturing

Nearly 95% respondents favored government involvement in the commercialization of nanomanufacturing, most preferring strong and meaningful incentives for industrial adopters of nanotechnology.

- These aggregate trends towards incentives were driven by two main issues:
    1. The belief the U.S. could lose its competitive advantage in future nanotechnology innovations, and needs to counter the offshore growth of traditional manufacturing and research operations
    2. Industry wants more government-led R&D collaborations in programs focused on regulation, nanotoxicity and environmental impact.

3.14 Nanomanufacturing Industry Challenges

The aggregate respondents indicated overwhelming consensus around the key barriers affecting the commercialization of nanotechnology. Industry perceives similar challenges and threats at three distinct levels (Figure 5).

3.15 Technology Transfer Preferences

Respondents expressed differing preferences for accelerating "nanoknowledge" transfer mechanisms across the manufacturing value-chain.

- The top three nearly equal selections depended on whether an organization's goal was to pursue partnerships, seek investors, technology scouting (technology pull) or dissemination (technology push) activities – they were:
    1. Industry trade shows and conferences
    2. Technology demonstrations
    3. Industry online media.

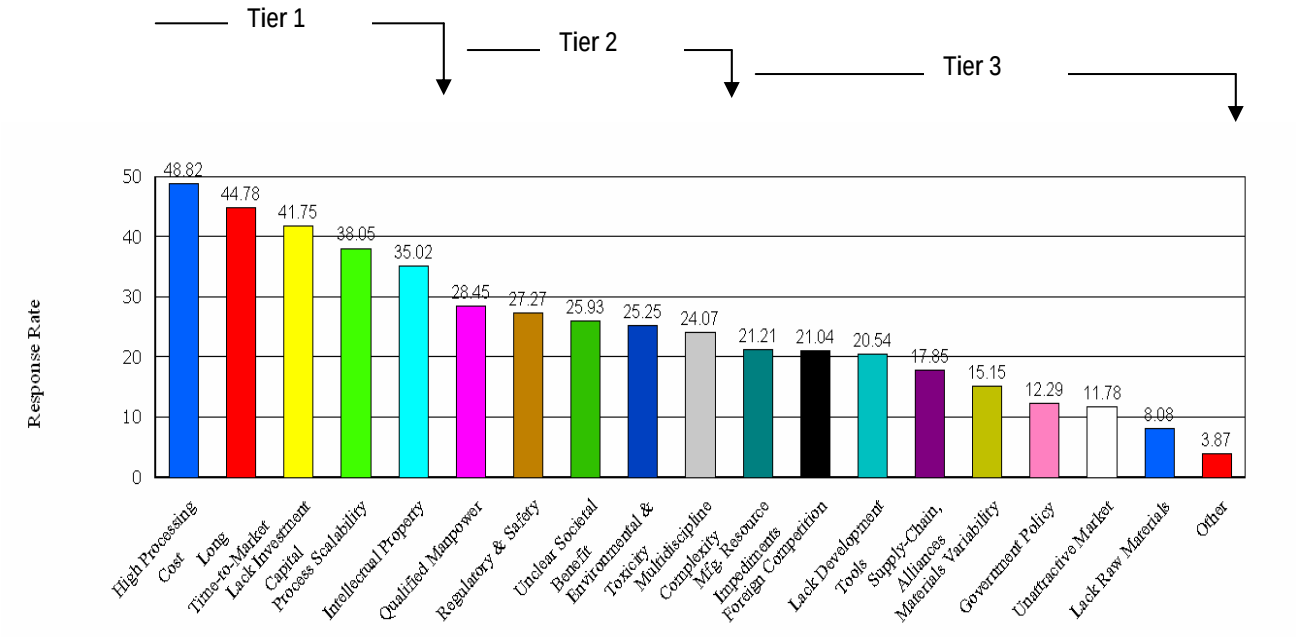

Figure 5. U.S. Nanomanufacturing Industry Faces Three Distinct Tiers of Barriers