

Project No. \_\_\_\_\_

Copy No. \_\_\_\_

## **BARRIERS TO NANOTECHNOLOGY COMMERCIALIZATION**

### **FINAL REPORT**

Prepared for  
U.S. Department Of Commerce  
Technology Administration

Authored By

Ronald D. McNeil, Ph.D.  
Dean and Professor of Business Management  
University of Illinois - Springfield

Jung Lowe, J. D.  
Distinguished Fellow  
College of Business and Management  
University of Illinois - Springfield

Ted Mastroianni, MPA  
Consultant to  
University of Illinois - Springfield

Joseph Cronin, Ed. D.  
Edvisors  
Boston, Massachusetts

Dyanne Ferk, Ph. D.  
Associate Dean and Associate Professor of Business Management  
University of Illinois - Springfield

College of Business and Management  
One University Plaza  
UHB 4000  
The University of Illinois at Springfield 62703-5407

September 2007

#### **ACKNOWLEDGMENT OF SPONSORSHIP**

This work was sponsored by one or more of the following as noted: U.S. Department of Commerce and KT Consulting, Inc.

#### **DISCLAIMER**

The opinions and conclusions expressed or implied in the report are those of the research agency. They are not necessarily those of the U.S. Department of Commerce or KT Consulting, Inc.

## **CONTENTS**

### **ACKNOWLEDGMENTS**

Research Team Members  
Preface and Overview  
Methodology for Research  
Relevant Barriers to Nanotechnology Commercialization

### **PREFACE AND OVERVIEW OF THE STUDY**

### **ABSTRACT**

### **EXECUTIVE SUMMARY**

### **CHAPTER 1 BACKGROUND**

Problem Statement and Research Objective  
Scope of Study

### **CHAPTER 2 RESEARCH APPROACH**

State of-the-Art Summary

### **CHAPTER 3 FINDINGS AND APPLICATIONS**

### **CHAPTER 4 CONCLUSION**

Conclusions  
Recommendations  
Suggested Research

### **REFERENCES**

## ACKNOWLEDGMENTS

This research report was performed under agreement between KT Consulting, Inc., and University of Illinois At Springfield.

### Research Team Members

Project Director, Ronald D. McNeil, Ph. D., became Dean of the College of Business and Management and Professor of Business Administration at the University of Illinois Springfield in the summer of 2002. He is the author or co-author of over 70 publications and journal articles, publications and presentations on entrepreneurship and small business management, including the International Council for Small Business, American Marketing Association, Southwestern Association of Administrative Disciplines, and The Association of Private Enterprise Education, to name a few.

Senior Research Leader, Ted Mastroianni, has more than 35 years of experience in the public arena and has held senior public service positions in three major cities: New York City, New York; Atlanta, Georgia; and Washington, DC. His span of experience includes leading major departments in city and federal government as well as serving as adjunct faculty member for the University of Southern California Public. He served as Chief of Staff to Congresswoman Marcy Kaptur, was Chief of Staff to the Secretary of Labor, United States Department of Labor, and was Associate Assistant Secretary, Employment and Training Administration. He holds a Master of Public Administration from the University of Southern California and a Bachelor of Science from the State University of New York.

Senior Research Specialist, Jung Lowe, J.D., serves as Distinguished Fellow of the College of Business and Management, University of Illinois at Springfield, and is an attorney with over 27 years in private practice of international business law. He is president of AmericAsia Global Law, Ltd., a private professional law corporation licensed in the State of Illinois. Additionally, he is an entrepreneur and is instrumental in advancing the deployment of new and emerging technologies, including nanotechnology. He has been affiliated with the MIT Enterprise Forum of Chicago, as Executive Director, Nanotech SIG, with the mission to help build a community of leading executives, scientists, entrepreneurs, financiers, government officials, and professors. He is a Senior Member of the Society of Manufacturing Engineers and its NanoManufacturing Tech Group, with a focus on the technologies and processes that help to conceive, develop, test, improve, and manufacture new products and bring them

to market faster and more cost-effectively. He is a graduate of the Yale Law School.

Senior Research Specialist, Joseph M. Cronin, Ed. D., is President of EDVISORS, Inc., an educational advisory service that assists colleges and universities, schools, states, corporations and foundations with plans, strategies and program reviews. Recent or current clients and their projects include: The University of Virginia on plans for the year 2020, University of Massachusetts, Dartmouth, and University of Illinois (Springfield) on accreditation self-studies and Harcourt General on planning and state licensing a new university online. He served as the Massachusetts Secretary of Education, Illinois State Superintendent of Education, President of the Massachusetts Higher Education Assistance Corporation, and President of Bentley College. He was Associate Professor of Educational Administration and Associate Dean at Harvard University. He holds the honorary Doctorate of Humane Letters from Lesley University where he served as trustee, chair of Academic Affairs, and, in 2003-04, as interim Dean of the School of Education. He earned AB and MAT degrees from Harvard in 1956 and 1957, respectively, and a Doctorate degree in Education from Stanford University in 1965.

**Senior Specialist, Dr. Dyanne Ferk, Ph.D., is Associate Dean of the College of Business and Management at the University of Illinois Springfield. She is a certified Senior Professional in Human Resources (SPHR)—the highest level of professional certification in Human Resources. Prior to joining the University, she spent more than 15 years working in Human Resources in the private, not-for-profit and federal sectors, including employment with the Department of Defense, service with the Springfield Aids Resource Association, and an appointment as a regional Human Resource Director with the Internal Revenue Service. Her research interests include managing careers, effective use of labor market information, search firm strategies, business ethics, online education and higher education pedagogy.**

## **PREFACE AND OVERVIEW OF THE STUDY**

This report covers the mission and scope of work of the contract with the United States Department of Commerce (USDOC) Office of Technology, the principals involved, the methodology used, the cities and states visited and the results of our study.

The contract was let by United States Department of Commerce through KT Consulting to the University of Illinois on behalf of the University of Illinois Springfield. The contract was effective from November 21, 2006 to September 30, 2007; however, a thirty day extension of the contract was agreed upon by all parties.

The Performance Work Statement (PWS) focused on **“Identifying the Barriers to Nanotechnology Commercialization”**.

**“Identifying the Barriers to Nanotechnology Commercialization”** project at the Technology Administration required the Contractor’s support in understanding how nanotechnology is currently being applied commercially. The purpose of the study is to identify barriers that constrain or hinder the commercialization of nanotechnology.

This study and the data information offers policymakers a stronger basis for informed policymaking for the purpose of ensuring that the United States, US-owned companies, and American workers can best capitalize on the strong R&D foundation. The United States has invested both capital and effort into nanotechnology basic research and is beginning to realize increased commercial applications.

The charge was to assist the Technology Administration and the Under Secretary of Commerce for Technology, Robert Cresanti, in identifying and addressing the barriers to commercializing nanotechnology. This report addresses barriers to nanotechnology commercialization as reported by study participants in roundtable discussions, focus groups, interviews, and a review of publicly available reports on the current state of nanotechnology research and commercialization. Based on the findings, recommendations have been formulated to address the barriers to nanotechnology commercialization and are included in this report. The underlying data was collected from a wide range of key nanotechnology stakeholders including members of the National Nanotechnology Initiatives, university centers, scientists, researchers, venture capitalists, alliances and private companies.

## Methodology for Research

Primary data for this research was obtained directly from roundtable and focus group discussions and participant interviews. Court reporters, audio tapes, and notes were utilized to record comments and data from participants.

Focus groups, roundtables, interviews and field visits occurred in the following locations:

Atlanta, Georgia  
Winston Salem, North Carolina  
Palo Alto, California  
Chicago, Illinois  
Little Rock, Arkansas  
Arlington, Texas  
Boston, MA  
Albany, NY  
Rensselaer Polytechnic Institute, Troy, N.Y.  
National Institute of Standards Technology (N.I.S.T)  
Philadelphia, PA  
Portland, Oregon  
Washington, DC

Participants involved in the research were venture capitalists, nano business representatives of large and small businesses, scientists, academics, public officials and researchers. Elected and appointed officials were present during several forums.

The roundtable forum leaders facilitated conversations between the participants. The team forum coordinator also solicited the participants' point of view. One positive outcome that resulted from the process was our ability to connect people that were in the same region but did not previously know each other.

An example of this was a conversation that occurred between a regional representative of the Federal Drug Administration and a scientist who was doing work on human tissue research in the same region. They were not aware of each other's work in nanotechnology prior to the exchanges in these meetings. In the exchange at our meeting, the scientist stated he was having a difficult time communicating with the Washington-based FDA on his work. The two decided to speak after the session. The interchange may have demonstrated an opportunity for overcoming a barrier to commercialization if, in fact, the research had an application in fostering tissue improvement.

Four categories of topics were distributed to participants prior to meetings and they were:

Capital Issues/Market Readiness

Regulation/Environmental, Health & Safety Issues

Public Attitudes and Perceptions

Other Issues (Workforce, Standards, Manufacturing, Infrastructure)

Participants were informed that these general topics were beginning points for discussions and that each participant was free to discuss their area of expertise and their important subjects constraining nanotechnology commercialization.

After the Portland, Oregon roundtable, a nine page list of questions was developed and distributed to participants prior to subsequent meetings. Participants were informed that the list of questions was merely a beginning point and that each should discuss what they considered major barriers to nanotechnology commercialization.

A great amount of important information was obtained by the team that may well have an impact on future public policies dealing with this subject matter. The information includes issues such as immigration policies, research and development funding, government intervention for startup firms, private funding sources, tax policies, safety and health issues, and public perception management.

The results of this study will bring into focus the challenges facing the need for specialized workforce skills, education policies that affect primary, secondary education and graduate studies and the need for establishing a national policy on education and training concerning this field.

Furthermore, the results will explore the regulations that affect patent and copyright methods and issues; environmental issues, safety and health issues; standards and measurements issues as well as our future competitive standing in the world.

The current status of nanotechnology commercialization was investigated. Research was conducted by reviewing publicly available reports. A paper summarizing the findings was developed and sent to the Department of Commerce. It should be noted that nano science and technology are advancing quickly; therefore, the status of nano technology commercialization is rapidly changing. Also, it was determined through the roundtables, focus groups, and

interviews that a number of products which are not listed as nanotechnology are nano technology commercial products.

Audio recordings, written records or notes were employed for roundtables, focus groups and interviews. The summary interview report categorizes comments to reduce redundancy, lists issues separately and identifies barriers where possible.

The list of those who worked with the Team to convene focus groups and the roundtables and the names of individuals who participated is included with the report. The only exclusion of names or comments occurs when an individual did not allow the Research Team permission to use their name and/or make attribution by name to comments.

This study also compiled a thorough search of existing literature on the topic. It is as current as we could determine. However, since this is a swift-moving science, there may be many types of literature being published as we write this report.

This research is an important step in providing data to policymakers, scientists, practitioners and the public on how the United States can benefit from the nanotechnology revolution.

### **Relevant Barriers to Nanotechnology Commercialization**

1. Time between research and commercialization is estimated to be 3 to 10 years. Venture capitalists and other sources of funding find this time factor to be a detriment.
2. The so-called “Valley of Death” is the often fatal interlude between scientific results of the researcher and initial funding for proto-typing and commercialization. The scientists may publish results and not be interested in commercialization. As often happens, where there is interest or not in commercialization, the common comment is that for every dollar invested into basic research, which is critical to the U.S.’s competitive strength, almost one hundred dollars is required for a competitive product to be produced. The commercialization of nanotechnology scientific investment has little relationship to the hi-tech dot.com, software commercialization paradigm. This is a serious gap between research and commercialization that must be addressed by government agencies and the venture capitalists.
3. Lack of proper infrastructure (labs, equipment, measuring devices, etc.) hinders the growth of small business and researchers. The infrastructure needed is very expensive. Furthermore, equipment becomes quickly outdated due to the major advances in technology.
4. Lack of usage of federal and university laboratories and equipment hurts small businesses that can’t afford this infrastructure.

5. Many of the employees or scientists are foreign nationals. They are not allowed access to federal labs in most cases.
6. Small businesses do not have the capacity to produce products at a large scale.
7. There is a lack of a coherent policy on tech transfer from universities to start-up businesses.
8. Audit control from federal government is a hindrance to small companies. It is very expensive to slow down work to comply with several federal agencies that conduct audits. There needs to be a centralized system.
9. Patent office takes up to 36 months to respond to applications registered.
10. Potential barriers may include the lack of trained scientists, engineers, technicians and researchers in this country. There is no federal policy addressing the deficit in scientific training at all levels of our educational institutions and in improving the workforce with better and improved technical skills.
11. The current tax policy does not assist research and development. There are not enough sufficient tax credits for funding groups.
12. FDA and Patent offices do not have enough qualified staff to assess nanotechnology products.
13. The development of nano tools must increase and be more available to universities and startup businesses.
14. SBIR encourages research and not commercialization. It does not support small companies.
15. Applied research needs to be encouraged more in universities and federal labs.
16. The public perception that nanotechnology products are unsafe must be challenged to insure the public fully understands its potential.
17. Lack of standards and measurements are hindering advancements in nanotechnology.
18. The reduction of research and development funding has been hindering advancement in research.
19. Current immigration policy is adversely affecting research. U.S. - educated foreign nationals are going back to their home countries because of the difficulty of going through the process to stay in the United States.
20. It is also difficult for an individual to obtain a visa to enter the United States.
21. National assistance for nano technology development in foreign countries is more effective than in the United States. It will be a problem for competitiveness.
22. Some academics and researchers fight efforts for commercialization.

## **ABSTRACT**

This Final Report summarily documents and presents the results of a U.S. national study to identify and address questions and issues regarding barriers to nanotechnology commercialization, identifies collective key strengths, and offers recommendations. The study collected data from recent publicly available reports and studies, roundtables, focus groups, and personal interviews of experts with diverse backgrounds related to nanotechnology. The data resulted in summary papers. The national study findings are analyzed and evaluated for comparison to related information in recent publicly available reports and studies. The end results identify current key strengths of nanotechnology commercialization, major barriers and underlying causal factors, with recommendations for policy actions and future studies. The potential of nanotechnology applications revolutionizing products and services to society is significant. However, in addition to global competition by researchers and those seeking to produce nano related products and services, there are barriers. These critical barriers to nanotechnology commercialization include: the ten year cycle time from science results in a laboratory to a commercial product; the gap between researcher and applied scientists; the gap in funding between basic research and applied research; a lack of understanding that for every dollar invested in basic research almost \$100 is required for a commercially viable product, and a list of constraints including, time to patent, uncertainty of potential regulations by EPA, OSHA, FDA; and the high risk of new scientific results becoming commercially viable.

## **EXECUTIVE SUMMARY**

The Federal Government has invested more than \$3 billion in nanotechnology since 2003. Federal funding has put nanotechnology on track to be the largest government funded science initiative since the space race. Nevertheless, so far there are only about 500 nano-businesses in the U.S. and about 500 nano-related products. By comparison, global revenues of nanotechnology products are estimated at \$40 billion. Products range from paints, cosmetics, microelectronics, and semiconductors to specialty coatings and tooling. These and many emerging nanotechnology markets worldwide are expected to grow rapidly in the next decade and reach \$1 trillion by 2015.

However, it is apparent from roundtables, focus groups, and personal interviews with nanotechnology scientists, venture capitalists, businesses, and consultants, there are no “home runs” in U.S. nanotechnology commercialization at this time. From these direct sources, it appears that start-up nanotechnology related companies are struggling to realize revenues and most are not at the breakeven point. There are also significant efforts and funding by regional, state and local

initiatives—mainly by governments and institutions—which have not yet made significant increases in new nanotechnology businesses or jobs.

The majority of participants in the study believe the goal of high volume manufacturing of nanotechnology materials and products is a very important activity to strengthen U.S. nanotechnology capabilities. But commercialization of such advanced functional materials and products requires that they can be produced in a predictable, reliable way and in sufficient quantities. Until that is achieved, production will be limited to academia and R&D departments within industry.

The most significant barriers to growth generally include: funding which favors research over development and commercialization of nano products; the need for more long term funding for startup nano companies; intellectual property issues; the science culture versus the deployment culture; and lack of prototyping facilities. In particular, federal and university laboratories and testing facilities ought to be made more easily accessible and economical for use by small businesses. The overriding major issue is whether government and industry can cooperate and take specific steps toward reducing or eliminating the significant present barriers to commercialization of nanotechnology innovation.

## CHAPTER 1 BACKGROUND

*Discussions of the problem that led to the study, current knowledge that can help in solving the problem, and the objectives and scope of the completed research are presented in this section. This chapter does not contain the details of any survey performed, any forms used in soliciting information, or details regarding procedures or analyses used. All such details are provided in appendices.*

### **Problem Statement and Research Objective**

Perhaps no single technology offers more economic and societal promise than nanotechnology. Nanotechnology holds the promise of both incremental improvements of existing products and the potential for revolutionary changes that could transform entire industries and create entirely new ones. To ensure U.S. technological leadership in this emerging field, the Federal government initiated the U.S. National Nanotechnology Initiative in 2001 and has subsequently invested more than \$5 billion in nanotechnology research. For 2008, President Bush has proposed \$1.4 billion for nanotechnology research, a three-fold increase since 2001. State governments and the private sector have invested billions as well. Early applications of nanotechnology are already yielding dividends on those investments.

Nevertheless, the commercialization of nanotechnology is presently slow paced due to many barriers identified by experts. Barriers and potential barriers that impede further commercialization may limit our ability to capture the full potential of nanotechnology, including economic growth, wealth and job creation, and improvements in our standard of living and quality of life. These barriers may include capital issues, market readiness, regulatory uncertainty, health and safety, workforce readiness, public attitudes and perceptions, infrastructure, standards, nomenclature, and manufacturability.

This study on the causes and analysis of barriers has been undertaken to assist the Department of Commerce's Technology Administration that will seek to inform policymakers so that government at all levels can help unleash the full potential of nanotechnology. We have current knowledge of major issues that should be explored in order to find ways of solving the problem of barriers to nanotechnology commercialization.

The present state of nanotechnology commercialization can be generally perceived by reviewing relatively recent reports and studies available to the public from reliable resources. These resources reveal each subject listed below as a vital link in a long and complicated chain of processes leading to the objective of nanotechnology commercialization.

Research and Development: Infrastructure availability is lacking, yet crucial to assist businesses, especially small companies that cannot afford the cost of nanotechnology instrumentation, equipment and facilities. Nanotechnology virtually demands university and industry cooperation due to basic science innovations, expensive laboratories, and need for highly trained workers.

Investment: The necessary and substantial Investment Capital cash is lacking early in business ventures for highly educated personnel and advanced R&D systems, high processing costs for nano products, perception of long lead time for nano products, and lack of process scalability.

Intellectual Property (IP): IP is vital for new ventures needing core technology licenses and help from investors. There is need to enhance IP protection to attract investors besides enacting stronger R&D tax credit and providing tax incentives for U.S. based development ventures.

Economic Development and Commercialization: Efforts by regional, state and local initiatives, mainly by governments and institutions, are not yet causing significant increases in new nanotechnology private sector jobs.

Workforce Development and Education: Companies seek to locate manufacturing in communities that have trained workforces. The U.S. national trend is leading away from traditional careers in technology at community colleges, undergraduate and graduate universities. Unfortunately, most of academia and the research community do not facilitate a nanotechnology-oriented type of multidisciplinary research.

Occupational Health: Human exposure to nanomaterials in the workplace and indoor and outdoor environments shows a need for early monitoring of workers subject to high nanotech exposures and toxicity concerns.

Public Policy and Health: The public perception towards the federal government from public knowledge about, and attitude towards, the Food and Drug Administration (FDA), Environmental Protection Agency (EPA), and U.S. Department of Agriculture (USDA) are good to excellent but ambiguous towards business, according to a survey.

Government Budget: Government assistance is vital to help finance nanotechnology infrastructure that requires higher investments and costs for multidisciplinary ventures, and risk research of the environment and human health. Government should offer tax incentives to encourage safer environment by business, purchase desirable nanotechnology products and services, and amend regulations to favor certain conduct and outcomes.

Nanotechnology Standards: There is urgent need to develop standards for each aspect of the new nanotechnologies: research, production, products, and waste disposal.

Global: Global concern is growing since about 75% of known nanotechnology R&D investment worldwide is done by foreign nations, and even more unknown amounts by private industry, thus making environment, health, and safety all international issues. Foreign competition might surge if they can operate with little regard for these issues.

Instrumentation and Metrology: Instrumentation and Metrology standards are lacking although vital to developing the basic terminology and comprehensive nomenclature of nano materials and products. Metrology, the science of measurement, underpins all other nanoscience and nanotechnologies not only because it allows the characterization of materials in terms of dimensions but also in terms of attributes such as electrical properties and mass.

Nano-Bio Technology: The science and engineering of nano-bio-systems is one of the most challenging and fastest growth sectors of nanotechnology. Although applications of nanotechnologies in medicine seem especially promising, the unknown dangers and potential liabilities could become daunting.

Energy: Nanotechnology and nanoscience advances are leading to improved energy resources that might be packaged in every conceivable way and location. The long term impact of such packages and eventual disposal in the environment are unknown.

Society: Nanotechnology acceptance by the public is subject to the extent of hyperbole in publications, classes of people with power and wealth compared to others who are helpless, and types of issues affecting public health and safety. The public impression generally is that risks from nanotechnology would outweigh the benefits derived.

Risk Management: An integrated risk research framework by government is needed to manage nanotechnology environmental, health and safety issues by coordinating many agencies.

Environment: There is immediate need to focus efforts on the types of nanoparticles already being used by industry, as these pose the most immediate exposure threat to humans and the environment.

Nanotechnology Materials: Developing and validating methods to evaluate the toxicity of engineered nanomaterials is required, especially in the next 5-15 years. Much of nanoscience and many nanotechnologies are concerned with producing new or enhanced materials.

Conflict of Interest: An issue universities should anticipate and help to manage is their nanotechnology innovation transfer terms and related conflicts of interests at all levels involving professors, industry and government.

Nanotechnology Devices: Nanotechnology applications as devices may include active nanostructures (anticipated rapid growth markets from 2005-2010) that change their state during use, responding in predictable ways to the environment around them. However, there is concern that the public would become wary and might refuse acceptance of such devices.

Nanotechnology Manufacturing: Systems of nanosystems (anticipated rapid growth markets from 2010-2015) are assemblies of nano-tools working together to achieve a final goal and could lead to large volume nano manufacturing processes. A key challenge is to get the main nano components working together as a network, possibly automatically exchanging information to make things from molecular size “bottom-up.” Over time, some traditional industries currently making things from existing materials “top-down” would be displaced, along with their workers.

Related Services: Successful commercial exploitation of nanotechnology products requires unprecedented levels of collaboration (both vertical and horizontal) across many different realms in order to adequately address the inherent complexities associated with the lifecycles of such products. Presently there are no sophisticated networks of collaboration.

Outer Space: Nearly every space program worldwide has found remarkable and successful roles for Micro and Nano Technologies (MNTs). These have been developed in response to the lighter-weight, smaller-size, less-power-dissipation, lower-cost mantra chanted by those involved with commercial outer-space, aerospace, and military applications. Although these highly specialized industrial sectors are not directly relevant to general business and consumers, the spin-off technology could enrich global markets.

## **Scope of Study**

The objectives and scope of the completed study are to understand how nanotechnology is currently being applied commercially, the industry R&D investments that may drive future change, and the size and composition of the workforce necessary to support nanotechnology-related innovation and production. The research identifies and addresses the various major components as causal factors that create barriers to commercializing nanotechnology, as well as the key strengths of U.S. industry for commercializing nanotechnology.

Resources of information are derived from publicly available reports and studies, conducting discussions at roundtables, focus groups, and personal interviews

with experts in diverse fields. From these inputs, there is derived an overall picture of the current state of nanotechnology commercialization in the U.S., with samplings of the parties involved in the nascent complex and growing networks, their strengths and weaknesses, and consequential barriers to rapid commercialization.

Research data and findings are the basis for making recommendations in the report that could lead to workable solutions for policymakers, government agencies, or Congress. These are based on analysis of data and information to deduce the underlying causes and possible solutions to avoid, minimize, or overcome barriers to nanotechnology commercialization.

## **CHAPTER 2 RESEARCH APPROACH**

*This chapter presents the approach used in addressing the problem.*

### **State of the Art Summary**

The research study gathered data on current barriers to nanotechnology commercialization starting with a thorough review and analysis of publicly available reports and studies on the state of nanotechnology commercialization. The present state of nanotechnology commercialization can be generally perceived by reviewing relatively recent publications and reports available to the public from reliable resources. Accordingly, more than sixty-two (62) such publications and reports were reviewed. Their contents were analyzed and categorized under twenty-four (24) different subjects. Each subject covers a significant scope of the wide field of activities reasonably connected to nanotechnology innovations and the processes involved in their commercialization.

The essence of publicly available derived information was cast into lists of subjects, questions and issues that were shared with individuals participating in roundtables, focus groups and personal interviews. Such information helped to seed the conversations and encourage free-flow of viewpoints from many angles of each subject and issue. The research team conducted not less than four roundtables, four focus groups, and thirty-four interviews in person, including two interviews by telephone to individuals in major cities of the U.S. and Australia.

A minimum of four summary papers of each session that comprised a combination of roundtable, focus group, and personal interviews were written by the research team to capture the essence of relevant information derived from conversations. Included in the summary papers is the identification of each participant and relationship to an organization and type of activity.

## CHAPTER 3 FINDINGS AND APPLICATIONS

*The material in this chapter expands on the Executive Summary. For each subject field below, the major research questions and issues explored in the study from analysis of recent publicly available literature research, roundtables, focus groups and personal interviews are described below as “finding.” The “applications” are their meanings as applied to nanotechnology commercialization. However, the details are presented in the appendixes.*

### 1. Research and Development:

#### A. Study findings:

U.S. nanotechnology Research and Development is the first and most important process link in the long chain of parallel processes leading directly and indirectly towards the objective of nanotechnology commercialization.

The majority of participants in the study believe U.S. basic Research & Development presently leads other countries and prefers government to become more heavily involved in fostering R&D.

Better bridges are needed leading from science to development to product manufacturing and markets. Today, nanotechnology is science driven in search of products and market with very little focus by scientists for later commercialization and the reality of the market place. Nanotechnology science is general but products and markets are very specific.

A large company usually has only several people working in nanotechnology R&D so it is difficult to get the attention of company management and budget funding. Small research staffs do not have any means to know what other small companies are doing which may be of technical interest to their large company for possible future acquisition. Even a large company has limited time and personnel to investigate the many universities and government laboratories to try and determine what kinds of R&D are available and the potential benefits the company would receive if it invested in those R&D projects.

Small companies would prefer to obtain university R&D that is developed to the latest stage when it is just about ready for production, without having to pay for prior R&D.

The small start-up companies or small businesses need more access to federal and university labs. Government policy should consider financial assistance to new nanotechnology ventures that require special needs for infrastructure and facilities. The university infrastructure is essential and should not be available only for the largest firms. Genuine partnerships should be established between

small businesses and these groups since not all of the start-up businesses can afford the research equipment needed for their work

University laboratory scientific results may lead to intellectual property rights and basic patents. However, a major barrier presents in the next important stage—using scientific research as the basis for carrying out needed engineering work and experiments with prototypes that are suitable for commercialization through production and sales.

Professors who are interested in developing their scientific innovations into prototypes presently do not have access to their own private workshop or other independent facilities separate and apart from the university laboratories. In a private workshop, a professor could transform scientific theory into practical applications that might qualify for new patents that they would own.

B. The above findings differ or corroborate related findings from current publicly available reports and studies as summarized below:

R&D infrastructure availability is crucial to assist businesses, especially small companies that cannot afford the cost of nanotechnology instrumentation, equipment and facilities. Nanotechnology virtually demands university and industry cooperation due to basic science innovations, expensive laboratories, and need for highly trained workers.

Nanotechnology is a multidisciplinary field. Advances in the area will require the expertise of chemists, physicists, materials scientists, biochemists, molecular biologists, engineers, toxicologists and medical scientists working together. Chemistry and physics are central to most nanotechnologies.

A majority of participants in the study believe domestic basic Research & Development in the U.S. leads other countries and prefers government to be heavily involved in fostering R&D.

2. Investment:

A. Study findings:

It is difficult to get venture capitalists interested in a transformational nanotechnology program that will take more than three (3) years to pay out.

Successful commercialization requires commitment to invest, research, development and high-volume manufacturing. There is a need for “Gap” funding to help out groups that may have a five to ten year cycle research issue.

There is a need to leverage federal and state funds with private sector funding.

A national fund may be set up for universities to teach people how to be entrepreneurs, to fund more research and patent protection, and for infrastructure improvements (labs, clean rooms, equipment and nano tools).

Capital availability is decreasing. Companies are attempting to be very creative in getting funding. Funding from SBIR seems to be focusing on larger companies leaving small companies in a lurch. SBIR model does not fit with today's research because of the time of research. It takes many years to come to production stage.

Earlier investment will require higher funding. The venture capital community has gravitated away from entrepreneurs and small companies to larger companies.

Leadership must come from State and Federal governments to support innovation because research may take between 3-4 years or up to 10 years to complete. Funding must be earmarked for risks and marshalling resources.

The federal government is absent in endeavors such as bringing together academia, businesses, researchers, local and state government and investors. There is a long gestation period from research to development. Some small businesses get federal grants, others get funding from private investors.

Challenges exist in the transit from government research to commercial ventures and there is a need to connect a facilitating relationship between public/private funding and government information.

A venture capital fund is usually planned to operate for ten years, with investments made in small companies during the first four years. Presently there are some nanotech investment opportunities but they do not seem to have promising high returns to satisfy fund investors' desires and objectives. Before ten years, the invested small companies with valuable technology need to find and be acquired by established large companies to bring financial returns to the venture capital firm. But venture capital firms do not know how to locate a large company that needs the invested small company and the search could take an additional four years or more.

There should be a more efficient way for a large company to find external funding sources like venture capital firms that would have possible interest in advanced research projects. Experience in working with a small company that has R&D of interest reveals the long time involved to investigate the technology available and negotiate possible business arrangements for continuing cooperation.

Venture capital firms aggressively seek to locate resource persons in large companies that could become interested in a venture portfolio of new companies.

This could lead to making co-development opportunities for a venture portfolio of new companies with large companies involving their joint ownership of developments and commercial rights clearly defined by agreement to specific applications. The large company brings a market need for the R&D work provided by the new small company and the agreement defines their sharing of intellectual property rights. However, finding such opportunities and coming to such an agreement normally takes years of effort.

Special funding by government has been a very good resource for new portfolio companies with contracts from DARPA and SBIRs over the past five years. Their development costs have been largely funded by the government and that leads to new products for commercialization, which is the stage mainly funded by venture capital.

The National Venture Capital Association has documented a serious problem in that in order to qualify for SBIR grants, an applicant company must be at least fifty-percent owned and controlled by U.S. individuals. However, most venture-backed companies are not so structured. This is a major disadvantage for nanotechnology startup companies that rarely have management personnel who own fifty-one percent or more of equity after receiving venture capital or other outside funding.

Venture capitalists are, in fact, ready to finance good ideas. But many have a threshold of ten million dollars for an investment. And perhaps only one-half or one or two million dollars are needed.

Some Venture Capital (V/C) companies don't care about the technology as much as the guidelines for getting to the market to sell products. Their questions always begin with "How long it will take? When will you have something you can send in a box to a customer?" The V/C view is to manage risk. The scientist or entrepreneur must be able to articulate what the product is.

Before funding comes in some cases, a market must exist and research must move toward a product. There should be more direct university and corporate partnerships. Time is a major factor when considering funding.

It might take six years from research to commercialization for many cases. There seems to be at least a two-year waiting list at the Patent and Trademark office.

Normally, in the early stage of academic research there is a gap between research and early stage commercialization (i.e., high risk investment for initial, laboratory proto-tying and then commercial proto-tying) where private investment is very difficult to next to impossible to obtain. Perhaps angel investors would fill the gap to minimize this barrier to nanotechnology commercialization. This

timeframe could be more efficient if government would shift some funding towards better production since the support is critical.

Scientists put too high of a dollar value on their discovery for the VC that needs three to five years return on investment. Typically, with scientists, the high risk development time is a decade or more.

More often than not, the scientist in business must be replaced with an executive who understands the market need for a product and the companies need for profits to stay in business.

B. The above findings differ or corroborate related findings from current publicly available reports and studies as summarized below:

The necessary and substantial Investment Capital cash is lacking early in business ventures for highly educated personnel and advanced R&D systems, high processing costs for nano products, perception of long lead time for nano products, and lack of process scalability.

Substantial cash is needed for highly educated personnel and advanced R&D systems.

The financial sector will have a key role in transferring technology knowledge from the research centers to the industry and the markets. For the development of new products and processes and also for the penetration of new markets, sizeable investments are needed especially in the seed phase. A closer cooperation between the financial community and nanotechnology companies can help to overcome these barriers.

For successful investments, two aspects will be of critical importance: timing and target selection. Applying the process of "technical due diligence" will be essential in making acquisitions.

A survey revealed the respondents ranked the following five top barriers they face in nanomanufacturing commercialization efforts:

1. High cost of processing
2. Lack of investment capital
3. Perception that nanotechnology products take a long time to market
4. Process scalability
5. Shortage of qualified manpower

The time to produce nanotech products takes years, not months. Biotech typically requires at least 1-2 years, however the dot-com era took considerably less time, producing profitable businesses in a few short months on rare occasions.

The first mover advantage has a huge effect in nanotech, meaning that a sometimes insurmountable advantage is gained by the first significant company to move into this new market.

Strong barriers to entry exist in the nanotech field, as opposed to the Internet, where virtually anyone with a basic knowledge of website development and a unique idea could create a profitable business.

It's not just VC firms re-entering the fray; corporations are now sticking their noses into early stage companies. While all investors lust after big returns, corporate VCs are often just as interested in getting an inside track on hot new technologies, reducing the costs of their own research, development and legal costs. A large advantage of investing in smaller companies is that they are able to focus on niche markets, creating a better atmosphere for exceptional research to be conducted. The cost/benefit analysis for large corporations makes this a no-brainer. Throw seed money into a small strategic start-up and the potential result can create large benefits with relatively little risk for corporations. If the start-up succeeds, they typically gobble them up, taking the IP and market with it; if they fail, the corporation is typically not liable for any legal battles that may ensue, allowing them to move onto the next venture with its hands relatively clean and checkbook relatively unscathed.

A Nanotech Boom is inevitable. The large global market and wide ranging applications will likely create multiple booms and busts over the next 20-30 years. With that said, the U.S. is not alone. Many countries, including Japan, Israel, China and numerous European nations are pumping significant amounts of money towards the science. Although overall shares of GDP (Gross Domestic Product) going towards VCs are markedly different amongst countries, investors are looking for the same characteristics in start-ups.

### 3. Intellectual Property (IP):

#### A. Study findings:

The patent system requires attention for the United States to have a competitive advantage in new inventions and, specifically nanotechnology. The European model for obtaining patents was cited as a better model than that of the U.S. There is an approximately 24, sometimes cited, to a 36-month wait time for a patent to be accepted. There is the Fastr-track patent process; however, participants either had not heard of it or they felt is not sufficient for nanotechnologies needs.

There has to be freedom for companies to operate their business and that could be an increasing problem due to increasing number of patents that might conflict

and serve to limit their operations. There is need to enter into more cross-licensing so companies can do their business with less possibility of infringements and litigation.

After getting patents, the real problem is using the rights in order to gain some benefits. Venture portfolio companies with valuable intellectual property must appear to be a competitive threat in order to negotiate the most desirable terms for their acquisition by larger companies.

Nanotechnology is different from some other technologies in that it is a platform technology with applications in diverse industrial sectors and very different products. The small nanotech company could choose to use its intellectual property rights in many of these sectors with different arrangements to expand its opportunities to enter new markets and exploit income sources.

The problem from a large company perspective is too many problems arise when attempting to use nanotechnology intellectual property as a platform to pursue commercialization in diverse fields, rather than concentrating on a particular product. The pharmaceutical companies would not be interested in using "patent pooling" where different owners of patents would share the rights to a collection of their patents.

A U.S. company with China operations is concerned about intellectual property issues so does not use its top technology in its plants over there.

By organizing a startup company to license technology in all fields on an exclusive basis, the company could attract investors and undertake costly development work based on having more licensees and their potential markets.

A startup company learned quickly by experience (losing a major potential investor after frustrating licensing negotiations with a university) that the company had to first negotiate a license for itself from a university for the basic technology. Then the company would be able to independently negotiate separate licenses to other third parties. Negotiating with the university was arduous with delays of over a year but, when completed, allowed the company with newly licensed technology to begin searching for investment capital.

The Intellectual Property, including patent rights, licensed from a university is rarely sufficient to operate and expand a new nanotechnology company but it is a vital base from which to start attracting seed money from investors. Most startup ventures seek to license rights to patents still pending while concurrently attempting to obtain funding from investors and this is a tenuous framework to build on for any successful outcome.

Even with a portfolio of issued patents, the use and leveraging of their potential is a difficult financial burden for a company. For some companies, patent

development and maintenance is the second or third most expensive budget item following the top expenses of employees' salaries and benefits. Very careful management of IP is vital to the welfare of the company. To begin, a new company should have from \$1.5 to \$2 million in seed money to acquire and leverage needed IP rights.

A new company is very unlikely to acquire the necessary IP rights by license from a single university that would completely protect it and give it freedom to operate the business. Some companies license their IP from several universities to rapidly achieve a dominant position in a nanotechnology field.

A new company continues to perform R&D that results in applying for more patents, and also acquires more patents as a defensive measure, so its IP expenses continually rise.

Separate and apart from acquiring IP by licensing patents, a small company has a major challenge in defending its existing IP rights. The legal fees and costs would be prohibitive for small ventures that face large companies with ample budgets so most ventures try to negotiate licenses and settle.

Universities rarely seek international patent protection for their innovations and new small ventures mainly license U.S. patents for their startup period. Faculty public presentations that disclose their inventions before applying for foreign patents would preclude obtaining patent rights in most countries

B. The above findings differ or corroborate related findings from current publicly available reports and studies as summarized below:

IP is vital for new ventures needing core technology licenses and help from inventors, in light of a new trend where power of patents could be concentrated due to increasing number of organized patent pools. There is a need to enhance IP protection, enact stronger R&D tax credit, provide tax incentives for U.S. based business, and expand broadband internet usage. The nanotechnology field has more patents with broad scope claims that might retard commercialization based on infringement; use of patent pools might further commercialization.

In considering enforcement of their intellectual property, it is important that universities be mindful of their primary mission to use patents to promote technology development for the benefit of society.

Even if applicants successfully patent their inventions, they could confront later challenges to their patents based on various doctrines in litigation; this is why it is so important to have many claims of varying scope that create fallback positions in future litigation. The first wave of early patents in nanotechnology is just starting to conflict with lawsuits as commercialization expands globally in 2007.

As important as IP is, there has so far been little litigation in nanotech patents, indicating how young the industry is. According to the US Patent & Trademark Office (USPTO), the number of patents is rapidly increasing due to the rapid growth in so many emerging technology fields such as nanotechnology, biotech and medical devices. The Patent Office expected about 500,000 new patent applications in 2005; however, with the current backlog, this means most patents will take more than two years before being approved, threatening to make some patents obsolete before they are even issued. This delay dampens interest from the venture industry that typically wants the assurance of patented technologies before they invest. This situation is particularly tough on independent investors and small companies who need those patents to secure funding and gain intellectual property rights. They are at the mercy of the USPTO and have virtually no control over the approval timeframe.

In comparison to the internet epoch, innovators and investors in nanotechnology have to pay special attention to intellectual property (IP). Plain and simple, IP is key. VC's must be able to navigate through a minefield of patents if investors are to ever see a return on their money but the IP issue can be sticky. Even if a startup has the brains and the cash to fuel its research, there are complicated IP issues that can throw a wrench into the best-laid business plan. Seed-stage nanotech companies often have little more in their chest of IP assets than a proof of concept and private equity investors may not have deep enough pockets – or enough patience – to fund such a startup to profitability.

Nanotechnology IP that is based on Size-Based Patentability could be adversely impacted by the USPTO rules for Anticipation, Inherency and Obviousness. The patent enablement doctrine requires the inventor to provide sufficient information to enable a person skilled in the relevant art to make and use the claimed invention without “undue experimentation.” This is difficult to describe in a patent application for diverse fields of practice.

#### 4. Economic Development and Commercialization:

##### A. Study findings:

Efforts by regional, state and local initiatives, mainly by governments and institutions, are not yet causing significant increases in new nanotechnology private sector jobs.

There is need for national policy to provide or assist in building the nanotechnology infrastructure. The infrastructure might include a foundry service for semiconductor manufacturers, such as Silicon Valley provides.

The recommendations are for more planning and more federal investment in research, beginning with universities.

The State of New York has a strategy for attracting new business ventures, including semiconductor corporations and Fabs. In 1998, an inquiry about a new semiconductor facility found no site or development plan ready so the successful initiative required almost ten years of collaborative planning among the public, private and academic sectors. There are four essential components to New York State's strategy:

1. Zoning and permitting acceleration; rather than piece meal approvals lasting two years, the objective is to develop a "shovel ready" pre-permitting track. This begins with a major study of energy, water and other resources, wetland protection, buffer zones and other issues.
2. Encouraging research and applied development
3. Demography, including the definition of a trained workforce and the welcoming of others, U.S. and internationals, needed to work in an industry.
4. The use of tax free Empire Zones. Each of the 61 counties in New York State can identify acreage or square feet which, when developed, avoids real property and business taxes for up to ten years.

What made this site attractive to AMD officials, who were considering sites in Asia and Texas or expanding in Dresden, were these factors:

- Pre-permitting, which expedited zoning, road and facility approvals
- A ten year real estate tax holiday, with NY State reimbursing the communities
- Sales tax exemptions
- No taxes on manufacturing and R&D equipment
- Significant NY State wage, tax and job credits
- Special reduced gas and electric rates
- The proximity of the University of Albany College of Nano Science
- The recreational and cultural venues of performing arts, equine attractions, and four season recreation opportunities including lakes and mountains
- The site was sandy and flat, reducing the dangers of vibrations and geological issues

The New York State "Tech Valley" now includes twenty counties on or near the Hudson River, beginning just north of New York City and extending to the Canadian border. The members include 350 corporations and major universities in the State.

- C. The above findings differ or corroborate related findings from current publicly available reports and studies as summarized below:

Efforts by regional, state and local initiatives, mainly by governments and institutions, are not yet causing significant increases in nanotechnology private sector new jobs.

Earlier-emerging industries caused rapid increases in small firms until the time when consolidation absorbed small firms into fewer larger companies.

A proactive approach is appropriate in responsible development; government partnerships with industrial sectors will ensure that responsible development is part of initial decision making.

The larger, established conventional manufacturing companies and end-users tend to look for partners with intellectual assets who could help them develop nanotechnology products or enhance existing products, e.g. the automotive, aerospace, off-highway/transportation and machine-tool manufacturers. Such organizations often have a department dedicated to organizing external collaborations, or technology acquisitions/licensing, and are, thereby, able to accelerate the introduction of nanotechnology into new products.

The smaller manufacturers and R&D laboratories seek new customers, end-users and other tier organizations who want to evaluate and use their nanotechnology products, such as nanoparticulate powders, nanotubes, nanocoatings and other highly engineered precursors.

## 5. Workforce Development and Education

### A. Study findings:

There exists a major education gap between needed skills and the current workforce. Better curriculum is needed at all levels of education that stresses science, biology, physics, math and chemistry. The nation must begin to think in terms of a marathon in considering many years for research and development to commercialization.

Having the right people with the right training is critical to commercialization. A gap exists but could be fixed with the proper education among the secondary education students.

Education, global competition and regulatory issues are connected issues. There is a worsening regulatory and legal climate for entrepreneurship and capital investment and insufficient achievement in science technology, engineering, and mathematics education, culminating in a shortage of the Ph.D.s.

The immigration bill must address the foreigners who get trained and educated in this country and then must return to their home due to restrictions. Immigration regulations must reflect the skills of the worker. As it is now, the workers or students go back overseas and, ultimately, compete with us. We need to develop knowledge of technology and science in schools. We need more skilled workers as small businesses are created. We need more scientists and researchers.

Some researchers or workers are foreign born and, therefore, have no access to federal labs or other technology in centers. This poses a problem for us.

There is an enormous shortage of United States citizens in the field of nanotechnology engineers. We need national leadership to encourage students to go into the sciences. There is also a shortage of B.A. level engineers.

We should have mandatory career orientation starting in the eighth grade through high school.

The present workforce in the sciences does not appear to have immediate replacements, especially within the United States. For example, in Arkansas teacher certifications for last year show just 1% in physics; only 120 math teachers and 3 physics teachers graduated last year.

Create an education alliance consortium with business to foster better communication.

Federal and state funding should increase for education and help support programs to encourage students to go into nanotechnology.

University of Texas has venture capitalist incubator-training for scientists to be entrepreneurs and understanding of micro enterprises. The program created 25 such enterprises and 12 are still operating. This program should be used as a universal model.

Security clearance currently can't be given to foreign nationals. A skilled workforce exists but not in the United States. We must have a homegrown technical and scientific workforce. Education in states must concentrate on more science, math and engineering courses.

The center in Albany has a program to train the working trades (pipe fitters, electricians, etc.) in construction of nano facilities. A semi-conductor facility may have 65% labor costs. Training and education should begin before high school. We are working with the business agents of the unions to train the workforce. This involves building as well as upgrading our infrastructure. We need more engineers and architects for nano based facilities.

Recently, during a conference in Baltimore, Maryland one presenter stated there are NanoSolar shingles for homes. There is presently a workforce of 3,000 installers. At the moment, 8,000 specially trained installers are needed to install 1 out of two homes. The U. S. has materials with a paucity of labor.

There are many foreign nationals being hired. The problem is they may not have been trained in updated labs. Our United States existing workforce has been educated using good equipment. The gap is closing fast, though.

Business is looking to hire PhDs, engineers, scientists and operators for the nanotechnology equipment. We are attracting foreign talent even in our strategic industries. Our drug industry has about 30% foreign nationals in its workforce.

We need to enhance talent in the United States. It is a barrier if we don't have a residential workforce. We also need to keep integrating the workforce with foreign nationals to gain valuable information from their research.

Government's role is to encourage more students into math and science courses. Perhaps a program could be instituted whereby government pays the education fee, provided that the student commits 5 years of service to the government. Pay scales for teachers are also abysmal and need to rise. A teacher's excellence program should be instituted.

The immigration barriers are preventing student and educated immigrants from coming to the United States.

There is not much need for a work force trained specifically for nanotechnology in the near future, based on large company experience presently. We would probably seek workers who had good general technical abilities and capable of working as multi-functional technicians. People who pursue multi-disciplinary studies would find it advantageous for future employment in diverse fields but nanotechnology work probably would not require specific training in that field.

The major issue would not be workers trained for product development so much as the need for better public education for workers generally in the fields of science, engineering and technology.

In the coming five to ten years, nobody knows what the nanotechnology platform effect would be in many different fields of industry so future work force needs are difficult to predict today. Perhaps, New York State and specifically the Albany area may be the best role model in the U. S. for job creation from laborer to scientists.

The major emerging need will be for more scientists and engineers trained in nano science. There will need to be schools and departments of Nanoscience at universities.

Increasingly programs must be interdisciplinary, crossing the usually separate scientific disciplines.

It will be important to provide business management training to nanotechnology entrepreneurs. Also, it will be vital to help investors, including hedge fund managers, understand the scientific potential of Nanotechnology.

In time, the forces of supply and demand may address the shortages. Even so, there is a need for a national science and engineering manpower and work force development policy.

There is already a serious problem with obtaining visas and HB1 permits for international workers in the United States. PhDs worry about whether they can stay in the U.S. after we have trained them.

The Immigration Bill constrains increasing the talented workforce we need. We educate foreign nationals and make it difficult for them to stay in the U.S. We are sending experienced and educated workers back to their home countries.

One suggestion is to issue a "green card with every diploma." Visa restrictions are a major problem to companies and for growth to continue.

When foreign nationals are in U. S, companies, they do not have access to DOD federal labs, including Sandia. That becomes a major problem. We need a workforce and the foreign nationals are available. Otherwise, the U.S. industry will decline, and Japan may emerge as a winner.

There does not seem to be a shortage of skilled workers for this field due to the large number of foreign nationals who are well educated and well trained.

The labor shortages are for technical people who recently graduated from school and studied the new and latest scientific and technical subjects and have gained working experience. Nanotechnology is a new advanced field so there are relatively few technicians with considerable work experience, and most of these people are already employed by large companies. This means the potential labor pool for new small nanotechnology companies excludes most workers at large companies and recently graduated students who lack working experience.

Desirable work experience includes soft skills acquired as an employee in a company including leadership practice, project management, patience in handling organization procedures, and being generally productive without need for much supervision.

A privately held company has an extensive patent and intellectual property portfolio with respect to molecular diagnostic platforms. The company is small

and 70% of its employees have graduate degrees. A barrier to nanotechnology long term growth is need for more students with skills in mathematics and science starting from primary school.

Nanotechnology companies in China are relatively large, committed to their nanotechnology divisions, well supported and very active in marketing their products domestically with potentially large markets. China is a powerhouse for manufacturing many products with ample labor and technicians better trained than other countries.

B. The above findings differ or corroborate related findings from current publicly available reports and studies as summarized below:

Companies seek to locate manufacturing in communities that have trained workforces. Naturally, the development and exploitation of new technologies or techniques cannot proceed without a sufficiently trained workforce.

The U.S. national trend is leading away from careers in technology at community colleges, undergraduate and graduate universities. Unfortunately, most of academia and the research community do not facilitate nanotechnology oriented type of multidisciplinary research.

The National Nanotechnology Initiative has adopted the multidisciplinary research classification of nanotechnology, biotechnology, information technology, and cognitive science.

The number of employees in each company engaged in nanotechnology commercialization, among nearly 600 respondents' organizations, is listed as a percentage of all companies responding to a recent survey:

- 57.5% – Less than 10 staff
- 18.2% – 11-20 staff
- 12.3% – 21-50 staff
- 6.7% – 51-100 staff
- 5.2% – Over 100 staff

The following three broad categories are suggested in addressing the unique needs of current generation of embryonic nanotechnology businesses:

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

## 6. Occupational Health:

### A. Study findings:

Health and safety issues need to be at the forefront and fear of nanotechnology should be confronted.

We need to be cautious with nanotubes but people should not panic. Put safety in perspective. For instance, the Institute of Carnegie Mellon can create a body to investigate and announce results of research and demonstrate that benefits may outweigh risks. National Science Foundation can have centers to address the process and understanding of nanotechnology.

Companies need to have good safety procedures for its workers who deal with chemicals, drugs and materials in its regular operations and they also apply to nanotechnology. More improvements are needed for testing procedures along with better safety regulations by government agencies.

Early stage technologies need much better government review requirements and safety test procedures along with laws and regulations.

### B. The above findings differ or corroborate related findings from current publicly available reports and studies as summarized below:

Human exposure to nanomaterials in the workplace and indoor and outdoor environments shows a need for early monitoring of workers subject to high nanotech exposures and toxicity concerns.

There is a need for more funding of safety issues, including workers, consumers and EPA. For the most part, companies see themselves as addressing worker and consumer issues for themselves but still feel there is a need for more basic and applied research funding on safety and EPA issues.

Workers may be exposed to nanoscale materials during manufacturing or synthesis, formulation or end use of products, or during disposal or recycling of the products.

Higher concentrations and amounts of nanoscale materials and higher frequencies and exposures are more likely in the workplace.

The government should review the adequacy of its regulation of exposure to nanoparticles, and in particular, consider the relative advantages of measurement on the basis of mass and number. There should be lower occupational exposure levels for manufactured nanoparticles.

## 7. Public Policy and Health:

### A. Study findings:

For example, fear that cell phone use caused brain cancer forced the FDA to perform a short-term study. The evidence did not support the hypothesis or perception that cell phone usage was related to brain cancer. Most problematic in this “public perception and media exposure” was that the scientific community was not prepared to answer that question and federal leadership assumed that role.

The EPA, OSHA, FDA and others are trying hard to do their job and to keep up with issues such as dealing with nano particle soot and pollution that will need to be addressed.

Some in the public and members of the press don't understand nanotechnology and are afraid of the consequences, side effects, waste product, toxic clouds etc.

### B. The above findings differ or corroborate related findings from current publicly available reports and studies as summarized below:

The public perception towards the federal government from public knowledge about and attitude towards Food and Drug Administration (FDA), Environmental Protection Agency (EPA), and U.S. Department of Agriculture (USDA) are good to excellent but the same public's perceptions towards business are ambiguous, according to a survey.

First, use of nanotechnology should be clearly labeled on products so consumers can make an informed choice as to whether to use a product. Second, companies should disclose to the Food and Drug Administration the results of safety testing they conduct; the FDA should immediately publicize results that show a negative health effect. Third, and most important, any testing policy that significantly delays use of some products should not also delay use of other products that did not prove to pose significant health risks.

There should be a long term policy and review program for public health and safety issues. U.S. regulatory agencies monitor existing laws that are inadequate to cover present and future complex nanotechnology: Toxic Substances Control Act; Occupational Safety and Health Act; Food Drug and Cosmetics Act; and major environmental laws—Clean Air Act; Clean Water Act; Resource Conservation and Recovery Act.

The public seeks participation in decision-making regarding nanotechnology government programs and has low trust of government agencies and business due to lack of testing and information. There is a need to develop strategic programs that enable relevant risk-focused research.

Standards for nanotechnologies may be approached from three directions:

1. Specifications for the production of the nano device, and the engineering practice of producing the nano-product;
2. How that nanoprodukt is integrated into other production supply chains;
3. How nanotechnologies are integrated into the product itself.

A key issue is how society can control the development and deployment of nanotechnologies to maximize desirable outcomes and keep undesirable outcomes to an acceptable minimum – in other words, how nanotechnologies should be regulated.

The U.S. FDA's regulatory role includes the Medical Device amendments of 1976, to protect public health, foster innovation and gain public confidence.

New laws and regulations are needed for manufacturers to demonstrate that their products will not present unacceptable risks to the public. Critical issues: There is a need to develop a short-term strategic plan for nanotechnology commercial products on the market, especially nanomaterials, with respect to toxicity internal dose; risk assessment; epidemiology surveillance; engineering controls, personal protective equipment; measurement; exposure; fire and explosion; communications and education.

Most managers believe government should have a major function to research, monitor and enforce health and environmental activities from nanotechnology. In 2007, more public groups want to know about nanotechnology in consumer products and will demand adequate health and safety assurances by governments and industry.

Concerns have been expressed that the very properties of nanoscale particles being exploited in certain applications (such as high surface reactivity and the ability to cross through cell membranes) might also have negative health and environmental impacts.

## 8. Government Budget:

### A. Study findings:

Basic research is the foundation upon which the United States built its global competitive advantage in the twentieth century. Funding for basic research is essential and needs to be increased. Additionally, the “valley of death” is the path where science emerges from the lab and evolves into application that has commercial viability. There is dirt of funding for, early proto-typing and early stage development. Federal, state, and regional governments should consider providing more technical assistance to the private sector. The Southeastern Ben

Franklin Group in Philadelphia provides high risk funding at the thirty to forty thousand dollar level to the early phase development and then up to almost three quarters of a million dollars funding to go to the next stage of development. Also, on a small scale, Wake Forrest's Technology Asset Management Team funds research and development through the Nanotechnology Center, the Life Sciences Research Programs and the Medical School.

Federal funding cutbacks were considered a barrier to important research projects, especially at the National Institute of Health. Others thought there is not enough access to university and federal laboratories and not enough access to their expensive equipment. This theme goes back to better cooperation between the public and private sectors.

Incubators need to be reinforced by government and tax credits need to support startup companies. N.I.S.T must increase its federal dollars in Research and Development.

Government must support innovations and investors to create small businesses. There must be a leverage of federal and state funds with private sector funding.

Funding from SBIR seems to be focusing on larger companies leaving small companies in a lurch. SBIR model does not fit with today's research because of time of research. It takes many years to come to production stage.

Leadership must come from State and Federal governments to support innovation because research may take from 3-4 years to as many as 10 years to complete. Funding must be earmarked for risks and marshalling resources.

State and federal leadership and funding is important to research. The average soldier is, today, carrying 31 pounds of batteries in Iraq. Defense Department must look for commercialization ventures to solve those particular problems.

We need to ask that a percentage of funds be devoted to nano research as opposed to applied research.

Our challenges are to transit from government research to commercial ventures and we need to connect a facilitating relationship between public/private funding and government information. SBIR is a valuable program.

The federal government needs to have a broad national vision for nanotechnology.

Perhaps we need to look at a better federal tax incentive to promote nanotechnology small businesses and research.

A potential improvement over present practice would be to provide more funding by government or other sources to accelerate early stage nanotechnology development towards commercialization of products. Small companies would prefer to obtain university R&D that is developed to the latest stage when it is just about ready for production, without having to pay for prior R&D. But taxpayers should prefer a government policy that does not fund university R&D work that is primarily for the product development stage; this investment should be undertaken and paid for by the private business that would ultimately reap most of the benefits of commercialization of the innovation.

The group acknowledged the need for periodic audits of federal nanotechnology grants. However, one CEO complained that three separate federal agencies sent audit teams at different times asking very similar questions, which required as much as \$100,000 in staff time.

There must be greater emphasis on Big Scale nano, with investments from DARPA and “National Centers” for the next generation of nano R&D.

We need more public funding for STEM (Science, Technology, Engineering, and Mathematics) education. There needs to be a heightened national effort to get more students into science fields.

**B. The above findings differ or corroborate related findings from current publicly available reports and studies as summarized below:**

Government assistance is vital to help finance nanotechnology infrastructure that requires higher investments and costs for nanotech multidisciplinary ventures and commercialization. Government ought to invest \$100 million over the next two years to fund risk research of environment and human health and continue to provide Federal government increases to fund risk research.

Government should sponsor nanotechnology vital risk research, offer tax incentives to encourage safer environment by business, purchase desirable nano products and services, and amend regulations to favor certain conduct and outcomes.

More than \$3 billion in U.S. Government funding has been earmarked for nanotechnology since 2003, putting it on track to be the largest U.S. Government funded science initiative since the space race, eclipsing even the Human Genome Project. As of 2005, nanotech has surpassed the Apollo space program to land a man on the moon as the most expensive scientific investment the U.S. Government has ever made.

Areas where greater 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.

## 9. Nanotechnology Standards:

### A. Study findings:

Measurement of nano standards must be established.

Some United States government agencies have excellent equipment and research information that start-ups could work with but potential users have problems getting through the bureaucracy. Some specific agencies mentioned are the Departments of Energy, Transportation, and National Institute of Standards and Technology (N.I.S.T).

Measurement of nano materials is a major issue. Some concerns for the future of nanotechnology will be manufacturing the right equipment and tools. Many of the needed support systems do exist. The real production capability and industry that exists today is the Silicon Valley model.

Start-ups may need assistance from the National Institute of Standards and Technology (N.I.S.T) for their infrastructure needs.

There are many potential issues that may require regulation. The bigger nanotechnology players such as Intel and IBM are already active on six committees addressing Standards, Nomenclature, Characterization and other questions where a common vocabulary will be essential.

B. The above findings differ or corroborate related findings from current publicly available reports and studies as summarized below:

There is urgent need to develop standards for each aspect of the new nanotechnologies: research, production, products, and waste disposal.

10. Global:

A. Study findings:

The rest of the world is spending more than the United States on research and technology. Competition between China and the United States will increase. There is a need to work to insure that the United States and international policy come together.

We may want to look at Israel as a model. They encourage incubator partnering to bring research from universities to commercialization. There are at least 24 such incubator models that are privately owned.

Another example can be found in New Zealand, with its grant program for nano with equal weights for basic, applied, development and commercialization grants. The same would not be true for U.S.

Export laws are barriers in a global research, development and commercialization world.

Large companies carry on R&D at laboratories and manufacturing plants located in many countries.

It is impossible to predict the next 10 years in the increasingly global economy. That means government policy should improve the overall education for the public and attract more and higher caliber teachers of science, engineering and technology.

There will be heightened international competition, especially with Asian nations. "We can beat the USA" is a sentiment expressed by nanotechnology leaders in some countries.

While this is cited earlier in this report is repeated in this section. The Immigration Bill encumbers the development of the talented workforce we need. We educate foreign nationals and make it difficult for them to stay in the U.S. We are sending experienced and educated workers back to their home countries.

Again, while this is cited earlier in this report it is appropriate to repeat in this section of the report. When we have foreign nationals in our company, they cannot have access to DOD federal labs, including Sandia. That becomes a major problem. We need a workforce and the foreign nationals are available. Otherwise, the U.S. industry will die and Japan could emerge the winner.

In our China operations, we were concerned about our IP (intellectual property issues). We did not take our top technology to our plants over there. International joint ventures, due to their complications, probably would not benefit from most new nanotechnology ventures.

Universities rarely seek international patent protection for their innovations and new small ventures mainly license U.S. patents for their startup period. Faculty public presentations that disclose their inventions before applying for foreign patents would preclude obtaining patent rights in most countries.

The U.S. export control laws require a company to comply with Department of Commerce rules solely because it has a foreign national employee with an H1-B visa, although the company never actually exported its products overseas. This exercise was lengthy, complicated and expensive and had no real purpose.

Most applicants for technical positions at our company are graduating students, usually Ph.D.s, and of these, most are foreign nationals who may not legally work in the U.S. It is expensive for our company to pay legal fees for processing H1-B visa applications in order to recruit from among the very few qualified employees in the U.S. In recent years, there has been a severe restriction on the number of available H1-B visas; this has prevented our company from hiring well qualified individuals already in the U.S. as students.

Nanotechnology is a wide field and barriers to commercialization in Asia-Pacific countries are similar to those existing in the U.S. Asia barriers are less related to FDA clearance procedures and nothing significant in most other aspects, other than working challenges similar to other new technology among the developing countries in Asia. Developed countries in Asia have similar barriers as the U.S., though they appear to be somewhat easier to manage due to smaller government and, hence, faster adjustment to changing circumstances of market and development.

Nanotechnology is, however, different from most new technology by allowing new innovations in many different industries that happen relatively quickly. In the short term, nanotechnology has real economic benefit since it can be combined with other products. The initial primary product of nanotechnology in Asia was mainly instrumentation, similar to U.S. In Asia today, the main development in industrial nanotechnology is in the manufacture of nanotechnology based input materials for consumer products and the value added industry. In Asia,

nanotechnology has become a diversified industry that spreads to many other fields.

Nanotechnology companies in China are relatively large, committed to their nanotechnology divisions, well supported and very active in marketing their products domestically with potentially large markets. Production capacity-wise, they are ready for substantial exports; however, current focus is on testing and refining products and input materials on the fairly large domestic market. China is a powerhouse for manufacturing many products with ample labor and technicians better trained than other in countries.

B. The above findings differ or corroborate related findings from current publicly available reports and studies as summarized below:

Global concern is growing since about 75% of nanotechnology R&D investment worldwide is done by foreign nations, and even more unknown amounts by private industry, thus making environment, health, and safety all international issues. Foreign competition might surge if they can operate with little regard for these issues.

The U.S. federal and state agencies, academia, the private-sector, other national governments, and international bodies, are considering potential environmental applications and implications of nanotechnology. There is a need to establish an international risk research network and coordination for public safety and health. Every debate over harmonization is about national differences in beliefs about workers, the environment, competitiveness, etc. At the same time, public demand for transparency in the harmonization of standards is likely to be a driving force.

University technology transfer offices should have a heightened sensitivity about export laws and regulations and how these bodies of law could affect university licensing practices.

Nanotechnology products are developing in 15 countries including the U.S., which has the highest number of products. Also participating in the nanotechnology fields are: Korea, Japan, UK, Germany, France, China, Taiwan, Australia, Israel, Finland, Mexico, Switzerland, New Zealand, and Sweden. Nanoscience and nanotechnologies are evolving rapidly, and the pressures of international competition will ensure that this will continue.

Some advantages cited in the argument for collaborating with Asian companies are:

- Abundant human resources
- Excellent facilities (Japan and Korea)
- Advanced technology (Japan, Korea, and Taiwan)
- Dynamic technology and strong market growth

For developing countries, the experts identify the top 10 nanotechnology applications desired would be:

1. Energy: There was a high degree of unanimity in ranking this area number one.
2. Agriculture: Researchers are developing a range of inexpensive nanotech applications to increase soil fertility and crop production and help eliminate malnutrition.
3. Water treatment: Nano-membranes and nano-clays are inexpensive, portable and easily cleaned systems that purify detoxify and desalinate water more efficiently than conventional bacterial and viral filters.
4. Disease diagnosis and screening: Technologies include the "lab-on-a-chip", which offers all the diagnostic functions of a medical laboratory.
5. Drug delivery systems: Technologies include Nano-capsules, dendrimers (tiny bush-like spheres made of branched polymers) and "buckyballs" (soccerball-shaped structures made of 60 carbon atoms) for slow, sustained drug release systems.
6. Food processing and storage: Improved plastic film coatings for food packaging and storage may enable a wider and more efficient distribution.
7. Air pollution remediation: Technologies include nanotech-based innovations that destroy air pollutants with light.
8. Construction: Technologies include nano-molecular structures to make asphalt and concrete more resistant to water; materials to block ultraviolet and infrared radiation.
9. Health monitoring: Nano-devices are being developed to keep track of daily changes in physiological variables such as the levels of glucose, carbon dioxide, and cholesterol without the need for drawing blood in a hospital setting.
10. Disease vector and pest detection control.

Partnering to Access Global Markets: Respondents in a survey indicated the following top six application markets their organizations are pursuing in nanomanufacturing:

1. Nanotechnology Equipment, Logistics and Distribution
2. Electronics and Semiconductors
3. Computing, IT and Telecommunications
4. Aerospace
5. Automotive
6. Chemicals and Process

Organizations are partnering to access global markets in the following top five areas of nanotechnology product development:

1. Semiconductors, nanowires, lithography and printing products
2. Nanostructures, nanotubes and self-assembly
3. Coatings, paints, thin films and nanoparticles

4. Environmental sensing and remediation
5. Defense applications and protection gear

Increased influence by foreign investors – As the technology continues to mature, additional countries will enter the fray, raising the flow of money and, in turn, increasing competition amongst investors. Japan, China, and England are becoming major “heavy hitters” in the nanotechnology market. These foreign firms will play key roles in driving innovative economic activity throughout the 2000’s not only in the U.S. but across the globe. U.S. nanotech investors are urged to create synergistic partnerships with foreign entities when strategically favorable.

#### 11. Instrumentation and Metrology:

##### A. Study findings:

There is a need for nanotechnology metrology standards.

##### B. The above findings differ or corroborate related findings from current publicly available reports and studies as summarized below:

Instrumentation and Metrology are lacking, although vital to the development of the basic terminology and comprehensive nomenclature of nanomaterials. Metrology, the science of measurement, underpins all other nanoscience and nanotechnologies not only because it allows the characterization of materials in terms of dimensions but also in terms of attributes such as electrical properties and mass.

Universities should ensure broad access to research tools and further open R&D.

Advanced instrumentation and sophisticated metrology need to be developed to characterize properties of nanomaterials and products. Greater precision in metrology will assist the development of nanoscience and nanotechnologies. Presently there are inadequate characterization and measurement tools and capabilities to enable on-line and in-line monitoring and processing control based on nanoscale features.

The first winners in the nanotechnology industry are likely to be the manufacturers of instruments allowing work on a nanoscale. According to market researchers, the nanotechnology tools industry (\$245 million in the U.S. alone) will grow by 30% annually over the next few years.

It will be important to develop instruments to assess exposure to engineered nanomaterials in air and water in next 3-10 years. Tools and devices required

are instrumentation including AFM, ISAM, Molecular Switches, Nanodevices and systems.

Global harmonisation in the field of nanomaterials metrology is of vital importance and is a prerequisite for the development of effective risk management and control policies.

## 12. Nano-Bio Technology:

### A. Study findings:

(Not applicable)

### B. The above findings differ or corroborate related findings from current publicly available reports and studies as summarized below:

The science and engineering of nanobiosystems is one of the most challenging and fastest growing sectors of nanotechnology. Applications of nanotechnologies in medicine are especially promising and areas such as disease diagnosis, drug delivery targeted at specific sites in the body and molecular imaging are being intensively investigated. Some products are undergoing clinical trials.

Nano-bio markets include: drug delivery, diagnostics, molecular biology, bio-nanodevices and systems, etc.

## 13. Energy:

### A. Study findings:

(Not applicable)

### B. The above findings differ or corroborate related findings from current publicly available reports and studies as summarized below:

The energy R&D strategies to reach research targets include: Using Interfaces to Manipulate Energy Carriers; Linking Structure and Function at the Nanoscale; Assembly and Architecture; Theory, Modeling, and Simulation for Energy Nanoscience; Scalable Synthesis; Catalysis by Nanoscale Materials.

EPA is actively participating in nanotechnology development and evaluation, funding research through EPA's Science To Achieve Results (STAR) grant

program, its Small Business Innovative Research (SBIR) program, and performing in-house research in the Office of Research and Development.

Nanotechnology and nanoscience advances are leading to improved energy resources that could be packaged in every conceivable way and location. The long term impact of such packages and eventual disposal in the environment are unknown.

#### 14. Society:

##### A. Study findings:

(Not applicable)

##### B. The above findings differ or corroborate related findings from current publicly available reports and studies as summarized below:

Nanotechnology acceptance by the public is subject to: the extent of hyperbole directed at the public, the classes of people with power and wealth compared to others who are helpless, types and extent of issues affecting public health and safety. The public impression generally is that risks from nanotechnology would outweigh the benefits derived.

Nearly 95% of respondents to a survey wanted a degree of government involvement in the commercialization of nanomanufacturing. This trend is partly due to the aggregate respondents' fear that the U.S. could lose its competitive advantage in future nanotechnology innovations due to the rapid growth of off-shoring of traditional manufacturing and research operations. Other concerns driving such a high response preference could be the executives' belief that the industry needs continued government funding and new policies addressing nanotoxicity and environmental impact. These unprecedented issues merit the government's proactive leadership in conducting unbiased, "good science" investigations.

If it is difficult to predict the future direction of nanoscience and nanotechnologies and the timescale over which particular developments will occur; it is even harder to predict what will trigger social and ethical concerns.

The Singularity (2020 and beyond) is the exponential curve eventually reaching a point where the growth rate becomes almost infinite. At the Singularity, technology continues to advance at exponential rates, a time at which scientific advances aggressively assume their own momentum and accelerate at unprecedented levels, enabling products that today seem like science fiction.

The United Nation's International Centre for Science and High Technology tackled such issues in February, 2005 at a meeting entitled "North-South" Dialogue on Nanotechnology. The Centre argued that nanotechnology may offer important benefits to developing countries and it is not correct to assume that it is too difficult or too expensive for them.

15. Risk Management:

A. Study findings:

(Not applicable)

B. The above findings differ or corroborate related findings from current publicly available reports and studies as summarized below:

An integrated research framework by the U.S. federal government is needed to manage environmental, health and safety issues of many agencies. Federal agencies should provide risk research for nanotechnology regarding environmental, health and safety.

EPA's mission and mandates are understanding health and environmental implications of intentionally produced nanomaterials. A challenge in evaluating risk associated with the manufacture and use of nanomaterials is the diversity and complexity of the types of materials available and being developed, as well as the seemingly limitless potential uses of these materials.

As an integral part of the innovation and design process of products and materials containing nanoparticles or nanotubes, industry should assess the risk of release of these components throughout the life cycle of the product and make this information available to the relevant regulatory authorities.

From a private insurance company's perspective more funding for independent research on risk issues is necessary and there should be a dedicated research center supported by government.

The similarity between carbon nanotubes and asbestos fibers has been highlighted by the toxicology community and is an issue of potential concern. Carbon nanotubes exhibit some characteristics that are similar to asbestos fibers with regards to shape, size and bio-persistence. Whether this indicates a similar toxicity is not known at present and research is needed urgently despite the current responsible attitude adopted for their handling in the wider scientific community.

An integrated risk research framework by government is needed to manage nanotechnology environmental, health and safety issues by coordinating many agencies.

17. Environment:

A. Study findings:

(Not applicable)

B. The above findings differ or corroborate related findings from current publicly available reports and studies as summarized below:

There is a need to focus efforts on the types of nanoparticles already being used by industry, as these pose the most immediate exposure threat to humans and the environment. Governments and industry should develop models for predicting the potential impact of engineered nanomaterials on the environment and human health, within the next 10 years.

Nanomaterials have promising environmental applications. For example, nanosized cerium oxide has been developed to decrease diesel emissions, iron nanoparticles can remove contaminants from soil and ground water, and nanosized sensors hold promise for improved detection and tracking of contaminants. In these and other ways, nanotechnology presents an opportunity to improve how we measure, monitor, manage, and reduce contaminants in the environment.

Most participants in the study stated that the risk to the public, the environment, and the workforce is presently unknown. It is recommended that factories and research laboratories treat manufactured nanoparticles and nanotubes as if they were hazardous and seek to reduce or remove them from waste streams.

Thus, there is an immediate need to formulate short-term toxicity testing protocols. Here, we believe that some of the approaches used in parallel and combinatorial screening may well have a valuable contribution to make, for at present, toxicologists are not able to keep up with the speed at which the nanotechnologies industries are developing nor to cope with the wide range of forms in which particles of the same materials may be produced.

18. Nanotechnology Materials:

A. Study findings:

(Not applicable)

B. The above findings differ or corroborate related findings from current publicly available reports and studies as summarized below:

Presently there are too few resources to develop and validate methods to evaluate the toxicity of engineered nanomaterials within the next 5-15 years.

Passive nanostructures marketed during 2000-2005 are products that take advantage of the passive properties of nanomaterials, including nanotubes and nanolayers. Simple nanotechnology uses mass production and dispersion of nanomaterials in random fashion, such as catalysts in composites and coatings in textiles. Currently and for next few years, the most important nanomaterials are nano crystals, nano tubes and nano particles.

Multiwall carbon nanotubes' basic patents have just expired so other companies could begin to commercialize related new products, with increasing manufacturing in low-cost countries.

Much of nanoscience and many nanotechnologies are concerned with producing new or enhanced materials. Such materials include: nanotubes, fullerenes (??), powders, ceramics and chemical manufacturing which includes thin film coatings, nanocomposites, etc.

19. Conflict of Interest:

A. Study findings:

(Not applicable)

B. The above findings differ or corroborate related findings from current publicly available reports and studies as summarized below:

An issue universities should anticipate and help to manage better is their technology transfer procedures and related conflicts of interests at all levels involved.

21. Nanotechnology Devices:

A. Study findings:

(Not applicable)

B. The above findings differ or corroborate related findings from current publicly available reports and studies as summarized below:

Nanotechnology applications as devices may include active nanostructures (markets 2005-2010) that change their state during use, responding in predictable ways to the environment around them. There is concern that the public may be wary of such devices and refuse acceptance of them.

Nanoparticles might seek cancer cells and release an attached drug. The use of nanomaterials to construct novel materials, devices and systems calls for a need to precisely fabricate and position nanostructures.

The expanding role of nanoscience and nanotechnologies in the development of information technology was anticipated in the International Technology Roadmap for Semiconductors, a worldwide consensus document that predicts the main trends in the semiconductor industry up to 2018.

## 21. Nanotechnology Manufacturing:

### A. Study findings:

(Not applicable)

### B. The above findings differ or corroborate related findings from current publicly available reports and studies as summarized below:

Systems of Nanosystems (markets 2010-2015) are assemblies of nanotools working together to achieve a final goal and may include molecular self-assembly manufacturing. A key challenge is to get the main components to work together within a network, possibly exchanging information in the process.

Manufacturing printed electronic circuits and solar power panel cells is a new strong trend in several countries for 2007. So far, the relatively small numbers of applications of nanotechnologies that have made it through to industrial application represent evolutionary rather than revolutionary advances. Current applications are mainly in the areas of determining the properties of materials, the production of chemicals, precision manufacturing and computing.

Taking a page from the natural process by which patterns are formed in nature on seashells and snowflakes, IBM announced on May 3, 2007 its ability to form trillions of holes to create insulating vacuums around the miles of nano-scale wires packed next to each other inside each computer chip. IBM says testing in its labs has proven that the electrical signals on the chips can flow 35% faster, or the chips can consume 15% less energy, compared to the most advanced chips using conventional techniques. The company says it's the first-ever application of a breakthrough self-assembling nanotechnology to conventional chip manufacturing. "This is the first time anyone has proven the ability to synthesize

mass quantities of these self-assembled polymers and integrate them into an existing manufacturing process with great yield results," said Dan Edelstein, IBM Fellow and chief scientist of the self-assembly air gap project. "By moving self-assembly from the lab to the fab, we are able to make chips that are smaller, faster and consume less power than existing materials and design architectures allow." The new technique to make air gaps by self-assembly skips the masking and light-etching process. Instead, IBM scientists discovered the right mix of compounds which they pour onto a silicon wafer with the wired chip patterns, then bake it. This new technology can be incorporated into any standard CMOS manufacturing line without disruption or new tooling, according to IBM. The self-assembly process was jointly invented by IBM's Almaden Research Center in San Jose, Calif. and the T.J. Watson Research Center in Yorktown, N.Y. The self-assembly process already has been integrated with IBM's manufacturing line in East Fishkill, N.Y. and is expected to be fully incorporated in IBM's manufacturing lines and used in chips in 2009. The chips will be used in IBM's server product lines and, thereafter, for chips IBM builds for other companies. The secret of the breakthrough, says IBM, lies in how the scientists moved the self-assembly process from the laboratory to a production manufacturing environment in a way that can potentially yield millions of chips with consistent, high performance results.

Commercialization of nanotechnology as an important goal by management depends on their type of organization— 62% component vendors and suppliers, 57% manufacturers/integrators, 56% contract R&D labs and 52% end-users, reported their organizations place high priority on nanotechnology developments; but 45% respondents from government labs, 30% from the service sector, and 32% respondents from academia stated commercialization goal received medium priority.

The size of an organization generally determines its goal—at least two-thirds of respondents from organizations with 50-100 staff in nanotechnology and nearly 60% of large players in nanotechnology (i.e. corporations with over 100 staff) indicated their organizations place high priority on commercialization of nanotechnology.

## 22. Related Services:

### A. Study findings:

(Not applicable)

### B. The above findings differ or corroborate related findings from current publicly available reports and studies as summarized below:

The successful commercial exploitation of advanced nanotechnology products requires unprecedented levels of collaboration (both vertical and horizontal) across many different realms in order to adequately address the inherent complexities associated with the lifecycles of such products.

Nearly 20% of respondents from large (>100 staff) organizations indicated their nanotechnology developments are “strictly internal” efforts, indicating highly proprietary nature of their developments; but nearly 75% of respondents from the smallest (< 10 staff) organizations indicated they rely on external collaborations for pursuing nanotechnology products.

### 23. Outer Space:

#### A. Study findings:

(Not applicable)

#### B. The above findings differ or corroborate related findings from current publicly available reports and studies as summarized below:

Nearly every space program worldwide has found remarkable and successful roles for Micro and Nano Technologies. The development of these technologies have occurred in response to the lighter-weight, smaller-size, less-power-dissipation, lower-cost mantra chanted by those involved with commercial outer-space, aerospace, and military applications. These highly specialized industrial sectors are not directly relevant to general business and consumers.

MNT's have come to the fore because they're the only technologies that can meet space and defense needs.

## **CHAPTER 4 CONCLUSION**

*The conclusions emphasize the most important findings and may extend the findings beyond conditions specific to the project. Specific recommendations are intended to facilitate application of the findings and are accompanied by information on potential benefits that can be expected from using the research study. A plan for implementing the research study is part of the recommendations. The project findings reveal specific areas where further research would be valuable, and these areas are described in this chapter.*

## **Conclusions**

Significant barriers to nanotechnology innovation and commercialization can be substantially lowered, and some barriers virtually eliminated, if major steps are taken, including the following:

A) Funding by government and corporations is already "research" biased; more funding is needed for the "development" of products.

B) More sophisticated and early market research is needed to bridge the science culture-to-commercialization gap. Markets and future products must be identified early in the R&D stage, followed by periodic impartial reviews as innovations are transformed into prototypes that are placed into production and finally offered for sale.

C) There is need to establish new federal and state laws and regulations that encourage nanotechnology small and medium business growth, the expansion and novel financing of more multidisciplinary R&D, better intellectual property protection, and development of larger, more sophisticated nanotechnology corporations and venture capital funds.

D) Federal, state and local government support is needed to encourage more networking, strategic alliances and joint ventures for expanding international collaboration involving universities, R&D laboratories, investors, manufacturers and product distributors.

E) Governments should proactively: authorize new laws and regulations that offer tax incentives to encourage safer environment by business; make and promote public purchases of desirable nanotechnology products and services; amend existing regulations to favor certain industrial conduct and outcomes for good public policy; and support more education and training of researchers and workers.

## **Recommendations**

Organize national and regional nanotechnology coordination and promotion centers to accelerate the potential benefits that can be expected by more rapid and efficient use of available resources including funding, cross licensing and patent pooling, risk research, etc.

## **Suggested research**

Further research studies would be invaluable on the subject of international barriers to nanotechnology commercialization, investment and trade.

## REFERENCES

- Adams, L. (2003, October). Video is Versatile. *Quality Magazine*, 32. Ahlgren, Martin, and Franchi, Helena Jonsson., Policy for a New Industrial Revolution- A Study of Nanotechnology in the USA. Swedish Institute for Growth Policy Studies.
- Aitken, R., Butz, T., Colvin, V., Maynard, A., et al. November 2006. Safe Handling of Nanotechnology. Nature Publishing Group. Vol. 444. No. 16. pp. 267-269.
- Anderson, P., & Tushman, M. L. (1990). Technological Discontinuities and Dominant Designs: A Cyclical Model of Technological Change. *Administrative Science Quarterly*, 35, 604-633.
- ANGLE Technology Group, "Commonwealth of Pennsylvania Nanotechnology Strategy," (August 10, 2004).
- Aragon, L. (2004, July 1, 2004). Nano-Bubble Ahead? *Venture Capital Journal*, July 1, 2004, 1.
- Bergman, B. (2005, April 1). License to Grow: An Explosion of Patent Filings Brings With it an Increase in Litigation Cases. What Can a Savvy Investor Do? *Venture Capital Journal*, 1.
- Braunschweig, C. (2003, January 1). Nano Nonsense: Venture capitalists are searching for the next big thing in the smallest of technologies. But even with the most powerful electron microscope, they will find it very difficult to detect a profit. *Venture Capital Journal*, 1.
- Braunschweig, C. (2004, May 31). Nanotech Company Raises \$45M Recap. *Private Equity Week*, 11(21), 2.
- Brookstein, Darrell. (2005). *Nanotech Fortunes- Make Yours in the Boom*. San Diego: The Nanotech Company.
- Bruns, B., 2001, Open Sourcing Nanotechnology Research and Development: Issues and Opportunities, *IOP Electronic Journals*, Vol. 12, (3), pp.198-210.
- Chemical Week* 167, no. 42 (Dec 14, 2005): p. 22-23.
- Christopher, A. (2000, October 1). The IT Hot List: Leading VCs Say Where the Smart Money is Headed. *Venture Capital Journal*.
- Conner, J. (2005). *Foresight Ideas and Other Nano Media*. Retrieved December 2, 2005, from [www.foresight.org](http://www.foresight.org)
- Coopers & Lybrand (1996). Three Keys to Obtaining Venture Capital.
- Darby, M., Zucker, L., 2003 Grilichesian Breakthroughs: Inventions of Methods of Inventing and Firm Entry in Nanotechnology, National Bureau of Economic Research.
- Davies, J. C. (2006, January 11). Stricter Nanotechnology Laws Are Urged. *The Washington Times*, A02.
- Davey, Michael E. 2006. Manipulating Molecules: Federal Support for Nanotechnology Research. CRS Report for Congress.

- Department of Health and Human Services. 2007. Progress Toward Safe Nanotechnology in the Workplace: A Report from the NIOSH Nanotechnology Research Center. CDC Workplace Safety and Health.
- Duggan, C. (2005, May). Come to Daddy. *Inc Magazine*, (May 2005), 48.
- The Economist (2006, April 12). Has All the Magic Gone? *The Economist*.
- Fishbine, G. (2002). *The Investor's Guide to Nanotechnology & Micromachines*. New York: John Wiley & Sons, Inc.
- Fluckiger, S., 2006, Industry's Challenge to Academia: Changing the Bench to Bedside Paradigm, *Experiential Biology and Medicine*.
- Friedman, R. S., McAlpine, M. C., Ricketts, D. S., Ham, D., & Lieber, C. M. (2005, April 28). High-Speed Integrated Nanowire Circuits. *Nature*, 434(April 2005), 1085.
- Foley, Edward T. and Hersam, Mark C., 2006. Assessing the Need for Nanotechnology Education Reform in the United States. *Nanotechnology Law & Business*. Vol. 3. No. 4. pp.467-484. *Futures* 38, no. 9 (Nov 2006): p. 1060.
- Gauthier-Jaques, A. (2005, January). Financial Market Perspective – The Commercial Potential of Nanotechnology and the Value for Investors. *Journal of Medical Marketing*, 5, 36.
- Geiger, Roger L., and Hallacher, P., 2005, NANOTECHNOLOGY AND THE STATES PUBLIC POLICY, UNIVERSITY RESEARCH, AND ECONOMIC DEVELOPMENT IN PENNSYLVANIA, Penn State University.
- Gubrud, MA (1997), 'Nanotechnology and International Security', paper presented at the Fifth Foresight Conference on Molecular Nanotechnology, Palo Alto, 5-8 November (p.3).
- Gupta, U. (2001, September 1). For Venture Capitalists, Life Sciences is Hot. *Venture Capital Journal*.
- Hassan, E., & Sheehan, J. (2003, May). Scaling-up Nanotechnology. *Organization for Economic Cooperation and Development*.
- Hiroshi, Yohsino, "High-Tech Development Strategy after the Collapse of the R&D Bubble," *Knowledge Creation and Integration*, May 2003.
- Hodge, G., Bowman, D., and Binks, P. 2005, Nanotechnology, The Next Big Business, *Monash Business Review*, 1, (2) pp.1-11.
- Holman, M., Kemsley, Nordan, M., et al. The Nanotech Report: 4<sup>th</sup> Edition. Investment Overview and Market Research for Nanotechnology. 2006.
- Horsley, P. (1997). Trends in Private Equity. *National Venture Capital Association*.
- Ikezawa, Naoki., 2001, "Nanotechnology: Encounters of Atoms, Bits, and Genomes," NRI Papers, No. 62.
- Ikezawa, Naoki., 2002, Nanotechnology to Japan's Rescue, Kodansha
- Ikezawa, Naoki., 2004, The Role of Venture Businesses in Supporting the Commercialization of Nanotechnology, Nomura Research Institute. Vol. 7, No. 1 (February 2005).
- Journal of the Minerals, Metals and Materials (2004, October). Venture Capital – Corporations Invest in Nanotechnology's Future. *Journal of the Minerals, Metals, and Materials*, 6.

- Knezo, Genevieve J. 2006. Federal Research and Development: Budgeting and Priority-Setting Issues, 109<sup>th</sup> Congress. CRS Report for Congress.
- Knol, E., 2004, Micro and nanotechnology commercialization: balance between exploration and exploitation, MANCEF COMS2004 conference, pp. 215-220.
- Krazit, T. (2005, June 9). HP Technology Lets Future Chips Live with Mistakes. *InfoWorld Magazine*.
- Lawrence, S. (2005, June 2005). Nanotech Grows Up. *Technology Review*, June 2005, 31.
- Lee, Alexander. Examining the Viability of Patent Pools to the Growing Nanotechnology Patent Thicket. University of Virginia.
- Lerner, J. (2002). Boom and Bust in the Venture Capital Industry and the Impact on Innovation. *Economic Review*, (Fourth Quarter 2002).
- Linquiti, P. and Teepe, P. 2006 Characterizing the Environment, Health, and Safety Implications of Nanotechnology: Where Should the Federal Government Go from Here? ICF International.
- Lux Research. 2006. The Nanotech Report. 4<sup>th</sup> Edition.
- Macoubrie, J. 2005. Informed Public Perceptions of Nanotechnology and Trust in Government. The Project on Emerging Technologies. *Machine Design* 78, no. 23 (Dec 14, 2006): p. 71.
- Malinowski, B. Magic, Science, and Religion, and Other Essays Garden City, N.Y.: Doubleday Anchor, 1948.
- Maynard, Andrew. 2006. Is Nanotechnology Hazardous to your Health? *Machine Design*. Vol. 78. no. 23. p.71.
- Maynard, Andrew. 2006. "Research on Environmental and Safety Impacts of Nanotechnology: What are the Federal Agencies Doing?" United States House of Representatives Committee on Science.
- Mazzola, L., 2003, Commercializing Nanotechnology, *Nature Biotechnology*, Vol. 21, (10), pp. 1-7. Meeting with Christopher T. Hill, Professor of Public Policy and Technology, George Mason University, 2005.
- Nanoscale Science and Engineering, Program Solicitation for FY 2005, National Science Foundation, 2004.
- Nanoscale Science, Engineering, and Technology Subcommittee. 2006. Instrumentation and Metrology for Nanotechnology: Report of the National Nanotechnology Initiative Workshop January 27-29, 2004.
- Nanoscale Science, Engineering, and Technology Subcommittee. 2005. Nanobiotechnology: Report of the National nanotechnology Initiative Workshop October 9-11, 2003.
- Nanoscale Science, Engineering, and Technology Subcommittee. 2005. Nanoscience Research for Energy Needs: Report of the National Nanotechnology Initiative Grand Challenge Workshop March 16-18, 2004.
- Nanoscale Science, Engineering, and Technology Subcommittee. 2006. Nanotechnology in Space Exploration: Report of the National Nanotechnology Initiative Workshop August 24-26, 2004.
- Nanoscale Science, Engineering, and Technology Subcommittee. 2005. Nanotechnology: Societal Implications-Maximizing Benefits for Humanity:

- Report of the National Nanotechnology Initiative Workshop December 2-3, 2003.
- Nanoscale Science, Engineering, and Technology Subcommittee. 2005. Regional, State, and Local Initiatives in Nanotechnology: Report of the National Nanotechnology Initiative Workshop September 30-October 1, 2003.
- Nanoscience and Nanotechnology: Opportunities and Challenges in California, California Council on Science and Technology, 2004.
- Nanotech Report, An Insiders Guide to the World of Nanotechnology, Forbes, 2002.
- [Nanotechnology Breakthroughs of the Next 15 Years](#). Futurist, Jan/Feb2007 Supplement, Vol. 41, p4-4, 1/2p; (AN 23934658)
- Nanotechnology in Massachusetts, A report on nano-scale research and development and its implications for the Massachusetts economy, Massachusetts Technology Collaboration and Nano Science and Technology Institute (NSTI), March 2004.
- [Nanotechnology knowledge gaps](#). Environmental Science & Technology, 11/15/2006, Vol. 40 Issue 22, p6871-6871, 1/6p; (AN 23312555).
- [Nanotechnology's Future](#). By: Roco, Mihail C. Scientific American, Aug2006, Vol. 295 Issue 2, p39-39, 1p, 1c; (AN 21506588).
- National Academy of Sciences/Engineering/Medicine. Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future.
- National Nanotechnology Advisory Panel, "The National Nanotechnology Initiative at Five Years," President's Council of Advisors on Science and Technology, (May, 2005).
- National Technology Initiative. 2006. Environmental, Health, and Safety Research Needs for Engineered Nanoscale Materials.
- National Nanotechnology Initiative. *NNI Budget by Agency*. Retrieved August 24, 2005, from [www.nano.gov/html/about/nnibudget](http://www.nano.gov/html/about/nnibudget).
- National Nanotechnology Initiative Workshop. 2003. Nanotechnology and the Environment.
- National Technology Initiative. Research and Development Leading to a Revolution in Technology and Industry. Supplement to the President's 2007 Budget. July 2006.
- National Venture Capital Association (2005). *Overview of the Venture Capital Industry*. Retrieved July 25, 2005, from [www.nvca.org/def](http://www.nvca.org/def).
- Organization of Economic Co-operation & Development. Venture Capital: Trends and Policy Recommendations. *Organization of Economic Co-operation & Development*, 4.
- O'Hara, T. (2005). Venture Firms Make Fewer, Smaller Deals. *The Washington Post*.
- Peters, L., Sundararajan, M., 2003, Acquisition of resources for commercializing emerging technologies: comparing large firms with startups. *Management of Engineering and Technology*. PICMET '03., Page 425-435.

- Plunkett Research. *Trends in Research and Development*. Retrieved July 2005, from [www.plunkettresearch.com](http://www.plunkettresearch.com)
- PricewaterhouseCoopers, Thomson Venture Economics, National Venture Capital Association (2005, April 26, 2005). Q1 2005 Money Tree Survey. *Moneytree Survey*, (Q1 2005).
- PricewaterhouseCoopers Moneytree (2005). *Historical Trend Data – Moneytree Survey*. Retrieved July 21, 2005, from [www.pricemoneytree.com/moneytree/nav](http://www.pricemoneytree.com/moneytree/nav).
- Private Equity Week (2005, February 28). DFJ Closes Fund with \$400M. *Private Equity Week*.
- Professional Engineering* 19, no. 16 (Sep 6, 2006): p. 45-46.
- Rashba, E. and Gamota, D., 2004, Anticipatory Standards and the Commercialization of Nanotechnology, [Journal of Nanoparticle Research](#), 5, (3-4), 401-407.
- Rocco, M. C. (2005, April). The New Engineering World. *Mechanical Engineering*, (April 2005), 7-11.
- Roco, M. C. (2005, October 3). *Subcommittee on Nanoscience, Engineering and Technology (NSET) and National Science and Technology Council Presentation*. Retrieved , from Roco, MC (2004), 'The US National Nanotechnology Initiative after 3 years (2001-2003)', *Journal of Nanoparticle Research*, 6, 1-10.
- Schlatka, B., Nanotechnology: Realizing the Promise of Universal Memory, *Nanotechnology Law & Business*, Vol. 2, (3), pp. 1-7.
- [Selecting the key research areas in nano-technology field using technology cluster analysis: A case study based on National R&D Programs in South Korea](#). By: Lee, Yong-Gil; Song, Yong-II. *Technovation*, Jan 2007, Vol. 27 Issue 1/2, p57-64, 8p; DOI: 10.1016/j.technovation.2006.04.003; (AN 23445342).
- Semiconductor International* 26, no. 4 (Apr 2003): p. 19.
- Service, R. F. (2004, June 18). Nanotechnology Grows Up. *Science*, 1732.
- Sheahan, M. (2005, February 2005). Investment Pace Starts to Return to Normal. *Venture Capital Journal*, February 2005, 28-30.
- Shulz, Max (1999, June 24). The End of the Road for Silicon. *Nature*, 729-730, Vol 399.
- Small Scale Technologies: Directions for Victoria Final Report. Centre for Strategic Economic Studies. Victoria University, Melbourne, December 2003.
- Small Times Media LLC (2004). The Rational Investors Guide to Nano & Micro Technology. *Small Times Media*, 18.
- Taylor, M. 2006. Regulating the Products of Nanotechnology: Does FDA Have the Tools It Needs? Woodrow Wilson International Center for Scholars Project on Emerging Nanotechnologies.
- The Economist (2004, April 3). After the Drought. *The Economist*, 371(8369), 71-74.
- The Henry Samueli School of Engineering, UC Irvine (2005, June 9). *UCI Scientists Use Nanotechnology to Create World's Fastest Method for*

- Transmitting Information in Cell Phones and Computers*. Retrieved June 9, 2005, from [www.today.uci.edu](http://www.today.uci.edu).
- [Visualization of the citation impact environments of scientific journals: An online mapping exercise](#). By: Leydesdorff, Loet. *Journal of the American Society for Information Science & Technology*, Jan2007, Vol. 58 Issue 1, p25-38, 14p, 4 charts, 10 diagrams; DOI: 10.1002/asi.20406; (AN 23463982).
- Thompson, D. (2005, August 9). *Nanotechnology Draws Investment, But Still Seeks Return*. Retrieved August 9, 2005, from [www.stephensmedia.com](http://www.stephensmedia.com)
- Toumey, C., 2004, *Narratives for Nanotech: Anticipating Public Reactions to Nanotechnology*.
- Walton, M. (2004, April 16). *Will Nanotech Save the World or is it Mostly Hype?*. Retrieved April 11, 2005, from [www.cnn.com/2004/tech/science/04/15/nanotech.ideas/index.html](http://www.cnn.com/2004/tech/science/04/15/nanotech.ideas/index.html)
- Weiss, R. (2005, March 28, 2005). *Nanotech Is Booming Biggest in US, Report Says*. *The Washington Post*, A6.
- Wejnert, J. (2004), 'Regulatory Mechanisms for Molecular Nanotechnology', *Jurimetrics Journal*, 44 (Spring) (p.4).
- Woodrow Wilson International Center for Scholars Project on Emerging Nanotechnologies. 2006. *Attitudes Toward Nanotechnology and Federal Regulatory Agencies*. Peter D. Hart Research Associates.