

AC 2008-1519: MITIGATION OF BARRIERS TO COMMERCIALIZATION OF NANOTECHNOLOGY: AN OVERVIEW OF TWO SUCCESSFUL UNIVERSITY-BASED INITIATIVES

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Mitigation of Barriers to Commercialization of Nanotechnology: An Overview of Two Successful University-Based Initiatives

Abstract

Nanotechnology, being a platform technology, feeds its output into numerous industries, which use these inputs to improve their products. In this context, it would be appropriate to refer to BASF, whose slogan is “we do not create products, we make them better”. Consequently, any effort to commercialize this technology has to be supported by scientific and engineering research in conjunction with an innovative well-funded product development and marketing program involving all downstream industries that are going to utilize nanotechnology products. There is no doubt about the potential of nanotechnology to impact numerous facets of human life and society, and the incentive for expeditious commercialization of this technology is strong. However, considerations and factors, such as long time between nanotechnology research and development of commercial products, large capital investment needed for a viable commercial venture, and financial/operational risks associated with commercial applications of nanotechnology, have impeded rapid adoption of this technology in the commercial domain. Substantial government funding, and involvement of academic institutions and research laboratories, are viewed as an essential response to these barriers. It is critical for the U.S. nanotechnology industry to speed up the process of commercialization, if we are to maintain a competitive position in the global nanotechnology market. Two progressive institutions of higher learning, The Pennsylvania State University and The University at Albany in New York state, have made very significant contributions in the arena of nanotechnology commercialization. This has been accomplished through education/training programs for workforce development, and through partnerships with large and small industrial organizations for conducting R & D, and commercialization programs. In this presentation, the two leading consortia involving these universities, namely Albany Nanotech/ Tech Valley and Nanofab, are profiled as role models for other educational institutions seriously interested in nanotechnology R & D and commercialization projects.

Nanotechnology Overview

The term “nanotechnology” covers processes associated with the creation and utilization of structures in the 1 nanometer (nm) to 100 nm range. Nanofabrication involves engineering at the atomic length scale. Engineering at this scale makes it feasible to create, atom by atom, fibers which are very small in diameter but extremely strong. In the health care domain, extremely minute probes can detect disease by examining individual strands of DNA. Nanofabrication makes it possible to manufacture capillary systems for providing nutrients to man-made replacement organs.

The nanofabrication process has been used for creation of new chemical and biological substance detectors, which incorporate structures holding molecules that change their

electrical conducting properties in the presence of the substances being detected. The development of a new class of nanoscale transistors and molecular electronics has also been made possible by the utilization of nanotechnology. These molecular electronics (transistor), combined with nanoengineered fabrics and structural members possessing amazing strength, have enabled engineers to create computers with incredible processing speed and enormous memory capacity.

In spite of the unlimited potential of nanotechnology in the consumer products domain, the commercial applications of this technology have been confined to utilization of colloidal nanoparticles in cosmetics, protective coatings, drug delivery, and stain-resistant clothing

Ongoing research and development at a large number of educational institutions and research laboratories should enlarge the set of commercial applications of nanotechnology in the near future. Two educational institutions engaged in these efforts are highlighted in this presentation.

Nanotechnology Applications

Despite the fact that the concept underlying nanotechnology was first discussed by Richard Feynman almost 50 years ago, it was not until 1980 that the term “nanotechnology” was defined in the context of its application by Dr. K.E. Dexter. (1) Two developments in 1980’s, the formalization of cluster science, and the invention of the Scanning Tunneling Microscope (STM) led to the discovery of fullerenes and carbon nanotubes, later during that decade. The Atomic Force Microscope (AFM), which was developed a few years later, stimulated the application of nanofabrication through the usage of the tip of a scanning probe to manipulate nanostructures. Competing with this bottom-up technique for nanofabrication is lithography, a top-down nanofabrication process designed to reduce bulk material (bulk, in the context of nanoscale!) to a nanoscale pattern. Along with the tools and techniques described above, Dual Polarization Interferometry (DPI) has stimulated the research and development that has taken nanotechnology into the domain of consumer and industrial applications.

Nanotechnology is capable of producing products, materials and devices that impact a wide spectrum of industries and consumer products. Therefore, it is pragmatic to view Nanotechnology as a “platform technology” with applications in a number of industrial sectors, and with potential for producing a variety of products. The list of current and potential nanotechnology applications continues to grow. However, it would be appropriate to consider the following areas of nanotechnology application as the most as the most promising beneficiaries (not ranked in any manner):

- Electronics and Semiconductors
- Information Technology (Computing and Telecommunication)
- Aerospace and Automotive Industries
- Chemical Processes and Engineering
- Agriculture
- Energy
- Disease Diagnosis
- Health Monitoring

- Drug Delivery
- Food Processing and Storage
- Water Treatment and Air Pollution Control

The five top ranking areas of nanotechnology product development are (2)

- Semiconductors, nanowires, lithography and printing products
- Nanostructures, nanotubes and self-assembly
- Coatings, paints, thin films and nanoparticles
- Environmental sensing and remediation
- Defense applications and protection gear.

Although tremendous excitement has been stimulated by the potential applications of nanotechnology, the usage of “first generation” passive nanomaterials accounts for most of the commercial application of this technology currently (3). The products/applications include titanium dioxide nanoparticles in sunscreen, cosmetics and food products (usage of nanoparticles as additives to existing consumer products); silver nanoparticles in food packaging, clothing, disinfectants and household appliances; zinc oxide nanoparticles in sunscreen and cosmetics, surface coatings, paints and outdoor furniture varnishes; and cerium oxide nanoparticles as a fuel catalyst (exploitation of surface characteristics of nanoparticles to improve chemical reactions and interfacial bonding). The relatively short list of actual applications of nanotechnology indicates that further research is needed to diversify the utilization of this technology.

Ongoing and planned R&D is focused on the development of new products such as optically switched computers, medical diagnostic systems, drug delivery systems capable of targeting precise application areas, and miniaturized consumer products.

Nanotechnology Commercialization

Nanotechnology is a combination of science and technology, and its commercialization requires theoretical understanding of the underlying process, and specialized equipment for producing nanotechnology products through nanofabrication. This attribute of nanotechnology has resulted in most of the research and preliminary development involving nanotechnology being conducted at universities and government funded research laboratories. Nevertheless, successful commercialization of nanotechnology generally requires cooperation between the research organization(s) and a commercial developer. In a report concerning best practices for nanotechnology commercialization, Waitz and Bukhari (4) pointed out that the most currently visible nanotech company, Narcosis was formed through the licensing of Intellectual Property (IP) from universities, where the world’s leaders in nanoscience academics and research are resident. Michael Darby and Lynne Zucken, in a study conducted for the National Bureau of Economic Research (5), stated that 70 % of university inventions cannot be utilized without the involvement of the inventor. The inventor team generally consists of university faculty members and students who conduct research. This background and overview of the commercialization process for nanotechnology, highlights the need for preparing the research faculty and senior students at major academic research centers for participation in successful commercialization of

their inventions and discoveries. As shown in Figure 1, academic institution based researchers have to be actively involved as knowledge-bearing assets, in at least two of the five steps in the progression from concept to marketing of technology/products in the commercialization process for nanotechnology.

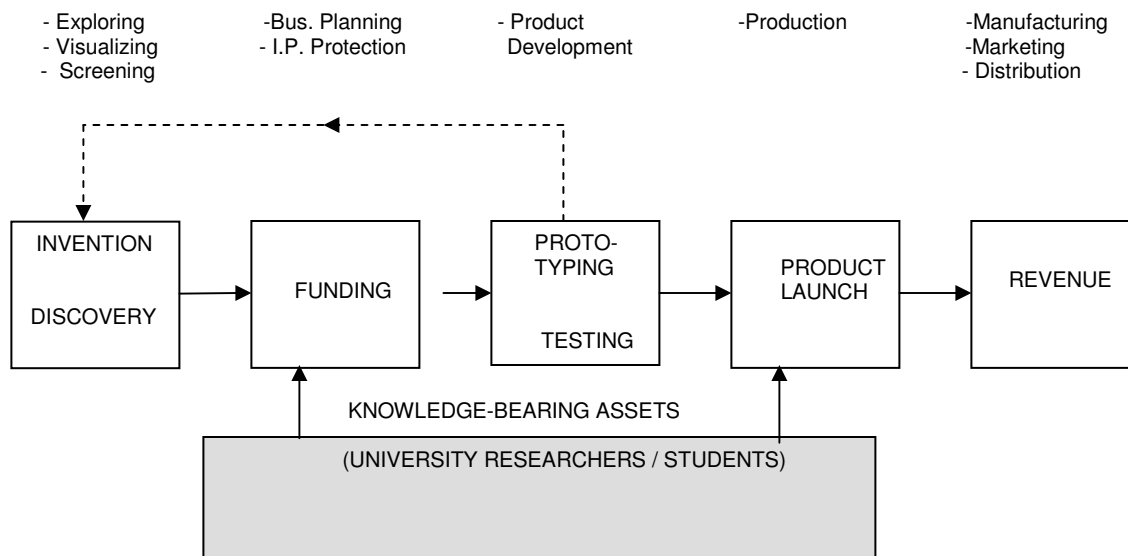


FIGURE 1
COMMERCIALIZATION PROCESS FOR NEW TECHNOLOGY

Therefore, the researchers and students conducting nanotechnology research should be exposed to the real world of technology transfer and commercialization, through courses and customized training programs at academic institutes. Many universities and colleges are now offering degree and/or certificate programs in entrepreneurship, for scientists and engineers.

Basically, the commercialization process for nanotechnology is similar to that for many other advanced technologies (e.g., Information Technology, Bio-Medical Technology, and Multi-Media Technology) developed and commercialized during the last two decades. However, the issues related to the protection of intellectual property, the long time period between researching a concept and creating a commercial product (up to 10 years), large capital investment needed for commercialization at a scale that is financially logical, barriers to the adoption of offshoots of this platform technology by potential users (lack of standards; health, safety and environmental concerns; and shortage of trained engineers

and technicians) will make it necessary to devote special attention to the commercialization process in the curriculum and training programs available at our educational institutions.

It is encouraging to note that most of the major nanotechnology research centers located at institutions of higher education in the U.S. have academic programs, and resource centers that address the commercialization issues and processes for this technology quite effectively. Some of leading institutions in this respect are listed below:

- The University at Albany
- Pennsylvania State University
- Rensselaer Polytechnic Institute
- University of Arizona
- University of Texas
- Massachusetts Institute of Technology
- University of California at Berkeley
- Cornell University
- City University of New York
- Louisiana Tech University
- University of Wisconsin
- University of Washington
- Northwestern University

It is realistic to anticipate that many other universities will join this group of pioneer institutions in promoting the development and commercialization of nanotechnology in the near future.

In the next two sections of this paper, two of the leading university based nanotechnology research, development, and commercialization programs, namely, the Pennsylvania State University Nanofabrication Facility (under National Nanotechnology Initiative), and the NanoTech Complex at the College of Nanoscale Science and Engineering, located at the University at Albany (a part of the State University of New York System), are highlighted.

The Pennsylvania State University Center for Nanotechnology Education and Utilization

As one of the leading stimulators of innovation in higher education, and research in science/engineering, the National Science Foundation (NSF) concluded that rapid development and commercialization of nanotechnology will require an infrastructure incorporating academic institutions, financial organizations, industrial entities, and business groups. This conclusion is in line with the need to link exploration (research) with exploitation (development and commercialization) in a successful endeavor focused on timely commercialization of a cutting-edge technology [6].

A prime example of such an infrastructure of partnerships is the National Nanotechnology Initiative (NNI) which provides a multi-agency framework to support the utilization of

nanotechnology to improve human health, economic well being, and national security of the U.S. The NNI supports nanotechnology commercialization through the following mechanisms:

- Funding research leading to discoveries – inventions
- Making available forefront research facilities – lowering costs of access to high-cost equipment
- Developing an academic and business environment that promotes innovation and commercialization
 - Organizing/conducting workshops and publishing reports
 - Working with the U.S. Patent and Trade Mark Office
 - Initiating programs for setting standards for nanotechnology
- Providing education and training to develop workforce necessary to support commercialization
- Providing funding and coordination for research on Environmental, Health, and Safety impacts of nanotechnology
- Providing focal points for public dialogue
- Direct funding for start-up/innovative activities

Nanotechnology Commercialization at The Pennsylvania State University

The Pennsylvania State University Nanofabrication Facility (Nanofab) is a completely open access National Nanotechnology Infrastructure Network (NNIN) user facility. The NNIN is an integrated networked partnership of user facilities, supported by the National Science Foundation (NSF), serving the needs of nanoscale science, engineering, and technology. The Nanofab facility provides state-of-the-art micro and nanofabrication equipment worth \$ 32 million, in Class 1 and Class 10 clean rooms.

The Nanofab facility was established to enable advanced interdisciplinary academic and industrial research and development in the semiconductor electronics and optoelectronics, micro- and nano- electromechanical systems (MEMS/NEMS), materials, biological and pharmaceutical fields. It also has a designated NNIN focus on materials, chemicals, and molecular scale technologies. Operating for over 12 years, the Nanofab has an established performance record of proactively identifying and engaging non-traditional users of nanotechnology, and linking nanoscience and nanoengineering to new disciplines.

Although the market for nanotechnology products is still in its infancy, buyers do not have to look far to find a consumer good with a nanotech connection. Sporting goods, clothing, passenger car tires, skin care products, even cooking oils, all incorporate nanomaterials in their production. The NNI Project on Emerging Nanotechnologies, undertaken by the Woodrow Wilson International Center for Scholars, has identified over 200 consumer products claiming to have a nanotechnology component.

The Pennsylvania State University spin out companies have taken several nanotechnologies into the marketplace. About 10 years ago, a Penn State team in the Department of Chemistry developed NanobarcodesTM, metallic rods with complex patterns

that can encode information at the submicron scale. A Penn State chemist founded Chiral Quest, a company that produces catalysts designed to facilitate the formation of molecules useful in the pharmaceutical industry. This company has been operational since the year 2000.

In 2005, Penn State jointly developed, with Philips Research, the new industry standard CMOS transistor model for future nanometer chip design. This chip model will be the standard to simulate the behavior of future CMOS chips at the 65 nm technology node and beyond.

NanoHorizons is a Penn State spin-out that licenses nanotechnology applications in a variety of areas, including antimicrobial silver nanoparticles for textiles; improved solar cell technology; and nanotechnology-based mass spectrometry targets for drug discovery.

Other current and near-future commercial developments by Penn State researchers include miniaturized ultrasound imaging arrays that, in the future, will be sensitive enough to monitor the drug reaction within an individual cell; molecular dots carrying fluorescent markers and anticancer drugs that will target tumors; and microminiaturized piezoelectric devices that can manipulate objects at the upper end of the nanoscale.

During the last 15 years, Pennsylvania State University has maintained its position as one of the leading academic institutions in the domain of nanotechnology R &D, and commercialization of this technology.

College of Nanoscale Science and Engineering-University at Albany, State University of New York

(a) Overview

The leading nanotechnology R & D and commercialization program in the U.S. (and possibly in the world) is being conducted at the College of Nanoscale Science and Engineering (CNSE) at the University at Albany, a part of the State university of New York (SUNY). The NanoTech Complex at CNSE is the centerpiece of the nanotechnology commercialization program at this institution.

The following statement in a U.S. Department of Commerce [2] report concerning the commercialization of nanotechnology confirms the key role that Albany NanoTech and the State of New York are currently playing in the commercialization of nanotechnology: “In the coming five to ten years, nobody knows what the nanotechnology platform effect would be in many different fields of industry, so future 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 scientist”. Along with an extensive program of advanced nanotechnology research and development, the NanoTech Center in Albany operates a program for training trades (pipe fitters, electricians, etc.) needed for the construction of nano-facilities. In addition to the University at Albany, Rensselaer Polytechnic Institute (RPI), and Hudson Valley Community College (HVCC) are also very actively engaged in nanotechnology R & D, and work force education and training. The

New York State “Tech Valley”, with 350 corporations and major universities as its members, operates in 20 counties, and has concentrated on the commercialization of nanotechnology during the last 5 years. The R & D activities at Albany NanoTech and RPI, the academic programs at CSNE, RPI, and HVCC, coupled with the nanotechnology work force training programs being conducted by Tech Valley and HVCC, justify the designation of Albany, NY as the nanotechnology commercialization capital of the world.

A condensed description of the nanotechnology academic programs, research and development facilities and activities, workforce training programs, and commercialization initiatives at CNSE and Albany Nanotech follows:

The College of Nanoscale Science and Engineering, and the Albany NanoTech Complex were established in 2001. This was preceded by the formation of New York State Center of Advanced Technology in 1993, construction of NanoFab 200 building in 1997, and formation of National Focus Center Consortium in 1998. The College of Nanoscale Science and Engineering (CNSE) of the University at Albany awarded the world's first Ph.D. degrees in Nanoscience in 2004. Albany NanoTech is the umbrella under which the CNSE and the five following Centers operate [7]. The five centers are:

- Center of Excellence in Nanoelectronics
- Center for Advanced Technology in Nanomaterials and Nanoelectronics
- Center for Interconnect Focus
- Center for Nanoscale Metrology and Imaging
- Center for Energy and Environmental Technology Applications

Since 2001, Albany NanoTech has been providing technology acceleration and business incubation support by partnering with a group of onsite corporations including Applied Materials, ASML, IBM, International SEMATECH North and Tokyo Electron. It receives substantial funding from private companies, which is matched by the State of New York. Albany NanoTech through partnerships of industry, university, and government, has created a triple helix model which is a new paradigm for research, technology development, education to support an accelerated nanotechnology commercialization in pursuit of economic development and job creation in the state of New York. As the leading member of this consortium, CNSE and has initiated new academic programs, implemented new nanofabrication facilities. CNSE also oversees and coordinates all of UAlbany’s work in both nano-and micro-technologies, including education, research and development, technology deployment, and economic outreach [7, 8].

CNSE's Albany NanoTech complex, a \$4.2 billion, 450,000-sq ft facility, has attracted over 250 global corporate partners and is the most advanced university based research complex in the world. Further expansion of the complex is underway, and it is expected to have 750,000 sq ft of floor space by the end of 2008; with 80,000 sq ft of Class 1 clean room space to accommodate over 2,000 scientists, researchers, engineers, students, and faculty [8].

CNSE was ranked nation's number one college in 2006 and 2007 for nanotechnology and microtechnology programs in the Annual College Ranking by Small Times magazine. CNSE also received top-10 rankings in 2007 from its peers in three areas: nano commercialization, micro commercialization and micro research. CNSE at UAlbany was awarded 98 nanotechnology patents, more than any other respondent in the 2007 Small Times' survey [9].

(b) Academic Programs

CNSE offers the following six graduate degree programs leading to M.S. and Ph.D. in the emerging interdisciplinary fields of nanosciences and nanoengineering [8, 9]:

M.S. in Nanoscale Science

Ph.D. in Nanoscale Science

M.S. in Nanoscale Engineering

Ph.D. in Nanoscale Engineering

M.S. in Nanoscale Science /Masters of Business Administration (Dual Degree)

M.S. in Nanoscale Engineering/Masters of Business Administration (Dual Degree)

These programs are organized to address four fundamental disciplines or constellations of CNSE: nanoscience, nanoengineering, nanobioscience, and nanoeconomics. The curriculum follows the tracks pertaining to nanoelectronics, nano/micro-electro-mechanical, optoelectronics, optical, energy, and nanobiological fields.

The cross-disciplinary graduate curriculum both for M.S. and Ph.D. degrees integrates the fundamental science principles of chemistry, physics, computer science, biology, and electrical, chemical, biochemical and mechanical engineering. Over 100 nano and micro technologies focused courses are offered to provide fundamental knowledge in basic science and engineering design. Growth properties of nanomaterials, such as semiconductors, metals, chemicals, biochemicals and polymers are studied in these programs. Each discipline places considerable emphasis on science and technology know-how for atomic-scale characterization, atomic scale modeling and metrology to develop the fundamental skills necessary for independent and original research. Entry requirements are designed to accept students with undergraduate and graduate educational background in Chemistry, Physics, Computer Science, Biology; and Chemical, Biochemical, Electrical, Mechanical engineering [9, 10].

There are two dual-degree (Nano+MBA) interdisciplinary programs at CNSE: one program links the M.S. in Nanoscale Science with the Masters of Business Administration, and the other program combines the M.S. in Nanoscale Engineering with the Masters of Business Administration. The "Nano+MBA" is a cooperative effort between the College of Nanoscale Science and Engineering and the School of Business at the University at Albany. The goal of the programs is to develop industry ready graduates who will be facilitators of change with the ability to integrate science, engineering, business, and management. The objectives of these programs are: (1) Integrate knowledge and skills from nanotechnology and business disciplines for effective responses to rapidly changing

environments; (2) Prepare scientists and engineers for effective participation in the management of nanotechnology-based organizations. The requirements for the M.S.-MBA dual degree programs include a minimum of 63 credits: 36 credits in required School of Business (SOB) coursework and 27 credits in required College of Nanoscale Science and Engineering (CNSE) coursework.

(c) Nano-Fabrication and Commercialization Facilities

CNSE's Albany NanoTech Complex with a total investment of \$4.2 billion has cutting edge facilities having 750,000 sq ft of total floor space; including a 65,000 sq ft Class-1 capable 300 mm wafer clean room which is being currently used by a number of nano-electronics industries. Albany NanoTech also has hundreds of tools for EUV lithography, Litho & Patterning, Thin Film & Growth, Etching & Polarization, Compound Semiconductor Processing, Analytics & Characterization, and sample preparation. This complex also provides 200-mm/300-mm wafer fabrication facilities that encompass nanoelectronic technologies for biochip, optoelectronic and photonic devices, system-on-a-chip, ultra high speed communication components, and closed-loop sensors for monitoring, detection and protection. The Albany NanoTech Center has three Nano fabrication incubation facilities, NanoFab 200 (CESTM), NanoFab 300(North), NanoFab 300(South). Another incubation facility, NanoFab 300 (East), is scheduled to open in 2008.

NanoFab 200 (CESTM) was completed in June 1997 with a total space of 70,000 sq ft and 4,000 sq ft clean room space. NanoFab 200 is used to provide pilot manufacturing with the only 200 mm wafer processing, characterization and prototype fabrication capabilities at the university, supercomputing center and advanced materials processing facilities [11].

NanoFab 300 South, completed in 2004 with a total floor area of 150,000 sq ft, has been used as technology acceleration facility for business incubation, classrooms for CNSE, and workforce training space and offices for Albany NanoTech and industrial sponsors and partners. This facility has a 32,000 sq ft clean room which is used to support IBM, and SEMATECH North research activities

NanoFab 300 North, which became operational in December 2005, has a 35,000 sq ft Class 1 clean room suitable for 300 mm wafer R&D. This clean room has been used for incubation, and as a pilot prototype and workplace training facility with a full nanoelectronics process line. It also houses the world's first extreme ultraviolet ("EUV") Alpha Demo Tool, developed by ASML.

NanoFab 300 East, projected to be completed in fall 2008, will have 250,000 sq ft of floor space, including 15,000 sq ft of 300 mm wafer, Class 1 clean room space.

These facilities are used for research, development and commercialization in the area of emerging nanosciences, including nano/ microelectronics, nano/microsystems including MEMS, nanophotonics and optoelectronics, nanometrology, nanopower, analytical sciences and process control, and advanced computer modeling for nanosystems and processes.

(d) Business Resources and Partnerships

Albany NanoTech has utilized its resources effectively in fostering partnerships with business, government, and academia to create jobs and economic growth in the region. Since 2001, Albany NanoTech has established partnerships with over 250 universities, Federal labs, and industrial organizations. The list of Albany NanoTech partners includes RPI, SUNY Stony Brook, Argonne National Laboratory, DARPA, NASA, AMD, ASML, Freescale, General Electric, Honeywell, IBM, International Sematech, Qimonda, SONY, Toshiba, and Tokyo Electron. Many of these partners are currently located onsite at the Albany NanoTech facilities.

For corporate partners, Albany NanoTech provides a virtual one-stop shop by assisting companies to overcome technical, market and business development barriers through technology incubation, pilot prototyping and test-bed integration support. This support by Albany NanoTech has generally resulted in accelerated deployment of nanotechnology-based products. Proof of concept technology incubation is provided through 450,000 sq. ft. of on-site office, laboratory and clean room incubation facilities. The Department of Energy National Renewable Energy Laboratory has designated Albany a "Clean Energy Incubator," that provides access to direct operating support and a national alliance of venture capital investors and technology companies located around the country. Product qualification support is provided via access to a unique state-of-the-art industry standard semiconductor fabrication facility, serving as a technology test-bed leading to the development, demonstration, integration and qualification of advanced fabrication technologies for the semiconductor industry [11].

Albany Nanotech has been involved in multi-year research partnerships with big corporations, and sponsored research collaborations with national defense agencies and start-up companies. All the partners, small, large, medium size corporations, and universities, have access to the state-of-the-art laboratories and an array of scientific centers serving their long and shorter-term technology development needs. These Albany NanoTech partners are able to collaborate, establish alliances, or form joint ventures and consortia within a technically and financially competitive environment [7].

CNSE has established partnerships with community colleges, high schools and industry for work force training/education of technicians, operators and technical trades by providing hands-on training in their state-of-the-art laboratories. CNSE also provides summer and year-round internships for students of local colleges and high schools, in addition to organizing four day "Chip Camps" targeting high school vocational students in partnership with Semiconductor Equipment and Materials International (SEMI).

Conclusion

Nanotechnology, which is considered an emerging platform technology, is bound to affect just about every facet of human life and society. There are high expectations about the benefits and commercial potential of this technology. Therefore, as this technology is being researched and developed in laboratories and industrial incubators, policy makers,

strategic planners and entrepreneurs are focused on the commercialization of the products of this new technology. The seriousness of the interest of the Federal government in the research, development and commercialization of nanotechnology is evidenced by the allocation of more than \$ 3 billion since 2003 for programs in this arena. It has been mentioned that the Federal government investment in nanotechnology may be exceeded in magnitude by the Federal funding for NASA programs only.

In spite of this massive support by the government, so far there are only about five hundred nanotechnology businesses producing fewer than 500 products involving nanotechnology in the U.S. [12, 13]. The following statements in a U.S. Department of Commerce report [2] concerning nanotechnology commercialization indicate that the progress of nanotechnology commercialization has not been satisfactory so far:

- There are no ‘home runs’ in U.S. nanotechnology commercialization at this time.
- The goal of high volume manufacturing of nanotechnology molecules and products is a very important activity to strengthen to U.S. nanotechnology capabilities.
- Commercialization of such advanced functional materials and products requires that they can be produced in a predictable, reliable way, and in sufficient quantities. Until this is achieved, production will be limited to academia and R & D departments within industry.

Since we are a long way from the objective of making nanotechnology industry robust and viable, the role of academia in speeding up the commercialization of nanotechnology will continue to be critical for many years in the future. The conclusions of the above referenced study emphasize the role of academia in maintaining the momentum that is required for timely commercialization of nanotechnology. Albany NanoTech, CNSE at the University at Albany, and Nanofab at the Pennsylvania State University have already confirmed that academic institutions can be very effective in facilitating, promoting and sustaining the commercialization of nanotechnology. Even after the nanotechnology industry attains maturity, progressive entities like Albany NanoTech and Nanofab will be needed to sustain the R & D activities, and nanotechnology work force education and training. Academic institutions will continue to be key participants in our efforts to maintain the competitive position of the U.S. in the commercial exploitation of nanotechnology world wide.

Therefore, other institutions should seriously consider emulating the role that Albany NanoTech and Nanofab are playing in the ongoing evolution of the commercial applications of nanotechnology. Let us hope there are several other institutions in the U.S. whose administrations have the vision and resources to become active participants in this endeavor.

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