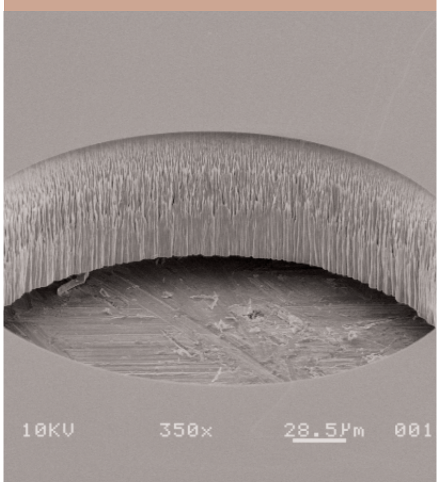
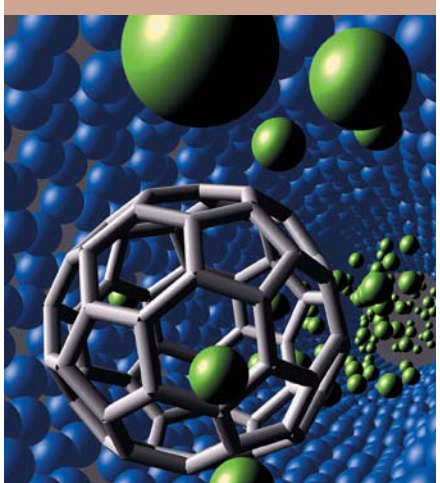
FINAL REPORT





RECOMMENDATIONS TO ADVANCE CONNECTICUT'S POSITION IN NANOTECHNOLOGY DEVELOPMENT

PREPARED FOR:

The Connecticut Office of Workforce Competitiveness
with the State Department of Higher Education

IN CONSULTATION WITH:

Connecticut Advisory Council on Nanotechnology

FACILITATION AND TECHNICAL ASSISTANCE PROVIDED BY:

Battelle
Technology Partnership Practice

February 2006

Battelle
The Business *of* Innovation

Recommendations to Advance Connecticut's Position in Nanotechnology Development

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Advisory Council on Nanotechnology

An Advisory Council on Nanotechnology, comprised of representatives from industry, university and state economic development organizations, was formed by the Office for Workforce Competitiveness, in collaboration with the Department of Higher Education, to advise in the development of recommendations to the General Assembly in positioning the state to advance nanotechnology development and education programs, as set out in Public Act No. 05-198 and Special Act No. 05-13.

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Executive Summary

An Advisory Council on Nanotechnology, comprised of representatives from industry, university and state economic development organizations, was formed by the Office of Workforce Competitiveness, in collaboration with the Department of Higher Education, to advise the development of recommendations to the General Assembly in positioning the state to advance nanotechnology development and education programs, as set out in Public Act No. 05-198 and Special Act No. 05-13.

The Advisory Council sees significant urgency for Connecticut to bolster its competitiveness in nanotechnology development. Nanotechnology, as one of the key drivers of the next industrial age, will be critical to the future competitiveness of Connecticut's diverse manufacturing sectors, from aerospace to advanced materials to fuel cells to pharmaceuticals and biotechnology.

But nanotechnology is a moving target. Nanotechnology will offer waves of development over time as new discoveries and innovations take place, similar to how information technology and biotechnology have played out in recent decades.

To miss the opportunity to grow in nanotechnology as this field emerges would be a strategic mistake. Trying to play catch up in nanotechnology in the future is a recipe for disaster.

Today, Connecticut is at risk of not keeping pace with the development of nanotechnology. While Connecticut has a growing base of activity in nanotechnology across its universities and companies, it is lacking in key infrastructure and targeted development activities. And the need to act is urgent because the pace of technology advancement is fast, the competition is aggressive and we risk falling behind with inaction.

Legislative Charge to Move Nanotechnology Development Forward in Connecticut

Over the past year, Connecticut has been actively assessing its potential with the completion of a *Call to Action: Advancing Nanotechnology Development in Connecticut* completed in May of 2005.

Based on this strategic assessment and broader concerns on how Connecticut can ensure its competitive position in an emerging technology area, the General Assembly passed two statutes in the 2005 legislative session calling for specific recommendations on how the state should proceed.

In Public Act No. 05-198, **An Act Concerning The Promotion Of Collaborative Research Applications With Industry**, under Section 4, the General Assembly called for the Office of Workforce Competitiveness to establish an Advisory Council on Nanotechnology to guide the preparation of "recommendations to advance this state's position in nanotechnology development, including recommended state investments to increase university research, develop centers of excellence and shared use facilities, promote partnerships and collaborations involving technology-based business and industry with institutions of higher education, leverage current federal resources and advance education and training programs in nanotechnology fields."

In addition, under Special Act No. 05-13, **An Act Concerning Nanotechnology, Molecular Manufacturing And Advanced And Developing Technologies At Institutions Of Higher Education**, the General Assembly called for the Commissioner of Higher Education, in consultation with the Office of Workforce Competitiveness, to "review the inclusion of nanotechnology, molecular manufacturing and advanced and developing technologies at institutions of higher education."

Specific Action Plan for Connecticut Nanotechnology Competitiveness Program

The Advisory Council sets out a specific, customized **Nanotechnology Development Program** for Connecticut as part of the state's approach to **Innovation Challenge Grants**, enacted in Public Act No. 05-198, to further talent generation, university-industry collaboration and commercialization of research.

Four nanotechnology-specific initiatives are proposed for Connecticut to advance its nanotechnology position:

The first is to establish a strong Connecticut focus on nanotechnology by building on the state's Office for Small Business Innovation and Research (SBIR). SBIR is a federal research program that assists small and emerging companies in advancing the development and commercialization of new products. SBIR is a strong fit with the needs of nanotechnology because it is targeted to small and emerging companies and to the critical need in nanotechnology of reduction to practice and prototype development. The state's SBIR-supported services can be effectively leveraged with just a small enhancement to bring a focused effort towards nanotechnology that includes more active outreach and workshops with federal agencies seeking nanotechnology SBIR proposals, enhanced advisory services for companies pursuing nanotechnology-related SBIRs, and more hands-on support in the development of ideas for SBIR proposals.

The second is the establishment of a Connecticut Nanotechnology University/Industry Collaboration Initiative. This nanotechnology-focused collaboration initiative can serve as the means to translate and seize the potential of nanotechnology in Connecticut by fostering industry-university relationships, and advancing nanotechnology product development and demonstrations in Connecticut.

To ensure that Connecticut has the workforce to support nanotechnology development, it must actively advance Post-Secondary Education Program Development and Educational Clearinghouse. Nanotechnology must be integrated more extensively into associate's, bachelor's, and master's degrees, and not simply left to Ph.D. programs. A number of Connecticut higher education institutions are already engaged in developing a nanotechnology curriculum. The goal should be to share approaches, fill needed gaps in curriculum development, and address access to instructional laboratories across higher education. Through the involvement of an industry advisory board, new curriculum development can be linked to specific skill requirements. There is also the opportunity to involve Connecticut's new Center for Science and Exploration, particularly for the K-12 system.

An enabler for both nanotechnology industry development and education-training is establishing a Connecticut Center for Nanoscale Sciences and Development, a shared use nanotechnology instrumentation facility with related programs. This would be a "signature facility" for nanotechnology in Connecticut. The value of a shared use nanotechnology instrumentation facility goes well beyond enhancing a university's competitiveness for federal grants; it also can enable nanotechnology discoveries to be more quickly advanced for proof-of-concept and future testing. A nanotechnology instrumentation facility can also offer an important "hands-on" component for nanotechnology-related education and training programs. Given the high cost and required technical support to operate sophisticated nanotechnology tools, it is best to organize these nanotechnology tools as shared use laboratories that can have broad reach to academic and industry researchers.

The Advisory Committee also recognizes that nanotechnology development in the state is dependent upon broader technology initiatives being in place in Connecticut. In particular, two recommendations for establishing an Innovation Network in Connecticut are critical to the success of Connecticut in reaching the economic development goals in nanotechnology, namely:

- Establishing a Connecticut-Focused Seed and Venture Fund Initiative
- Establishing a comprehensive Technology Commercialization Services Program

Advisory Committee Recommendations to Guide the Strategic Objectives and Vision For Ensuring Connecticut's Leadership in Nanotechnology in the Short and Longer Term

Given the strategic importance of nanotechnology, Connecticut cannot accept anything less than being a top 10 state in nanotechnology as it develops over time.

The Advisory Council on Nanotechnology is calling for a strategic and sustained initiative in nanotechnology development in order for Connecticut to remain a leading state in nanotechnology as this next frontier in technology development continues to emerge and mature.

In the short term, Connecticut's strategic objectives must balance the economic development aspects of commercialization, manufacturability, and entrepreneurship related to nanotechnology and at the same time build the "capacity" in the state to ensure that our companies, workers and universities are able to adopt and advance nanotechnology-related innovations.

Over the period of 2006 to 2008, the recommended strategic objectives for Connecticut are to:

- Demonstrate success in new nano-related product development and company formation
- Establish ongoing industry-university research collaborations
- Establish nanotech-educational programs
- Establish a statewide Connecticut Center for Nanoscale Science as a signature facility enabling nanotech research, product development and education.

Achieving these short term strategic objectives can allow Connecticut to advance as the nanotechnology field matures. By 2011, when nanotechnology is expected to be even more widely applied, Connecticut will be recognized as a national leader in specific nano-related applications, such as:

- Fuel cells
- Bio-nano, including sensing, regenerative medicine and drug delivery
- Nanomaterial intermediates, such as nanocoatings and nanocomposites

This national leadership would be recognized by a critical mass of companies engaged in that field as well as leading research centers in those fields.

A decade from today, when nanotechnology is expected to realize enter a period when it serves as the competitive edge for advanced manufacturing activities, the Advisory Council endorses a strategic vision of Connecticut in which:

"Connecticut will be recognized as a leading state in the development and application of nanotechnologies to advance new products by existing and newly formed companies anchored by a set of well-established nanotechnology research and education assets across its public and private colleges and universities."

Resource Requirements

Across the four main nanotechnology-related initiatives recommended, the annual investment by Connecticut is expected to average approximately $7 million per year to sustain ongoing program activities. There is also a requirement for a significant one-time matching capital expenditure of $10 to $20 million to attract an additional $20 to $40 million from federal, industry and university sources.

The specific funding recommendations are as follows:

- Connecticut nano-focused SBIR effort funded at $250,000 annually.
- The Connecticut Nanotechnology University/Industry Collaboration Initiative Fund is recommended to be funded at a level of approximately $5 million annually.
- Education programs for curriculum development, scholarships and outreach funded at approximately $1 million annually.
- Connecticut Center for Nanoscale Sciences and Development requires both a one-time matching capital expenditure and ongoing program support through at least a start-up phase. The launch of the Center is estimated to require a total capital investment of $25 to $35 million. It is recommended that the state support one third to one half this capital cost. It is also critical for the state to jumpstart development by providing operational program support to get the Center off the ground. It is expected to be around $500,000 to $1,000,000 annually over a three to five year period.

INTRODUCTION

Nanotechnology is an emerging field of technology viewed by many as leading the next industrial revolution. Indeed, recent progress in the measurement, modeling, and manipulation of matter at the nanoscale has mankind on the verge of revolutionizing materials, data storage and processing, sensors, power generation, environment, and medicine.

For Connecticut, nanotechnology has significant implications for the state's overall economic competitiveness. A recent study for the Connecticut Office of Workforce Competitiveness (OWC), *Connecticut's Core Competencies for the Knowledge Economy,* reveals that Connecticut has strategic technology opportunity areas, drawing upon its broad range of core competencies, that can be affected by nanotechnology, involving advanced product development, biomedical engineering, and translational medicine.

Even more compelling is that nanotechnology can be seen as an opportunity to build upon (a) the natural evolution of Connecticut's long-standing, specialized, and distinctive capabilities to reach ever-diminishing scales of production ("top-down" nanotechnology development); *and* (b) the state's scientific and engineering talent to pursue new materials, coatings, catalysts, and other applications at the atomic scale ("bottom-up" nanotechnology development).

Legislative Charge

Over the past year, Connecticut has been actively assessing its potential with the completion of a *Call to Action: Advancing Nanotechnology Development in Connecticut* completed in May of 2005. This 2005 strategic assessment was authorized by the General Assembly and commissioned by the Office of Workforce Competitiveness in its role in advancing the state's position in the Knowledge Economy. Based on this strategic assessment and broader concerns over how Connecticut can ensure its competitive position in an emerging technology area, the General Assembly passed two statutes in the 2005 legislative session calling for specific recommendations on how the state should proceed.

In Public Act No. 05-198, AN ACT CONCERNING THE PROMOTION OF COLLABORATIVE RESEARCH APPLICATIONS WITH INDUSTRY, under Section 4, the General Assembly called for the Office of Workforce Competitiveness to establish an Advisory Council on Nanotechnology to guide the preparation of "recommendations to advance this state's position in nanotechnology development, including recommended state investments to increase university research, develop centers of excellence and shared use facilities, promote partnerships and collaborations involving technology-based business and industry with institutions of higher education, leverage current federal resources and advance education and training programs in nanotechnology fields."

In addition, under Special Act No. 05-13, AN ACT CONCERNING NANOTECHNOLOGY, MOLECULAR MANUFACTURING AND ADVANCED AND DEVELOPING TECHNOLOGIES AT INSTITUTIONS OF HIGHER EDUCATION, the General Assembly called for the Commissioner of Higher Education, in consultation with the Office of Workforce Competitiveness, to "review the inclusion of nanotechnology, molecular manufacturing and advanced and developing technologies at institutions of higher education."

In light of these legislative requirements, an advisory council on nanotechnology was formed, with OWC and the Department of Higher Education drawing on the council's expertise and input in developing their recommendations to the General Assembly.

Results of 2005 Strategic Assessment of Connecticut's Competitive Position and Updates on Recent Developments

The starting point of the deliberations of the Advisory Council on Nanotechnology was the 2005 strategic assessment commissioned by the Connecticut Office of Workforce Competitiveness. The questions addressed by this 2005 nanotechnology strategic assessment for Connecticut were as follows: What key markets for nanotechnology applications are relevant to Connecticut? How are Connecticut companies and universities positioned for nanotechnology development? How can industry, universities, and the state work together in Connecticut to advance nanotechnology research and applications?

The key findings from this initial study were that:

- **Nanotechnology can be expected to have a broad reach across the existing industry base of Connecticut.** Industries in which Connecticut has long enjoyed significant economic success and specialization will need to integrate and advance their capabilities in nanotechnology. Based on the expected impact of nanotechnology across a wide range of industries, 15.4 percent of Connecticut's overall manufacturing employment (or an estimated 31,000 jobs) will be impacted by nanotechnology over the coming decade.

- **Today, Connecticut universities are active in nanotechnology research, but have not reached the critical mass and focus to support a major federally funded nanotechnology research center.** Connecticut colleges and universities receive approximately $12 million a year in R&D support for nanotechnology through the federally-funded National Nanotechnology Initiative (NNI), or roughly two percent of annual NNI funding to universities. While this level of NNI funding is on par with what Connecticut receives of all federal R&D support to universities, Connecticut is in the second tier of states in receiving NNI funding and is notable in not having a designated NNI research center in its borders to further nanotechnology research as in Massachusetts, New York, Pennsylvania and a host of other states.

  Since the completion of the 2005 strategic nanotechnology assessment, Connecticut universities are continuing to demonstrate their competitiveness in winning grants and advancing the field of nanotechnology. Of particular note is that Connecticut has been awarded its first ever Materials Research Science and Engineering Center, led by Yale and involving Southern Connecticut State University along with Brookhaven National Laboratory. The initial scientific focus

Summary of Connecticut's Strengths, Weaknesses, Opportunities, and Threats in Nanotechnology

Strengths

- Growing base of university research with emphasis on several areas of nanotechnology research
- Strong Small Business Innovation Research (SBIR) grant activity of Connecticut companies
- Presence of over two dozen companies in Connecticut focused on nanotechnology development

Weaknesses

- No national nanotechnology centers of excellence in Connecticut
- Not a national leader in university or industry nanotechnology-R&D activity as measured by grant and patent activity
- Few large companies engaged in conducting nanotechnology R&D work in-state
- Limited industry-university interactions in nanotechnology R&D
- No significant nanotechnology tools development stemming from Connecticut's machinery/ instruments legacy
- Significant gaps in technology infrastructure

Opportunities

- Strong advanced product development industry complex in Connecticut, needing to integrate nanotechnology in the future to remain competitive
- University and industry strengths in the biosciences in Connecticut, opening opportunities for advancing bioscience-nanotechnology applications
- Proximity to nearby universities and national labs with centers of excellence in nanotechnology research
- Pursuit of commonalities between industry needs and university research in materials, coatings, membranes, filters, and sensors for biomedical, energy, and homeland security applications

Threats

- Lack of focused state support, making Connecticut less competitive with other states
- Major federal nanotechnology infrastructure investment window coming to a close—difficult to attract a research center to Connecticut with more than 40 centers currently funded
- Federal budget constraints—already expected to impact Department of Defense research funding
- Companies advancing nanotechnology-related product developments out-of-state

of the Center for Research on Interface Structures and Phenomena is the surfaces of oxide materials and the "interface" where an oxide material joins together with another material. Applications can include magnetic storage, new electronic devices and chemical sensors. The Center will also have an active educational program component, including research experiences for high school science teachers and a summer research program for undergrads, among others. Other key university activities include: University of Connecticut success in advancing a method for separating nanotubes based on connectivity with many applications for use in chemical processes, including fuel cells; a Nanotechnology Interdisciplinary Research Team award to Yale focusing on advancing the manufacturing of well controlled and characterized carbon-based nanoparticles and their toxicology; and a recent funding to teams of Yale researchers from DARPA in nanosensors and nanocomputing.

- **Key areas of university research show significant strength and promise in the near term in nanomaterials and the interface of biosciences and nanotechnology and, for the longer term, in areas of nanoelectronics.** Connecticut's university research base is engaged in advancing carbon nanotubes, nanoparticles, and nanoelectronics with broad applications for unique coatings, new materials, smaller and more robust electronic and computer devices, optoelectronics, improved combustion technologies, and fuel cells. Connecticut's university research efforts are also engaged in biosensors, tissue engineering, and drug delivery and benefit from the state's strong university and industry biomedical research cluster.
- **Connecticut is not a "hot spot" of industry nanotechnology activity.** On a positive note, there are over two dozen companies in Connecticut engaged in nano-related research, development, products, and near-term business functions and opportunities. The companies involved in Connecticut run the gamut of large, mid-sized and emerging companies as represented by UTC's efforts in nanostructured materials, ATMI's advances of electronic materials and Inframat's efforts in nanocoatings. Yet, many Connecticut companies engaged in nanotechnology are actually conducting this work in their out-of-state research laboratories or with key partners outside the state.
- **Connecticut is being outflanked by other states because it lacks a targeted and sustained investment program.** Other states have actively targeted investments to establish a focus of nanotechnology research that can enable their universities to build the capacity to attract federal nanotechnology research centers. These states often directly invest matching funds to win these federal research centers.

  One indication that Connecticut is at risk of falling behind in nanotechnology is that in the 2005 rankings by *Small Times Magazine*, Connecticut slipped to 11^{th} in the nation among all states in micro and nanotechnology development, falling from 9^{th} in 2004.

  More to the point is that other states are making the investments, even states that have not been the traditional leaders in nanotechnology. Consider what Georgia Governor Sonny Perdue set out in his State-of-the-State Address this past January:

  "To lead, we must innovate. That means, we must become a State of Innovation. That means making innovation our competitive advantage in every area of our economy—in our existing industries, in our homegrown small businesses and in the growth of industries of the future, such as life sciences and nano-manufacturing…To strengthen our investment infrastructure, I am recommending investments in nanotechnology. My budget includes $38 million in bonds to complete the construction of a Nanotechnology Research Center at Georgia Tech to establish Georgia as a global leader in this emerging industry."

Examples of Leading State Initiatives in Nanotechnology

Massachusetts: In 2003, Massachusetts passed a $100 million economic stimulus package that includes $35 million in direct support for science and technology research in support of economic development. That $100 million investment is now heavily focused on nanotechnology. The state is making significant investments to enable UMass Lowell and Northeastern to win and grow an NSF-sponsored Center for High-Rate Nanomanufacturing. The state provided a $5 million match from the John Adams Innovation Institute, to be used to seed industry collaborations for the Center. In addition, the Governor's FY06 budget also included a $21 million earmark for construction of a headquarters for the Center in the Lawrence Mills brownfield redevelopment area.

New York State: University nanotechnology research and commercialization activity in the State of New York divides into several broad categories:

- Huge state investments of nearly half a billion dollars in migrating existing microelectronics and thin-film capability at SUNY Albany to the nanoscale, conceived as a program for industrial retention (IBM's 300-millimeter wafer fabrication facility at Fishkill) and attraction (Sematech, Tokyo Electron, Applied Materials, ASML, and others).
- More modest state matching of long-standing, federally funded materials-science infrastructure at Cornell University, which led naturally to federal funding of a nanobiotechnology focus that fits well with the university's major life science initiative and has led to both industry partnerships and spin-off formation at Ithaca.
- Strong, but essentially self-generated initiatives at Columbia University and RPI, which leverage small amounts of state support.
- Marketing and packaging of every nanotechnology-related development statewide on a NanoNY Web site maintained by the state science and technology agency.

To kick off 2006, NYS announced it was selected as the site for the Institute for Nanoelectronics Discovery and Exploration (INDEX) by the Semiconductor Industry Association and the Semiconductor Research Corporation. It will involve a total investment by the public and private sectors of $435 million, including an additional $80 million in state funding. Part of INDEX will be a multi-university consortium, involving MIT, Harvard, Yale, Purdue and Georgia Tech, along with UAlbany and RPI. On-site corporate researchers will be working in concert with university researchers, including leading semiconductor companies such as Intel, Micron, AMD, IBM, Texas Instruments and Freescale Semiconductor.

Ohio: Ohio State University recently received an Nanoscale Science and Engineering Center (NSEC) in polymer nanomaterials for bioengineering, leveraging equipment purchased with a $2-million Wright Capital Project Fund award made in 2003 from the state's Third Frontier Initiative and $4 million in parallel nanotechnology awards from the Board of Regents' Hayes Investment Fund, a program that has not been refunded since the Third Frontier got under way. Additionally, a $22.5 million award from the Third Frontier Initiative's Wright Centers for Innovation program was recently announced to create the Ohio Center for Multifunctional Polymer Nanomaterials and Devices (CMPND), providing for the acquisition of highly advanced equipment to develop new materials and to link nanotechnology to economically important polymer and associated manufacturing industries in Ohio.

Oregon: In 2003 the Oregon Legislature allocated $20 million for the capital cost of user facilities and $1 million for operation of an Oregon Nanoscience and Microtechnologies Institute (ONAMI). The Governor's current budget includes a $7 million recommendation for operating funds. The Institute builds on existing collaborations among microelectronic laboratories at OSU, UO, and the semiconductor industry clustered in the Oregon "Silicon Forest." ONAMI includes facilities for characterization and product testing and development.

RECOMMENDATIONS OF ADVISORY COUNCIL ON NANOTECHNOLOGY

The Advisory Council on Nanotechnology sees a significant urgency for Connecticut to bolster its competitiveness in nanotechnology development.

Nanotechnology, as one of the key drivers of the next industrial age, will be critical to the future competitiveness of Connecticut's diverse manufacturing sectors, from aerospace to advanced materials to fuel cells to pharmaceuticals and biotechnology.

But nanotechnology is a moving target. Nanotechnology will offer waves of development over time as new discoveries and innovations take place, similar to how information technology and biotechnology have played out in recent decades.

To miss the opportunity to grow in nanotechnology as this field emerges would be a strategic mistake. Trying to play catch up in nanotechnology in the future is a recipe for disaster.

Today, Connecticut is at risk of not keeping pace with the development of nanotechnology. While Connecticut has a growing base of activity in nanotechnology across its universities and companies, it is lacking in key infrastructure and targeted development activities.

And the need to act is urgent because the pace of technology advancement is fast, the competition is aggressive and we risk falling behind with inaction.

Strategic Objectives and Vision for Ensuring Connecticut's Leadership in Nanotechnology in the Short and Longer Term

Given the strategic importance of nanotechnology, Connecticut cannot accept anything less than being a top 10 state in nanotechnology as it develops over time.

The Advisory Council on Nanotechnology is calling for a strategic and sustained initiative in nanotechnology development in order for Connecticut to remain a leading state in nanotechnology as this next frontier in technology development continues to emerge and mature.

In the short term, Connecticut's strategic objectives must balance the economic development aspects of commercialization, manufacturability, and entrepreneurship related to nanotechnology and at the same time build the "capacity" in the state to ensure that our companies, workers and universities are able to adopt and advance nanotechnology-related innovations.

Over the period of 2006 to 2008, the recommended strategic objectives for Connecticut are to:

- Demonstrate success in new nano-related product development and company formation
- Establish ongoing industry-university research collaborations
- Establish nanotech-educational programs
- Establish a statewide Connecticut Center for Nanoscale Science as a signature facility enabling nanotech research, product development and education.

Achieving these short term strategic objectives, can allow Connecticut to advance as the nanotechnology field matures. By 2011, when nanotechnology is expected to be even more widely applied, Connecticut will be recognized as a national leader in specific nano-related applications, such as:

- Fuel cells
- Bio-nano, including sensing, regenerative medicine and drug delivery

- Nanomaterial intermediates, such as nanocoatings and nanocomposites

This national leadership would be recognized by critical mass of companies engaged in that field as well as leading research centers in those fields.

A decade from today, when nanotechnology is expected to realize enter a period when it serves as the competitive edge for advanced manufacturing activities, the Advisory Council endorses a strategic vision of Connecticut in which:

> *"Connecticut will be recognized as a leading state in the development and application of nanotechnologies to advance new products by existing and newly formed companies anchored by a set a well-established nanotechnology research and education assets across its public and private colleges and universities."*

Recommended Connecticut Nanotechnology Approach: An Integrated and Balanced Nanotechnology Investment Program Within the Context of the State's Overall Technology Development Efforts

The leaders in nanotechnology today, such as California, New York, Massachusetts and Texas, have the benefit of significant size. They can afford to have multiple, often competing and redundant, investments in nanotechnology given the diversity and size of their states. Connecticut cannot afford this approach.

Instead, Connecticut needs an integrated and balanced investment program tied to specific goals and objectives. Connecticut must pursue collaborative approaches in nanotechnology across its academic base and in concert with industry development. Connecticut must get "dual use" from its nanotechnology investments so that they serve not only to bolster our competitiveness for federally funded research grants, but the ability of Connecticut to spur new company formation, have existing companies conduct product development integrating nanotechnology, and prepare the future workforce through nanotechnology-oriented education and training programs.

To achieve this integrated and balanced nanotechnology investment program, Connecticut must bring a dedicated focus to nanotechnology to spur advanced manufacturing similar to its efforts in stem cell research for advancing biosciences development. Ripe fields for Connecticut to make its mark in nanotechnology include fuel cells, nanomaterial intermediates and bio-nano applications. In this regard, nanotechnology does not stand alone from other technology initiatives of Connecticut, but is critical to their success. Take, for instance, Connecticut's ongoing emphasis on alternative energy development, particularly in fuel cells. Nanosciences is critical to advancing fuel cell catalysts as well as storage components. Another area of primary focus of Connecticut's ongoing technology initiatives is biotechnology development. Nanosciences offers enabling technology to advance new substitutes for bone and tissue as well as for advancing drug discovery, development and delivery, and so is a key complement to the state's initiative in stem cell research, particularly aiding in the development of novel biomedical products.

While much of nanotechnology is an enabling technology that affects a broad range of academic disciplines and market sectors, Connecticut can not afford to have nanotechnology get lost in the shuffle of competing technology investments. Having a focused effort on nanotechnology is also important for Connecticut to brand its efforts in nanotechnology investment to better reach out to industry. Without it, the current dynamics of industry investment will be to seek opportunities outside of Connecticut because we lack the "signature" facilities found at competing states, from the Albany Nanoelectronics Complex to the major shared user centers at Penn State or Cornell to the nano centers of excellence at University of California to the significant national labs at Oakridge or Los Alamos.

Still, advancing nanotechnology does not exist outside of the state's broader technology development efforts. There are some areas of nanotechnology development in which it is appropriate for Connecticut to actively leverage its broader investments in technology development. Particularly in the areas of seed and follow-on venture financing, there is not a sufficient demand to have nanotechnology-specific activities. Instead, nanotechnology must be a component of Connecticut's efforts in these areas.

Specific Action Plan

The Advisory Council sets out specific customized recommendations focusing on nanotechnology as part of the state's approach to ***Innovation Challenge Grants***. The Innovation Challenge Grant program was enacted in the same legislation—Public Act No. 05-198—calling for OWC to establish the Advisory Council on Nanotechnology to guide the preparation of "recommendations to advance this state's position in nanotechnology development…" The Innovation Challenge Grant program provides Connecticut with the comprehensive tools required to advance the integrated goals of talent generation, university-industry collaboration and commercialization of university-based research. The application of the Innovation Challenge Grant program to nanotechnology is the cornerstone of the Advisory Committee's recommendations for the Nanotechnology Development Program.

Guiding Principles for the Innovation Challenge Grant Program

- Focus investments on strategic technology opportunity areas.
- Focus investments in four main activities—talent generation, basic research enhancements, applied research, and innovation.
- Place a priority on initiatives promoting multi-institutional collaboration and a mix of activities across talent, technology, and innovation.
- Ensure matching requirements across activities.
- Manage as a single comprehensive program under the direction of an industry-government steering council.

Four nanotechnology-specific initiatives are proposed for Connecticut to advance its nanotechnology position.

The first is to establish a strong Connecticut focus on Nanotechnology by building on the state's *Office for Small Business Innovation and Research (SBIR).* SBIR is a federal research program that assists small and emerging companies in advancing the development and commercialization of new products. SBIR is a strong fit to the needs of nanotechnology because it is targeted to small and emerging companies and to the critical need in nanotechnology of reduction to practice and prototype development. The state's SBIR-supported services can be effectively leveraged with just a small enhancement to bring a focused effort towards nanotechnology that includes more active outreach and workshops with federal agencies seeking nanotechnology SBIR proposals, enhanced advisory services for companies pursuing nanotechnology-related SBIRs, and more hands-on support in the development of ideas for SBIR proposals.

The second is the establishment of a *Connecticut Nanotechnology University/Industry Collaboration Initiative.* This nanotechnology-focused initiative can serve as the means to translate and seize the potential of nanotechnology in Connecticut by fostering industry-university relationships, and advancing nanotechnology product development and demonstrations in Connecticut. What will distinguish this initiative is that by focusing specifically on advancing nanotechnology innovations it can be more active in fostering new relationships, assessing opportunities and linking innovations to needs of existing Connecticut-based companies and state agencies.

To ensure that Connecticut has the workforce to support nanotechnology development it must actively advance *Post-Secondary Education Program Development and Educational Clearinghouse.* Nanotechnology must be integrated more extensively into associate's, bachelor's, and master's degrees, and not simply left to Ph.D. programs. A number of Connecticut higher education institutions are already engaged in developing a nanotechnology curriculum. The goal should be to share approaches, fill needed gaps in curriculum development, and address access to instructional laboratories across higher education. Through the involvement of an industry advisory board, new curriculum development can be linked to specific skill requirements. There is also the opportunity to involve Connecticut's new Center, for Science and Exploration, particularly for the K-12 system.

An enabler for both nanotechnology industry development and education-training is establishing a *Connecticut Center for Nanoscale Sciences and Development,* a shared use nanotechnology instrumentation facility with related programs. This would be a "signature facility" for nanotechnology in Connecticut. In nanotechnology, the starting point for developing, measuring, and testing nanotechnology applications is through the use of advanced atomic-level instrumentation, whether related to academic research or industrial product development. The critical importance of having access to nanotechnology tools is found in the history of nanotechnology. The promise of nanotechnology was significantly advanced in the 1970s and 1980s with the advent of new tools to see and manipulate individual atoms and molecules, enabling the translation of scientific research into commercial activities. Given the high cost and required technical support to operate sophisticated nanotechnology tools, it is best to organize these nanotechnology tools as shared use laboratories that can have broad reach to academic and industry researchers. The value of a shared use nanotechnology instrumentation facility goes well beyond enhancing a university's competitiveness for federal grants; it also can enable nanotechnology discoveries to be more quickly advanced for proof-of-concept and future testing. A nanotechnology instrumentation facility can also offer an important "hands-on" component for nanotechnology-related education and training programs.

For each of these action steps, there is a detailed write-up containing the rationale, best practices, program design, key milestones and funding requirements.

The Advisory Committee also recognizes that nanotechnology development in the state is dependent upon broader technology initiatives being in place in Connecticut. In particular, two recommendations for establishing an Innovation Network in Connecticut are critical to the success of Connecticut in reaching the economic development goals in nanotechnology, namely:

Establish a ***Connecticut-Focused Seed and Venture Fund Initiative*** that can support development stage nanotechnology companies in the state and attract out-of-state emerging nanotechnology companies to locate in Connecticut. In the face of nanotechnology's strong basic research roots, long-time horizons and need for proof-of-concept, it is not surprising that large companies are not actively engaged in licensing university research. Instead, much of the focus of commercialization of university nanotechnology discoveries is being realized through university licensing to start-up companies. A key to success is making the transformation from interesting technology to innovative company is access to seed funding and follow-up venture financing.

Establish a comprehensive ***Technology Commercialization Services Program.*** A comprehensive Commercialization Services Program will expand the technology based economy by promoting entrepreneurship and private investment and by providing direct assistance to new ventures in starting and growing businesses. Commercialization services currently provided or financed by State agencies should be consolidated to create efficiencies and a single point of accountability. In addition, the Commercialization Services Program will create linkages with other commercialization organizations, e.g., tech transfer and commercialization offices at UCONN and Yale, incubators, networking forums, business plan competitions, and funding forums.

Measures of Success

The bottom-line measure of success for Connecticut in nanotechnology is whether we can maintain our national leadership in the emerging field of nanotechnology and its applications. This is particularly crucial since nanotechnology is now widely understood to be an enabling technology for the 21st century.

Connecticut is widely recognized as a top 10 state in technology. Nothing less can be sought in the field of nanotechnology. Therefore, as the field of nanotechnology emerges over the next ten years, the goal is for Connecticut to be a top tier state in nanotechnology, as measured by key indicators of activity:

- Companies engaged in nanotechnology activity;
- Jobs associated with nanotechnology fields;
- Innovation measures of nanotechnology including patents, venture financing and SBIR awards;
- Nanotechnology university research funding.

Resource Requirements

Connecticut needs a targeted and sustained investment in nanotechnology in order to keep up in this fast-moving and emerging field. As Lux Research in their benchmarking of states' economic development efforts in nanotechnology points out, Connecticut has an over-reliance on corporate and federal funding for nanotechnology and spends little state resources on advancing its position.

Across the four recommended main nanotechnology-related initiatives the annual investment by Connecticut is expected to average approximately $7 million per year to sustain ongoing program activities. There is also a requirement for a significant one-time matching capital expenditure of $10 to $20 million to attract an additional $20 to $40 million from federal, industry and university sources.

The specific funding recommendations are as follows:

- Connecticut nano-focused SBIR effort funded at $250,000 annually.
- The Connecticut Nanotechnology University/Industry Collaboration Initiative is recommended to be funded annually at a level of approximately $5 million.
- Education programs for curriculum development, scholarships and outreach funded at approximately $1 million annually.
- Connecticut Center for Nanoscale Sciences and Development requires both a one-time matching capital expenditure and ongoing program support through at least a start-up phase. The launch of the Center is estimated to require a total capital investment of $25 to $35 million. It is recommended that the state support one third to one half this capital cost. It is also critical for the state to jumpstart development by providing operational program support to get the Center off the ground. It is expected to be around $500,000 to $1,000,000 annually over a three to five year period.

Detailed Action Plans for Recommended Nanotechnology Initiatives to Advance Connecticut's Position

NANOTECHNOLOGY SBIR INITIATIVE

NANOTECHNOLOGY UNIVERSITY/INDUSTRY COLLABORATION INITIATIVE

NANOTECHNOLOGY EDUCATION PROGRAM DEVELOPMENT

CONNECTICUT CENTER FOR NANOSCALE SCIENCES AND DEVELOPMENT

Concept for:

Nanotechnology SBIR Initiative

RATIONALE

The Small Business Innovation Research grant program is a federal research program that assists small and emerging companies in advancing the development and commercialization of new products. SBIR is a good fit with the needs of nanotechnology because it is targeted to small and emerging companies and to the critical need in nanotechnology of reduction to practice and prototype development.

Connecticut has established a new state supported SBIR program through the Office of Workforce Competitiveness and operated by the Connecticut Center for Advanced Technology. This effort has proven effective in raising the level of awareness and applications by Connecticut companies for the SBIR program, which had fallen off in recent years. In particular, the state supported SBIR effort has active outreach programs to Connecticut companies to make them aware of SBIR opportunities, offers mentoring and technical assistance in learning about the requirements of the program and has held a number of successful conferences and workshops, including federal agency staff responsible for the SBIR program.

The existing Connecticut SBIR program effort can be effectively leveraged to offer more intensive services to access federal SBIR funding to advance nanotechnology product development in the state.

BEST PRACTICES

Many states possess an organization, whether a state agency or a private for-profit/non-profit entity, that is structured to facilitate the SBIR and Small Business Technology Transfer (STTR) program within the state. The objective of these organizations is to increase the number of federal awards going to qualifying state businesses. Some organizations offer very little assistance beyond technical support or one time proposal writing workshops/courses. These types of organizations operate much like consulting firms or networking associations. Other organizations are very systematic and operate in-depth structured programs that offer award winning SBIR/STTR recipients incentives to commercialize newly developed technologies.

Two examples of more intensive efforts found in Oklahoma and in Tennessee.

The Oklahoma Center for the Advancement of Science and Technology (OCAST) is an example of a state organization possesses several highly structured financial technology development programs. OCAST focuses on technology transfer, development, and commercialization. OCAST's Small Business Research Assistance (SBRA) programs focuses exclusively on increasing and leveraging federal SBIR/STTR awards. SBRA's technical assistance and monetary incentives encourage qualifying Oklahoma companies to apply for SBIR/STTR awards.

- The SBIR Phase I Incentive provides companies funding to offset proposal preparation costs. The program covers 50 percent of proposal preparation costs up to $3,000 for a company. The incentive is a one time reimbursement per submission. A company is eligible for a maximum of $5,000 until at least one SBIR grant has been successful awarded to the applicant company.

- The SBIR Matching Funds program provides bridge funding for companies that have successfully completed a Phase I award. The program is designed to encourage these companies to continue to develop their technology and pursue a Phase II award. The program matches 50 percent of the Phase I award up to the amount of $25,000. The program is only a one-time funding opportunity for each Phase II award submission. The only stipulation is that 51 percent of the Phase II award be spent within Oklahoma.
- The STTR Incentive Fund reimburses companies that have successfully been awarded an STTR grant. The fund covers 50 percent of proposal preparation costs up to $5,000. A company is eligible for a maximum of $10,000 until at least one STTR grant has been awarded to the applicant company.
- OCAST's SBRA programs also offer SBIR/STTR Phase I and Phase II Proposal Development Workshops

Cumberland Emerging Technologies, Inc. (CET) is an example of a public-private partnership. This joint, for-profit initiative combines the resources of Cumberland Pharmaceuticals, Vanderbilt University's Office of Technology Transfer, and the Tennessee Technology Development Corporation. The collaboration helps to bring biomedical technologies and products initially conceived at Vanderbilt and other regional research centers and institutions to the marketplace. CET provides:

- Universities with a vehicle for commercializing the work initiated by their researchers.
- Cumberland Pharmaceuticals with a long-term product pipeline.
- Tennessee with a vehicle to complement the state's biotechnology initiatives in its New Economic Strategy, aimed at the creation of hi-tech jobs and other benefits to the local economy.

CET operates by partnering with prospective SBIR/STTR award recipients to develop new, early stage technologies. The private for-profit entity works with researchers to evaluate the suitability of projects for development and commercialization though the SBIR /STTR grant programs. Although a prime objective is to seek projects of relevance to Cumberland Pharmaceuticals' core activities, a broader range of technologies can be developed for subsequent licensing to other companies when such opportunities are found. When projects meet the criteria for development and commercialization, CET works with the academic investigators to prepare and submit the SBIR/STTR grant proposal.

Upon successful grant funding or private sector investment, CET provides program management to support the research investigators. The research and the associated intellectual property remain owned by the research organization, but CET is granted an exclusive option on that technology and intellectual property for the subsequent commercial phase.

The flexibility of the CET approach enables research to be conducted either by CET employees or university employees contracted by CET to make the most efficient use of their respective skills and facilities. As part of this effort, CET is establishing its own office and wet laboratory space in which grant-funded product development work can be carried out in collaboration with the universities and research institutions. After the completion of funded projects, CET can implement commercialization plans either by licensing the technologies to existing firms—including Cumberland Pharmaceuticals, should the developed products fall within its targeted specialties—or by establishing a new company.

Suggested Program Design

It is suggested that Connecticut's existing SBIR program can be leveraged to offer more intensive hands-on support services and specialized networking and matchmaking to advance SBIR awards for nanotechnology development in the state. Among the suggested additional services focused on advancing nanotechnology-based SBIR activity would be:

- Creating a nanotechnology focused industry advisory board, who can serve as mentors and assist in outreach;
- Hold SBIR nanotechnology exchange meetings with key federal agencies interested in supporting nanotechnology developments through their SBIR program;
- Offer intensive technical assistance services involving market research, technical reviews and proposal reviews with expert advisors;
- Connect nanotechnology companies with major OEMs and defense prime contractors with an interest in SBIR-related topics proposed by federal agencies.

These activities are less about adding new staffing, but about complementing existing staffing with new resources in support of nanotechnology-based companies in Connecticut pursuing SBIR opportunities.

Cost Estimates

It is estimated that the cost of these additional SBIR support services focused on nanotechnology would be approximately $250,000 annually. This cost would go primarily for outreach, workshops and conferences, and enhanced technical assistance and advisory services.

Concept for:

Nanotechnology University/Industry Collaboration Initiative

RATIONALE

A Nanotechnology University/Industry Collaboration Initiative for Connecticut can serve as the focal effort to translate and seize the potential for advancing nanotechnology innovations and product development in Connecticut. This initiative would operate across the continuum of commercialization from proof-of-concept of an idea or testing of a possible solution to a key requirement or need to application development involving prototype development to scale up of activity and possible new venture development.

Today, the vast majority of Connecticut companies needing to integrate nanotechnologies as they advance are acting as spectators rather than participants. Partly this is because nanotechnology is an emerging scientific field. Much of the action in advancing nanotechnology is taking place in the basic research laboratories found in universities. The key question is whether Connecticut companies will be able to gain the skill sets and knowledge of advancing nanotechnology and whether that activity will take place in Connecticut. One way to better enable Connecticut companies to make this leap into nanotechnology is to broaden industry collaborations with colleges and universities in Connecticut through joint projects typically involving graduate students and post-doctoral fellows. This project will be more oriented toward addressing questions relating to the ability of nanotechnology innovations to add value and will typically be far before actual commercialization or product development takes place.

At the same time, discussions with industry and university officials demonstrate that nanotechnology is proving to be more like biotechnology than information technology in the time it takes to go from discovery to revenue generation—even without the regulatory constraints of biotechnology. Even in nanomaterials, it is taking five to seven years to realize revenues, in large part because of the need for substantial product development work to integrate a nanotechnology discovery into an application. Moreover, many nanotechnology advances face daunting challenges in reaching required production level volumes—not a trivial engineering feat and often very expensive in terms of specialized facility costs. There is a growing consensus that to commercialize nanotechnologies, there needs to be a major focus on advancing nanotechnology discoveries through the prototype phase. The inability to demonstrate prototypes of applications from nanotechnology discoveries is holding back the commercialization of the field, including new venture formation. This is true in other technology fields, but has become a major bottleneck for nanotechnology commercialization. Much of the federal funding to universities fails to reach beyond the discovery phase; yet companies are not interested without demonstrated prototypes.

Ultimately, the Nanotechnology University/Industry Collaboration Initiative should contribute to creating within Connecticut a superior environment for advancing the "business" of nanotechnology. Connecticut's leadership in nanotechnology will be found in its ability to develop and apply nanotechnologies to advance new products by existing and newly formed companies. An interesting possibility beyond the direct assistance in advancing the commercialization of nanotechnology innovations is to consider unique ways Connecticut state agencies can advance demonstrations of nanotechnology-related applications.

BEST PRACTICES

Various aspects of the recommended University/Industry Collaboration Initiative Fund can be found across state activities in support of technology development and are discussed below. The idea of combining various activities under one umbrella initiative is also well demonstrated. For instance, the **Indiana 21st Century Research and Technology Fund**[1] serves as a highly flexible funding vehicle funded at $50 million per biennium. It may make grants or loans, either to "increase the capacity of Indiana institutions…to compete successfully for federal or private research and development funding" or to "stimulate the transfer of research and technology into marketable projects" or to "encourage an environment of innovation and cooperation among universities and businesses to promote research activity." The fund makes competitive awards for up to $5 million over two years. "Clear commercialization intent" is required.

For initial industry-university collaborations to undertake proof-of-concept of ideas and testing of approaches to meet industry needs and requirements, there is a notable set of benchmarks to consider, including:

- The **University of California Discovery Grant**[2] is a $20 million, internally-managed, annual pool of competitive funding to spur university/industry partnerships. Eligible applicants are any PI at any of the 10 UC campuses, the three national labs currently managed by UC, or the Agricultural Experiment Station. Discovery grants range from $50,000 to $250,000 annually for up to four years and must be matched 1:1 by private-sector partner with defined in-state operations. Though the program started in biotechnology (the former BioSTAR program), it now has parallel competitions in communications/networking; digital media; electronics manufacturing and new materials; information technology for the life sciences; and microelectronics (the former Berkeley MICRO program). UC believes the program generates $50 to $60 million in total R&D activity.
- The University System of Maryland system is budgeted at $1.35 million for the **Maryland Industrial Partnerships** (MIPS) program.[3] The competitive program makes grants of between $5,000 and $100,000 a year for up to two years for university research projects involving in-state companies. Startup-companies (generally fewer than 12 employees and limited sales and business history) must match the university contribution with 10 percent in cash (or equity by advance arrangement) and 35 percent in-kind. Matching requirements scale up with the size of the research partner: small firms (up to 100 employees) must match 35 percent in cash, 30 percent in kind; medium firms (up to 1,000 employees) must match 75 percent in cash and 25 percent in kind; large firms must match in cash, and must make additional in-kind contributions.
- The Washington Technology Center, a state-funded, private nonprofit charged to spur collaborations between Washington State-based companies and the state's universities and nonprofit research institutions, offers a **Research and Technology Development**[4] matching grant. The program is budgeted at $1 million per year and competitive grants range up to $300,000 divided into three phases. Any size company may team with faculty to apply, but there is a stated preference for industry partners with fewer than 250 employees. Phase I offers up to $100,000 for a 9-month project

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[1] See http://www.21fund.org.
[2] See http://ucdiscoverygrant.org/. For a recent performance review see http://ucdiscoverygrant.org/pdf/performance_report.pdf.
[3] See http://www.erc.umd.edu/MIPS/overview.html.
[4] See http://www.watechcenter.org/index.php?p=R%26D+Funding+and+Support&s=66.

with a requirement of 20 percent cash match. Those that complete Phase I successfully may apply for Phase II, offering $200,000 over one or two years, with a scaled match requirement: Firms with 10 or fewer employees: 20 percent; 11–100 employees, 35 percent; 101–250 employees, 50 percent; and larger companies 100 percent. The WTC also offers a smaller, $5,000 "Entrepreneurs Access" grant to encourage companies to explore collaboration with a university faculty member, including developing data for SBIR/STTR proposals. Two WTC staff members are dedicated to serve as "coaches" who guide projects to desired economic-impact orientation.

For more focused prototype development of specific applications, there are other examples from across states, including:

- The New York State Office of Science, Technology and Academic Research (NYSTAR) offers a **Technology Transfer Incentive Program**.[5] The program states it is intended to assist in commercialization of a specific piece of intellectual property though it has also funded broader collaborations. It makes competitive grants of between $100,000 and $750,000 over one or two years, with a 1:1 match. Review criteria include technical merit, capability, and marketing and commercialization plan. A licensing agreement with the matching provider must be in place or in negotiation. This program is in addition to matching-grant programs run internally to the state's network of **Centers for Advanced Technology**, including the one associated with the **Albany Nanotech** "Center of Excellence."
- The Ohio Third Frontier Commission offers a **Biomedical Research and Commercialization Program,**[6] which continues the former Biomedical Research and Technology Transfer Trust fund operated by the state Board of Regents. The program is budgeted at $24 million and offers competitive grants in the range of $5 to $8 million each, with a 1:1 matching requirement. Each project must involve at least two of the following three types of organizations: an Ohio university, an Ohio research organization, and an Ohio for-profit company. Proposals must include commercialization plans, and matching requirements are rigorous (Federal OMB definitions of cost-sharing). Since 2002 this program and its predecessor have made $103 million in awards to 15 projects. A similar program with smaller matching requirements is operated in the area of Fuel Cells.

SUGGESTED PROGRAM DESIGN

The Connecticut Nanotechnology University-Industry Collaboration Initiative by focusing specifically on advancing nanotechnology innovations can be more active in fostering new relationships, assessing opportunities and linking innovations to needs of existing Connecticut-based companies and state agencies than a more generalized technology development initiative.

The Connecticut Nanotechnology University-Industry Collaboration Initiative would be designed to address the key milestones in the commercialization process, namely:

- Problem identification and proof of concept involving earlier investigations in whether nanotechnology innovations can address commercial needs;
- Technology development involving a more substantial applied research program to advance an application; and

[5] See http://www.nystar.state.ny.us/ttiprfp.htm.
[6] See http://www.thirdfrontier.com/open_rfps.asp.

- Prototyping of the application or new product development.

By featuring several specific program activities across the milestones in the commercialization process, the Initiative would be a predictable ongoing effort in support of nanotechnology-related commercialization. Still, the specific allocation of funding across the specific program activities of the Nanotechnology University-Industry Collaboration Initiative should be managed in a flexible way to ensure that Connecticut is opportunistic in seizing potential opportunities.

A key requirement of the Collaboration Initiative would be to require some level of matching support from industry, with more early stage activities providing allowance for lower levels of match or more in-kind match and additional later stage activities requiring more hard matches at higher levels per state funding.

The specific program activities recommended for the Connecticut Nanotechnology University-Industry Collaboration Initiative would be:

- An industry-university "Discovery Grant" at a \$50,000 to \$75,000 level involving support for a post-doctorate or graduate student to work with industry under the supervision of a faculty member. Key would be having simplified application and reporting requirements, and only an internal technical review to ensure it is nanotechnology related. An industry match of \$1 for every \$1 publicly invested would be required, but could be in the form of in-kind contribution for small, emerging companies.
- An industry-university "Collaborative Grant" at \$100,000 to \$150,000 level involving a university research team (faculty, post-doc, graduate students) working with industry on a collaborative research project focused on application development. This would be a competitive program with an outside peer review. Successful applicants would need to present a clear problem statement and rigorous technical approach to addressing the problem. A similar industry match of \$1 for every \$1 publicly invested would be required, but could be in the form of in-kind contribution for small, emerging companies.
- Nanotechnology Business Prototype Support to enable universities and emerging nanotechnology companies to undertake rapid prototyping activities to demonstrate functionality, manufacturability and cost effectiveness. Grants of \$150,000 to \$250,000 would be available to universities on a competitive basis and for industry activities would require industry matching funds of \$2 for every \$1 of public investment.

A related feature in which Connecticut can further advance the commercialization process is to encourage state agencies to advance "nanotechnology demonstration" projects by encouraging state operating agencies to use Connecticut research universities as an intermediary that allows development of a three-way partnership among state operating agencies, the university sector, and the community of small technology firms based in Connecticut who want to sell nano-enabled technology solutions to the operating agencies. For example, if ConnDOT is interested in acquiring advanced remote-sensing technology that could avert future bridge calamities like those experienced in the past. Is it not possible that Connecticut nanotech companies are on the trail of stress and strain sensors that could meet just this need? How is it possible to fund and encourage the early-stage development that takes this possibility to the stage of practicality, and how is it possible to keep this work in Connecticut without running afoul of Commerce Clause requirements for non-discrimination in procurement? One possibility would be for ConnDOT to fund a transportation nanotechnology center at UConn or Yale, which would in turn issue RFPs for university/industry partnerships in technology development, with responses to be reviewed by DOT engineering staff. Companies that want to avail themselves of partnerships through the Connecticut universities will naturally want to have a local presence—the "be near the base gates" approach to military-driven economic development that has worked so well at Groton.

COST ESTIMATES

The University/Industry Collaboration Initiative Fund is recommended to be annually funded annually at a level of approximately $5 million. Cost estimates for the Fund are based on the following assumptions:

- 5 to 10 Discovery Grants each year – Total cost would be $250,000 to $750,000 annually;
- 2 to 3 Collaborative Research Project Seed Grants – Total cost of $200,000 to $450,000 annually;
- 2 to 3 Nanotechnology Business Prototype Financing – Total cost of $300,000 to $750,000 annually.

RATIONALE

Education and training in nanotechnology needs to be stimulated in Connecticut. Nanotechnology must be integrated more extensively into associate's, bachelor's, and master's degrees, and not simply left to Ph.D. programs. A number of Connecticut higher education institutions are already engaged in developing a nanotechnology curriculum. The goal should be to share approaches, fill needed gaps in curriculum development, and address access to instructional laboratories across higher education.

BEST PRACTICES

Nanotechnology is by its nature a multi-disciplinary field, drawing on the disciplines of physics, chemistry, biology, materials science and engineering. Yet, as the field is emerging, it is also becoming more specialized in the assortment of specific tools and techniques that it requires. This poses a question on how best to integrate nanotechnology into educational programs.

Not surprisingly, educational programs in nanotechnology are advancing as the field of study emerges. These programs are primarily found at the post-secondary level, but it is useful to point out growing efforts at the K–12 level.

Graduate Level: With the notable exception of the University at Albany College of Nanoscale Science and Engineering, nearly all graduate programs are not pursuing "stand-alone" nanotechnology degrees. Instead, there is an increasing focus on having students across disciplines specialize in nanotechnology fields—more as a concentration or emphasis—to their existing graduate program.

An excellent example of this type of effort is a joint program in nanostructured materials, devices and bio-nanotechnology found at the University of Pennsylvania and Drexel University. This program allows Ph.D. students to learn about nanotechnology beyond the scope of their particular research project, through activities such as team based research programs, seminars, industry and government speakers, and international research exchange opportunities. Through support from the National Science Foundation (NSF) Integrated Graduate Education and Research Traineeship (IGERT) program, graduate students at either institution who have an interest in nanoscale research can apply to the program. If accepted to the program, students can earn a certificate in nanotechnology in addition to their departmental degree.

Similarly, at the University of California at Berkeley, doctoral students in many science programs have the opportunity to pursue a specialization in nanoscale science and engineering and receive recognition for it when awarded their degree. A focused faculty group has been established in Nanoscale Science and Engineering (NSE), involving over fifty faculty members from 11 departments. Together they administer areas of "Designated Emphasis" into which students can enroll, similar to having a minor. These areas include nanoscale synthesis and processing, nanoscale characterization and nanoscale modeling. To fulfill the requirements of the Designated Emphasis in Nanoscale Science and Engineering, students are required to take supplementary coursework and nano-related dissertation research. Upon successful completion, it is recorded on the student's official transcript as "Ph.D. in X with Emphasis in Nanoscale Science and Engineering."

Yet, another example is Lehigh University, which offers a four course certificate program in nanomaterials for graduate students to gain a working knowledge of a broad range of instrumentation for solving nanotechnology problems. Courses offered include two core courses (materials for nanotechnology and strategies for nanocharacterization) and elective courses (thin film processing and mechanical behavior, electron microscopy and microanalysis, crystallography and diffraction, advanced transmission electron microscopy and advanced scanning electron microscopy. Credits earned are part of either a Ph.D. or Master's program in related disciplines. As noted earlier, the University at Albany College of Nanoscale Science and Engineering is unique in the nation in offering both a Ph.D. and a Master's degree in NanoSciences and NanoEngineering. This degree offering reflects the fact of the lack of an established engineering or materials science program at the school together with that university's strong focus in nanotechnology. As would be expected, it is a highly interdisciplinary course of study with focused nanotechnology course work.

What is surprising is that nanotechnology has not taken on a more discrete presence as a degree across academia. Unlike bioengineering, which has recently emerged as a separate area of engineering despite its multi-disciplinary nature (frequently with separate departments in engineering schools and in a number of cases as a separate college within a university), no strong movement in this direction is taking place for nanotechnology in academic today, outside of the University at Albany.

What is shared by the vast majority of schools offering new focus graduate programs in nanotechnology within the traditional academic programs and even the University at Albany are:

- New course work in nanotechnology tools and techniques
- Emphasis on multi-disciplinary course offerings to supplement existing degree programs
- Nanoscience-focused graduate research projects.

Bachelor's Level: Nanotechnology has even less of a presence in undergraduate education than in graduate education. This is not surprising given the emerging nature of nanoscience and its focus on basic research.

Louisiana Tech University in February of 2005 announced a new undergraduate degree program in nanosystems engineering, which it claims is the first such program in the nation.

More typically, undergraduates are being exposed to courses introducing nanotechnology, but they are exclusively being educated in basic disciplines.

Community College: The community college level offers a range of different options, because not only is it focused on educating students to be able to matriculate to bachelor's programs, but it is also focused on more career-oriented technical training.

While not extensive, there are programs emerging in training technicians to support nanotechnology R&D activities. Most notable is the Penn State program.

Penn State, through the **Nanomanufacturing Technology Partnership** (NMT), which is housed at the Center for Nanotechnology Education and Utilization (CNEU), has developed one of the nation's first programs for nanotechnology manufacturing-technician training, with heavy industry participation from the region. The focus of the NMT is Penn State's Fabrication Facility, which evolved from the former Electronic Materials and Processing Research Laboratory at the Materials Institute and is now a node on the **National Nanotechnology Infrastructure Network**.[7] The NMT uses the Fab to offer a one-semester, six-course, 18-credit academic **capstone.[8]** These courses, which focus on safe materials handling and an introduction to basic fabrication operations, are integrated by partnering institutions into a newly created associate's degrees in Fabrication *or* used to satisfy requirements for a Fabrication concentration or minor within existing baccalaureate programs in chemistry, physics or biology. There is also a non-credit certificate offered to continuing education students by the Penn State School of Engineering. This summer 39 students are taking the capstone at Penn State. In the future, an effort will be made to limit it to 20 students in three cycles per year. These activities are also recognized by the National Science Foundation as a **Regional Advanced Technology Education Center**, with significant matching funds from the Commonwealth of Pennsylvania.

Interestingly, NMT has found that a key limitation to producing nanotech manufacturing technicians is the ability of community colleges to expose students to more chemistry and physics, including geometrical and physical optics and the conceptual basics of quantum-wave phenomena. In terms of articulation into bachelor's degrees, the NMT observes that students are easily able to matriculate from the Fabrication associate's degree to *four-year programs in engineering technology*, but not so easily with four-year programs in engineering unless they have taken additional mathematics. 2+2+2 program development is just starting and not well defined.

K-12: Nanotechnology at the K-12 level is more an effort to motivate students to engage in the study of a broader range of sciences through the exposure to nanotechnology's promise and applications.

For instance, Center for Nanotechnology Education and Utilization (CNEU) at Penn State, in addition to the community college program it operates, offers many other outreach efforts primarily focused on K-12 including:

- Workshops for Pennsylvania teachers at the high school and college levels;
- "Nanotech Camp" (3-day) for high school students;
- Displays, videos and a speakers' bureau;
- Web-based remote control of the Fab's Atomic Force Microscope and other advanced equipment; and
- Evolving 2+2+2 programs, effectively providing "advanced placement" for high school students headed to community college and perhaps on to a four-year degree.

Lehigh University, which operates one of the nations's most advanced laboratories in electron microscopy —a key tool in nanotechnology characterization—also is engaged with secondary schools. Its ImagiNations program housed in the Lehigh University Center for Advanced Materials and Nanotechnology uses Internet2 to enable K-12 students to access microscopes at Lehigh from classroom desktops and offers hands-on problem solving.

Another key strategy to introduce nanotechnology and engage students through nanotechnology is NSF's Nanoscale Informal Science Education Network, a $20 million, five year effort. Boston's Museum of Science, the Science Museum of Minnesota and San Francisco's Exploratorium were selected to lead and develop the initiative in October of 2005. The efforts will include interactive programs and exhibits, immersive media such as 3-D cinema, visualization labs, and web-based programs and public outreach.

[7] See http://www.nnin.org/nnin_site.html.
[8] For the course list see http://www.cneu.psu.edu/edAcademicCap.html.

Suggested Program Design

The emerging field of nanoscience is widely recognized as the frontier for emerging research in the biological, engineering, and physical sciences. The field is a far-reaching revolution in the understanding and control of increasingly complex phenomena and systems at the nanoscale, and is opening new collaborative and interdisciplinary opportunities

The question on how to incorporate nanotechnology—more properly, nanoscience—into college and university curriculums rests on recognizing that nanoscience is highly multidisciplinary. It is also a field which is changing rapidly, so foundations must be laid in any curriculum related to the field to provide students with the fundamentals of scientific knowledge which will enable them to make adjustments to that evolutionary change and to work in multidisciplinary team-based research.

Degree Programs

Educational foundations may include the following, at various degree levels.

Associate Degree Programs

Preparation at the associate degree level would focus on the teaching of fundamental courses, that is, education in physics, chemistry, biology, engineering and related disciplines. There should also be an emphasis on safe materials handling and an introduction to basic nanotechnology instrumentation operations, perhaps for a new career-oriented Nanotechnology/Advanced Materials Technician degree. This approach would prepare students either for continuing higher education or for entering the workforce. These two paths would have a different emphasis in how nanotechnology is treated.

Baccalaureate General Education Requirements

On the undergraduate level more broadly, especially as general education seeks to educate good citizens and not only provide specialized training, nanoscience would be a good topic for a non-majors course. Cross-listing would be important. Adding to current requirements for graduation would be a detriment. In terms of the non-majors course, the topic of nanotechnology lends itself well to courses that teach science which examine issues of public concern, including aspects related to ethics, environmental effects, and health, among others.

Baccalaureate Science and Engineering Degree Programs

The key to a modified curriculum that lays the foundation for essential multi-disciplinary collaborations is that the interdisciplinary aspects of nanotechnology must be clearly introduced into the various courses in the curriculum.

Nurturing the Process of Scientific Thinking

What is most important is that science students learn the process of scientific thinking and learning, which can be done in any of the physical sciences (engineering, physics, chemistry, biology).

Instead of creating curriculums around nanoscience, nanoscience should be incorporated within existing disciplines, where it will serve to broaden student foundational knowledge and emphasize the importance of multidisciplinary science while still retaining the necessary depth of the chosen major.

Specific Courses or Areas of Undergraduate Study

Such incorporation into existing disciplines can take many modes, and may include a few courses woven into the existing curriculum, either at the senior level or as a beginning freshman exploratory course, such as an introductory course in the fundamentals of nanoscience and a senior/graduate course on quantum device physics.

There are, though, certain courses or areas of study in the science and engineering disciplines at the undergraduate level that could also be aimed at the technical areas focused on nanotechnology. These include colloidal and surface science; quantum confinement physics and nanoscale architecture; thermodynamics and bonding and forces at the nanoscale; synthesis and processing of inorganic and organic nanomaterials/systems; macromolecular and biomolecular nanostructures, catalysts, proteins and nanomachines; self-assembly, directed organization and nanosytems integration; nanoscience specific instrumentation and analytical techniques; physical and mechanical behavior of nano-systems; and processing of nano materials/systems.

The discipline of materials science and engineering (MSE), for example, might be an area of special multidisciplinary thrust.

Team-Based Research

Because nanoscience represents an engaging topic with solidly multidisciplinary content, drawing upon all of the sciences and engineering makes it an ideal topic for modeling team-based research and education. Participation in such team nanoscience research projects can be used to engage students in cutting edge research with a multidisciplinary thrust. Students can learn about the scientific method in the best way possible...through first hand experience. This may be particularly attractive for students at teaching (as opposed to research) universities.

Master's Degree Programs

A sequential baccalaureate and master's degree program would include the standard undergraduate curriculum, including aspects that introduce nanotechnology, and a focused set of courses, including laboratory courses, that result in a master's degree in the nanotechnology area.

The master's degree would be interdisciplinary in nature so that the education provided, although focused, would clearly define the wide range of science/engineering necessary to allow graduates to be immediately productive in the field.

For example, a multidisciplinary master's level degree in materials science would be attractive to students from all of the science disciplines including physics, engineering, chemistry and computer science. Its aim would be to engage students in cutting edge research while specifically training them in nanoscience techniques including imaging and manufacturing. Graduates from such a program would be ideally prepared for Ph.D. level graduate work or would be able to enter the Connecticut workforce immediately.

Doctoral Degree Programs

At the doctoral level, a wide range of possibilities exists. All those possibilities depend on the availability of state-of-the-art facilities. Such facilities would enable faculty to address opportunities for funded research and related graduate education.

Courses would have to be more advanced than those described above, and more specialized nanotechnology courses and topics would have to be introduced.

A Ph.D. in MSE, for example, would prepare students for research in nanoscience.

Clearinghouse Approach

The meeting place for advancing shared nanotechnology programs across institutions can be the new Connecticut Nanotechnology Instrumentation Laboratory, which can offer a series of hands-on courses open to all universities and colleges in Connecticut on the use of various instrumentation. A planning team comprised of involved faculty from across Connecticut's post-secondary education institutions could help in the planning and development of the courses.

More generally, Connecticut, through the educational program capacity at the Connecticut Nanotechnology Instrumentation Laboratory, could collect various course curriculums, engage industry advisory panels and undertake other voluntary, but collaborative efforts to advance nanotechnology curriculum and assess "community" needs for specialized instructional equipment that could be jointly utilized across institutions.

Industry Advisory Board

In order to help guide the state's investment in curriculum development and to create a more seamless system of workforce development in an emerging field, it is critical to have in place an industry advisory board. In particular, it is important to learn from industry the specific skill needs as well as match graduate levels to actual job demands.

Given the diversity of industries impacted by nanotechnology developments, it will be important to have broad representation of industries on the advisory board.

Building the Pipeline and Outreach Efforts

One can also use nanoscience as a popular science motivator, and our colleges and universities should offer public lectures or junior high school visits, etc, to capture prospective students and ensure they keep an ongoing interest in required underlying math and science fields.

Building the pipeline is essential if we are to maintain: appropriate achievement and sustained and sustainable interest in the field.

Cost Estimates

It is estimated that the annual cost for supporting nanotechnology-related post-secondary education programs and clearinghouse would be approximately $1 million annually. The proposed funding requirements would include:

Scholarships

Master's Degree Fellowships – a total of 125 Master's Prize Fellowships would be provided (25 one-year fellowships per year over five years) to students pursuing interdisciplinary science/engineering Master's degrees directed toward careers in nanotechnology—$375,000 annually.

Doctoral Fellowships – A total of 5 Doctoral Prize Fellowships would be awarded to students who have completed their doctoral coursework and who are embarking on research/dissertation work in a nanoscience related field. Fellowships would consist of an annual stipend of $25,000, renewable for a maximum of three years—$125,000 annually.

Curriculum Development

Collaborative Course/Program Development – Ten $15,000 grants would be awarded each year for five years for collaborative course and/or program development in nanoscience by teams of faculty members. Collaborative teams would have to consist of faculty members from at least two different institutions and from at least two different scientific/engineering disciplines—$150,000 annually.

Collaborative On-line Course/Program Development – Ten $20,000 grants would be awarded each year for five years to develop asynchronous courses and/or programs focused on nanotechnology and supporting fields. Collaborative teams must consist of faculty from at least two different institutions and from at least two different scientific/engineering disciplines—$200,000 annually.

Outreach/Pipeline/Clearinghouse

A total of $50,000 each year for five years would underwrite a comprehensive outreach campaign aimed at educating students about nanotechnology and the exciting career and research opportunities available in this emerging field and in supporting fields. In addition, $100,000 would be used to support the coordination of outreach and clearinghouse development activities (.5 FTE position plus operating expenses)—$150,000 annually.

Draft Concept for:

Connecticut Center for Nanoscale Sciences and Development

RATIONALE

In nanotechnology, the starting point for developing, measuring, and testing nanotechnology applications is the use of advanced atomic-level instrumentation, whether related to academic research or industrial product development.

The critical importance of having access to nanotechnology tools is found in the history of nanotechnology. The promise of nanotechnology was significantly advanced in the 1970s and 1980s with the advent of new tools to see and manipulate individual atoms and molecules and now we are able to translate that scientific research into commercial activities.

Given the high cost and technical support required to operate sophisticated nanotechnology tools, it is best to organize these nanotechnology tools as shared use laboratories that can have broad reach to academic and industry researchers, while promoting specific applications development in focused fields of activity.

The value of a shared use nanotechnology instrumentation facility goes well beyond enhancing a university's competitiveness for federal grants; it also can enable nanotechnology discoveries to be more quickly advanced for proof-of-concept and future testing. A nanotechnology instrumentation facility can also offer an important "hands-on" component for nanotechnology-related education and training programs.

Combining all of these pieces together—academic research, industrial product development and education and training—into the development of a nanotechnology instrumentation facility can offer Connecticut a "signature facility" for nanotechnology that can bring together the full community engaged in advancing nanotechnology.

BEST PRACTICES

Across science and engineering disciplines, core laboratories are an important way for universities to create a critical mass of researchers needed for institutional excellence and for building collaborations with industry and other universities. In nanotechnology, there is already a well-documented record of the value of investing in shared use lab facilities as a means to advance an institution's capability to attract researchers and major federal research funding. For instance, Harvard made a strategic decision in the late 1990's to build up its capability when it invested nearly $100 million to launch its Nanoscale Science and Engineering Center, which involves an active partnership with MIT and several out-of-state institutions. This is a broad-based research effort focusing on the fundamental properties of nanoscale structures including the construction and testing of new types of electronic and magnetic devices primarily from nanocrystals or nanomagnets. Since this initial investment in facilities, Harvard garnered a major NNI supported Center for Imaging and Mesoscale Structures.

Oregon state government helped launch the Oregon Nanoscience and Microtechnologies Institute, as part of a broader effort to establish "signature facilities" recommended by the Oregon Council on Knowledge and Economic Development. In 2003 the Oregon Legislature allocated $20 million for the capital cost of user facilities and $1 million for operation of the **Oregon Nanoscience and Microtechnologies Institute**

(ONAMI).[9] ONAMI includes facilities for characterization and product testing and development. ONAMI has leveraged additional support for the state investment including: $2 million in equipment donations, a $2 million donated building lease from Hewlett-Packard, and $20 million in additional federal research funding.

Perhaps the most explicit strategy of advancing key facilities as a means to build up research prowess in nanotechnology has been undertaken by the University of California. Recently, the University of California assembled a list of nanotechnology "resources"[10] within the system, and it is quite extensive. Nearly every California campus, as well as the cross-cutting **Discovery Grant**[11] program, has something to offer industry. However, the premier investment made by the state was in the **California NanoSystems Institute (CNSI)**. CNSI is one of four similar **California Institutes for Science and Innovation**[12] created in 2000, with commitments of $100 million each, as part of a deliberate drive to direct resources to research areas of strategic importance to the state's future economic growth.

CNSI binds together resources at UCLA,[13] where collaborations are already strong between engineering and medicine, with physical science and advanced materials expertise at UCSB.[14] In all, it involves 10 departments in seven colleges at both campuses, supporting 56 faculty members at UCLA and 33 at UCSB, with more than 225 students and postdocs at both facilities combined. The state funding is paying for an 184,000-square-foot building at UCLA and an 110,000-square-foot building at UCSB.

The research focus areas of CNSI are as follows:

- Nanosystems and sensors
- Nanofabrication
- Biomedical applications
- Applied materials.

The California Institutes were intended to generate at least three times the state commitment in federal and industrial matching funds, and CNSI claims collaborations with at least two dozen major firms and start-ups with nanotechnology interests. CNSI claims to have leveraged $150 million in federal awards in 2002–2003, including

- The DARPA and DoD-sponsored **Center for Nanoscience Innovation for Defense**,[15] shared among the two CNSI institutions and the University of California at Riverside;
- An NSF NSEC for **Scalable and Integrated Nanomanufacturing**[16] based at UCLA in partnership with the University of California at Berkeley, Stanford, the University of California at San Diego, the University of North Carolina at Charlotte, and Hewlett-Packard Laboratories;
- The NSF-funded **Center for Embedded Network Sensing;**

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[9] See http://www.onami.us/ao_overview.html.
[10] See http://www.universityofcalifornia.edu/research/nanotech.html.
[11] See http://uc-industry.berkeley.edu/welcome.asp.
[12] See http://www.ucop.edu/california-institutes/about/about.htm.
[13] See http://www.cnsi.ucla.edu/mainpage.html.
[14] See http://www.cnsi.ucsb.edu/.
[15] See http://www.engineer.ucla.edu/stories/2002/cnid.htm.
[16] See http://www.sinam.ucla.edu/.

- The Army-funded **Institute for Collaborative Biotechnologies** (in partnership with MIT and Caltech);
- NASA-funded **Institute for Cell Mimetic Space Exploration**;[17] and
- SRC/DoD-funded **Functional Engineered Nano Architectonics Focus Center**.[18]

A key state role in advancing shared use facilities and broader research centers is providing matching funds to attract federal funding for university research centers. For instance, Cornell had matching state support to win two new federal research centers in nanotechnology. For one of these new nanotechnology centers, the Nanobiotechnology Center, the state made a separate $2.8 million grant for an Alliance for Nanomedical Technologies as a bridge between Cornell's nanotechnology activities and its separate biotechnology initiatives. Similarly, the University of Massachusetts–Lowell (UMass-Lowell), known for its polymer processing strengths, but not widely considered a top-tier nanotechnology research center, initially failed in its efforts to attract a federal nanotechnology research center with Northeastern University. A second bid with $5 million in state support in the form of a Center for Nanomanufacturing to seed industry collaborations succeeded in winning the NSF-supported Center for High-Rate Nanomanufacturing. Now, the state is proposing a $21 million investment for construction of a headquarters for the Center in the Lawrence Mills brownfield redevelopment area.

SUGGESTED PROGRAM DESIGN

Key Features:

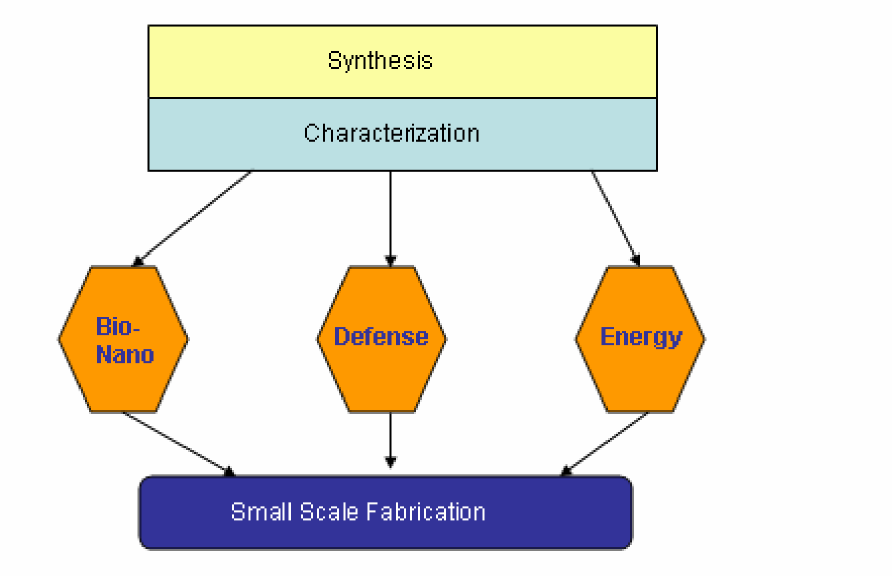
- Advance the concept of shared use labs at key nodes in Connecticut that are accessible to a critical mass of academic and industry researchers and can ensure a cost effective access to specialized lab technicians needed to operate the facility. Existing equipment should be organized within the new shared use labs consistent with their support of non-nanotechnology research and development.
- Be customer-driven by addressing the needs of existing researchers, including filling key gaps in current Connecticut nanotechnology equipment, as well as ensuring a sufficient supply of key equipment to meet demand in a reasonable timeframe..
- Be strategic by addressing the life-cycle needs from synthesis to characterization to small-scale fabrication in focused areas of nanotechnology development. For Connecticut, three areas of focus are suggested:
    - Defense – involving composites, thermal barrier coatings, ultra-tough materials, advanced alloy design and smart materials involving novel electronic and sensing properties.
    - Energy involving fuel cells, hydrogen and hydrogen storage, solar cells, and catalysis.
    - Bio-nano involving drug discovery, development, and delivery and tissue engineering and bio-materials.
- **Offer a single point of contact** to the university and industry community.
- **Establish a mechanism to support the majority of operating expenses over-time through fees** generated by academic and industry users, as well as by education and training courses.

[17] See http://www.cmise.ucla.edu/.
[18] See http://fcrp.src.org/member/centers/nmat/about.asp?bhcp=1.

- **Develop nanotechnology instrumentation facility largely supported by state funding**, with the subsequent acquisition of equipment driven by large instrument grant proposals and as part of large research grants. An industry user consortium would also be a potential source of sustained instrumentation funding. A fee structure would be partially based on depreciation could offer some resources for instrumentation replacement /addition.

The figure below depicts the concept of Connecticut's nanotechnology instrumentation laboratory from a high level perspective.

Figure 1: Depiction of Nanotechnology Instrumentation Facility



Facility Investment Requirements:

Connecticut has an established base of nanotechnology research and development that it is seeking to build upon, and along with that base is the presence of an initial inventory of nanotechnology-related equipment. However, the deficiencies in nanotechnology equipment are significant in Connecticut, particularly in nanocharacterization and small-scale nanofabrication.

Nanocharacterization involves use of advanced microscopes to create images at nanoscale resolution. There are several main types of nanocharacterization approaches:

- Electron microscopy builds images at the nanoscale level by accelerating electrons and passing them through a sample and observing the results. Two main types of electron microscopy are key. One is scanning electron microscopy (SEM), which creates images with resolution as fine as a few nanometers. The other is transmission electron microscopes (TEM), which images a smaller area at higher resolutions than SEM. Although a number of these systems exist throughout the state, many are not fully instrumented with some of the extremely valuable spectroscopy tools that these systems can leverage (such as EDS, EELS and cathodoluminescence), nor are they configured as a user facility. A new type of SEM and related Field Emission Gun TEM introduced within the last year gives images and chemical information on an atomic scale by focusing an intense monochromatic electron beam to a diameter of 0.1nm which is less than the width of an atom. No such instruments are available anywhere in the state, or indeed anywhere in New England.

- Surface science analysis, the understanding of the chemical composition of nanostructures, is as important as imaging. A variety of characterization tools developed and used commonly in the semiconductor industry, have been developed for this analysis. Examples of these are scanning SIMS (secondary ion mass spectroscopy, which allows one to have an elemental analysis of surfaces), scanning AES (Auger Electron Spectroscopy, complementary to SIMS, but sensitive to elements that SIMS cannot detect well but with much lower sensitivity), and ESCA (Electron Spectroscopy for Chemical Analysis, sensitive to chemical state information).
- Scanning probe microscopes, which drag a very fine tip across the surface of a sample, using the interaction between the two to measure the size or other properties of structures on the surface. The most common type of SPM is the atomic force microscope (AFM), which is used to measure the force exerted on the probe tip as it moves along the surface. Another frequently used SPM is the scanning tunneling microscope, which measures the amount of electrical current flowing between a scanning tip and a surface, and can be used to test the local geometry or to measure the local electrical conducting characteristics. Among other often used variations on SPM are magnetic force microscopy (MFM), near-field scanning optical microscopy (NSOM), and electrostatic force microscopy (EFM) and electrochemistry microscopy.
- Dual-beam microscopes, which combine an electron beam for scanning electron microscopy (SEM) with a focused ion beam (FIB), can be used either to mill away parts of the sample or to cut it into thin slices to prepare it for TEM imaging. Commonly used in the semiconductor industry for defect analysis and photomask repair, nanotechnology researchers are now beginning to use dual-beam microscopes to build three-dimensional images of nanostructures by taking an SEM image of a sample, slicing a layer of it off, imaging the newly exposed layer and repeating the process. This instrument can be used in a variety of different applications including: site-specific precision machining of TEM samples from nanostructured materials and devices; serial sectioning of such materials and devices for tomographic reconstruction; and manufacture of one-off prototype devices from nano-scale materials for proof-of-principle experiments.
- Spectroscopy refers to shining of light of a specific wavelength(s) on a sample and observing the absorption, scattering and other properties of the material under those conditions. Typically, spectroscopy is of great importance in characterizing nanostructures en masse, but does not get into the details on the scale of nanometers given the limitation that spectroscopy cannot study structures smaller than its wave-length. There are many spectroscopy approaches used in nanotechnology, including Fourier Transform Infrared Spectroscopy (FTIR), which measures chemical bonds and composition using absorption of light by molecular vibrations; Raman Spectroscopy which uses the scattering of light from molecular vibrations to measure chemical bonds and composition; Nuclear Magnetic Resonance (NMR) spectrometry measuring the mobility of particles in electric fields to measure chemical bonds and composition; X-ray diffraction to measure crystal structure, among others; and photoluminescence spectroscopy, which allows for the identification of the energy states in nanostructures. A similar suite of analysis tools exist for soft or liquid systems relevant to bio-nano, including HPLC (High Performance Liquid Chromatography) and GC/MS (gas chromatography/mass spectrometry) for trace analysis.

Small-scale nanofabrication involves creating structures with nanoscale dimensions. The ability to undertake nanofabrication is critical in order to make nanointermediary products and devices, which allow the properties of nanoscale materials to be put to use. Key tools here include:

- E-beam lithography, which uses electrons to make structures at the nanoscale, overcoming the size limitations of light generated lithography.
- Nano-imprinting which this uses a template with electron beam nanopatterned features to stamp out images on a surface covered with a polymer precursor ink, which can form solid structures when polymerized with ultraviolet light or heat.
- Dip-pen nanolithography which draws nanoscale features directly on a surface using an Atomic Force Microscope tip dipped into ink and dragged across a surface.
- Inductively coupled plasma reactive ion etching systems in which a beam of charged particles cuts nanometer-wide grooves, pits, or holes in materials.

Specific Connecticut Equipment Needs

Identified needs across the spectrum of nanotechnology instrumentation in Connecticut are significant, including:

Electron Microscopy, including Field-Emission Gun Scanning Transmission Electron Microscope; Low-Voltage Low-Dose Transmission Electron Microscope with Cryo-Transfer; Thermionic Orientation Mapping Scanning Electron Microscope; Field Emission Orientation Mapping Scanning Electron Microscope; Scanning Electron Microscope with the Polarization Analysis (SEMPA); Low Energy Electron Microscope (LEEM) with Polarization Analysis; Four-Circle X-Ray Diffractometer; Dual-Beam Focused Ion Beam Apparatus; Soft material TEM; Lattice Image TEM; EELS TEM; 3D Temography TEM; Cryo Stage TEM.

Surface Science Instrumentation, including: High resolution scanning auger microscope; MS/MS mass spectrometer; Double Focusing Sector Mass Spectrometer; High Resolution X-Ray Photoelectron Spectrometer; Tof Sims; Field Emission Auger; Total Reflection X-Ray Fluorescence; Rutherford Backscattering Spectrometer; Additional AFM/STM Liquid/Vacuum Etc. Capability; Extended Scanning Probe Microscopy Facility Low Temp. Stm; Dedicated Magnetic Force Microscope; Structured Tip PM.

Spectroscopy, including Raman, UV, FTIR, NMR and XRD/XRF, LC/GC/Mass Spec

Nano Processing and Fabrication, including segmented clean room capability for nanofabrication; Lithography system(s)—Nanoimprint Lithography (both with thermal and UV capabilities)—for up to 8″ wafers; SEM dedicated to electron beam lithography; Mechanical alloying/synthesizing systems.

Program Activities:

- **Applications Support:** This component will facilitate use by corporate users in need of research and development support. It can play a key role in SBIR/STTR proposals and development/performance. If appropriate, research problems/topics may stimulate corporate/academic partnerships (e.g., research topics for research experiences—see below).
- **Educational Programs and Workshops:** Educational programs and workshops will be offered to academic and corporate users (potential and current), focusing on hands-on instruction in the use of nanotechnology instrumentation. The goal will be to instruct users in applications, data collection and interpretation. This effort could be part of a more extensive “Nanotechnology Education Consortium and Clearinghouse.”
- **Research Experiences:** Fellowships will be offered for University/College faculty, graduate and undergraduate students to make use of and learn the techniques in the facility. Fifteen summer

fellowships will be offered (four weeks for faculty; eight weeks for students) at $5K per fellowship. Supplementary support will be provided by external grants to offset stipend and materials costs. Topics may be based on corporate R&D needs (see above).

- Professional Development: Professional development short courses will be offered for University and Corporate technology staff seeking training in cutting edge nanotechnology tools for fabrication and characterization. These professionals will gain skills that will facilitate their future interactions with the Center. They will also utilize these skills at their present job site to enhance technology competency.

COST ESTIMATES

Connecticut needs to jumpstart the development of the Connecticut Center for Nanoscale Sciences and Development. Similar to other states, such as Oregon or New York or Massachusetts, the state investment should be viewed as one key funding source, which would leverage additional funding from industry, federal government and universities.

Based on discussions with leading nanotechnology researchers on appropriate instrumentation and programs to be housed within a proposed nanotechnology-characterization facility, the upfront investment could reach $25 to $35 million.

It is recommended that the state support one third to one half this capital cost.

As crucial as the initial state matching support for the facility, it is also critical for the state to jumpstart development by providing operational program support to get the Connecticut Nanocharacterization and Processing Center off the ground. It is expected to be around $500,000 to $1,000,000 annually over a three to five year period.