Initial Inputs from colleagues at The Joint School of Nanoscience and Nanoengineering for OSTP's RFI on the Bioeconomy

OSTP seeks comment on the questions listed below to inform the development of the National Bioeconomy Blueprint:

Grand challenges: President Obama has identified ``grand challenges'' as an important element of his innovation strategy, such as ``smart anti-cancer therapeutics that kill cancer cells and leave their normal neighbors untouched; early detection of dozens of diseases from a saliva sample; personalized medicine that enables the prescription of the right dose of the right drug for the right person; a universal vaccine for influenza that will protect against all future strains; and regenerative medicine that can end the agonizing wait for an organ transplant.''

(1) Identify one or more grand challenges for the bioeconomy in areas such as health, energy, the environment, and agriculture, and suggest concrete steps that would need to be taken by the Federal government, companies, non-profit organizations, foundations, and other stakeholders to achieve this goal.

12/09/11: Daniel J.C. Herr, [redacted], Chair - Department of Nanoscience, Joint School of Nanoscience and Nanoengineering, Greensboro, North Carolina

Comment #1: On what a bioeconomy can learn and leverage from Nature
What clues and guiding principles can Nature and living biosystems reveal to us about the requirements and architecture of a thriving and sustainable bioeconomy? In the **Fabric of Life**, Fritjof Capra describes a robust living system, not as a collection of discrete and isolated components, but as an integrated network of interdependent systems, with dynamic and adaptive feedback processes. More than fifty years ago, Richard Feynman shared a vision for the hierarchical dimensional convergence between top down and bottom up science and technology. The next frontier is the horizontal reconvergence of complex, information rich systems across disciplines. Nature cares little about how or where we artificially draw disciplinary boundaries. In fact, one could argue that traditional siloed approaches to education, research, development, commercialization, nanomanufacturing, economics, environmental impact, history, communication, and art are rather unnatural. Siloed disciplines assume varying degrees of independence, which creates blinders to the reality of their intricate interdependencies and their dynamic and adaptive feedback processes.

Recommended Action #1: Support new research frontiers in convergent technologies, especially between disciplines that may seem to be unrelated, such as metabolic pathways and processes and sustainable economic networks. In another embodiment, consider research that explores linkages between the impact of environmental dynamics

on an ecosystem's evolution with adaptive models for local, regional, and global economic development, in a world of ever changing resource, environmental, workforce, technology, and political requirements and constraints. This vision calls for innovative and hands-on seed corn programs that leverage the interdependence of education, research, development, commercialization, nanomanufacturing, economics, environmental impact, history, communication, and art.

Research and development: R&D investments, particularly in platform technologies, can support advances in health, energy, the environment, and agriculture, and accelerate the pace of discovery in fundamental life sciences research.

(2) Constrained Federal budgets require a focus on high-impact research and innovation opportunities. With this in mind, what should be the Federal funding priorities in research, technologies, and infrastructure to provide the foundation for the bioeconomy?

12/09/11: Shyam Aravamudhan, [redacted] Assistant Professor, Department of Nanoengineering, Joint School of Nanoscience and Nanoengineering, Greensboro, North Carolina
Daniel J.C. Herr, [redacted] Chair - Department of Nanoscience, Joint School of Nanoscience and Nanoengineering, Greensboro, North Carolina

Comment #2a: On the bioeconomy in health applications
Health biotechnology, which is the use of knowledge of cell functions and genetics at the molecular level, including the understanding of DNA, RNA, proteins and enzymes to develop new therapeutics and diagnostics. Two main biotechnologies in health are: (a) Biotechnology therapies and (b) Bioinformatics and diagnostics (source: Report – Human health biotechnologies to 2015). The scope of this effort would include the following key attributes: Drivers to change, technology and research, government policies and regulation, health care delivery systems, stakeholders, global economies, demographics and human resources, climate changes, security, and the interaction of animal and human health drivers. (Source: OECD International Futures Project on "The Bioeconomy to 2030: Designing a Policy Agenda - Health Biotechnology to 2030)

Recommended Action #2a: Increase the emphasis on interdisciplinary research that fuels the bioeconomy by accelerating the discovery, innovation, and application of nanoscale properties that catalyze high impact market opportunities.

12/09/11: Dennis LaJeunesse, [redacted] Associate Professor, Department of Nanoscience, Joint School of Nanoscience and Nanoengineering, Greensboro, North Carolina

Comment 2b: On the biomimetic development of novel "green" textile and composite materials, using nanobiotechnology

The natural world is filled with biologically significant composite materials that are biocompatible, sustainable, and diverse in organization and utility.

Recommended Action 2b: Discover, understand, and develop new technology to identify and implement novel textile and composite materials, with designed and useful functionality. For example, biomimetic approaches fabricating and manipulating nanofibers, such as those based on chitin and cellulose, could enable a revolution in sustainable, highly selective, and low energy nanomanufacturing.

12/09/11: Daniel J.C. Herr, [redacted] Chair - Department of Nanoscience, Joint School of Nanoscience and Nanoengineering, Greensboro, North Carolina

Comment 2c: On high risk, high impact bioeconomic opportunities
Nature offers a hierarchy of approaches to patterning structures. At one end of the spectrum, erosion and top down sculpting approaches to fabrication are examples of processes that depend on external forces, such as wind water, and light that subtractively remove material to create structures. At the other end of the fabrication hierarchy, the programmed assembly of living systems represents a bottoms-up approach that leverages the rich information contained within the material building blocks that assembly into useful nanostructures that maintain and replicate living systems. Research in nanomanufacturing will be a key driver for a sustainable bio-economy. However, the lag time for revolutionary high impact concepts to impact and benefit society is typically thirty years (See D. Herr's and V. Zhirnov's study on the discovery and innovation cycle.) These long discovery and innovation lead times for breakthrough technologies require strategic and sustained support. Potential high impact R&D breakthroughs in the next 20 years include:

- Biomimetic and deterministic design and low energy nanomanufactuing of high performance, functional materials, such as by directed self-assembly.
- Systems that are powered from ambient biological temperatures and leverage bioenergetic materials and processes, such as ATP and photosynthesis.
- Self-adapting and self-healing materials and fabrication methods.
- Distributed intelligent networks of autonomous systems, composed at the nano-level, with adaptive emergent behaviors, such as a synthetic neutrophil.

Recommended Action #2c: Develop mechanisms for providing strategic and sustained support, i.e. 15-20 years, for high impact, high risk research that enables a robust bioeconomy.

Recommended Action #2d: Support research that develops a foundational understanding of the language of materials and biomimetic assembly processes. This knowledgebase will enable us to leverage emergent nanoscopic processes to facilitate the fabrication of useful and functional nanostructures, nanodevices, and integrated nanosystems.

(3) What are the critical technical challenges that prevent high throughput approaches from accelerating bioeconomy-related research? What specific research priorities could address those challenges? Are there particular goals that the research community and industry

could rally behind (e.g., NIH $1,000 genome initiative \http://www.genome.gov/27541190\)?

12/09/11: Daniel J.C. Herr, [redacted] Chair - Department of Nanoscience, Joint School of Nanoscience and Nanoengineering, Greensboro, North Carolina

Comment #3: On nanomaterials and nanofabrication trends that would accelerate the emergence of a bioeconomy

There is a trend towards biomimetically designed materials that express desired structure and function. For example, directed self-assembly, which exhibits potential for forming sub-10 nm structures in desired and useful patterns, is emerging as an alternative to traditional photoresist-based pattern transfer processes. Eventually, these self-assembling materials may incorporate other useful functionality, such as insulating, semiconducting, conducting, sensing, and/or energy harvesting properties, which will obviate the need for certain etch processes. This biomimetic approach would facilitate the trend towards green and sustainable, high performance chemistries and low energy processes.

Additionally, for emerging More-than-Moore technologies, where scaling is less important, there is a tremendous need for designing and synthesizing functional materials in adjacent spaces, to the nanoelectronics domain, such as energy and bioelectronics, which can be integrated onto a CMOS platform. With respect to bioelectronics, the highest priority emergent needs include personalized medical diagnostics and monitoring, implantable devices and prosthetics, and biocompatible imaging systems. In the areas of implantable devices and prosthetics, there is a tremendous research need for understanding and engineering a robust biotic-abiotic nanointerface, which does not biofoul over time.

Innovations in carbon based electronics, i.e. carbon nanotubes and graphene based devices, require a significant amount of fundamental chemistry to understand their growth mechanisms and dynamics and their interactions with other matter. For carbon nanotubes [CNTs], the 'holy grail' has been to grow them with controlled dimensions, chirality, and functional properties. We are on the verge of developing strategies for achieving this level of control in CNT synthesis. For graphene systems, we are much lower on the learning curve, and a significant level of foundational work is needed before these can be considered for manufacturing.

Deterministic fabrication may be considered an extension of nanoengineered patterning, as it may leverage top down, hybrid, or bottom up approaches. As devices continue to scale, fewer dopant atoms are needed in the channel region. Soon, the number of required dopant atoms will correspond to a small number, say around 100 atoms. At this point, any variation in dopant count and position will adversely impact device performance and performance uniformity. Hence, there is a trend towards fully depleted devices, for which there are no dopant atoms in the channel region. However, even in this scenario, any variation at the interfaces between the channel and the source, drain, and gate stack will induce variations in device performance. Ultimately, more deterministic approaches to nanofabrication will be needed to achieve the required levels of performance and uniformity. As a proof of principle, biological systems have mastered the ability to grow precise replicates of complex functional structures.

Recommended Action #3: **Support and accelerate the creation of a predictive nano- and bio-materials by design infrastructure, with integrated experimental, nano-measurement, and theoretical tool development. Simulation tools are needed to predict and assess trade-offs between material manufacturability, functional performance, cost, and sustainability. However, a considerable amount of 'dotting-the-I' type research will be needed to develop the required materials database. High impact Science and Nature type papers work against this strategic need. I see very little national support for funding this type of work. The nanomaterial genomics initiative represents a first step towards achieving this goal.**

(4) The speed of DNA sequencing has outstripped advances in the ability to extract information from genomes given the large number of genes of unknown function in genomes; as many as 70% of genes in a genome have poorly or unknown functions. All areas of scientific inquiry that utilize genome information could benefit from advances in this area. What new multidisciplinary funding efforts could revolutionize predictions of protein function for genes?

Moving life sciences breakthroughs from lab to market: It is a challenge to commercialize advances in the life sciences because of the risk, expense, and need for many years of sustained investment. The Administration is interested in steps that it can take directly, but is also interested in encouraging experimentation with new private-sector-led models for funding commercialization of life sciences research.

(5) What are the barriers preventing biological research discoveries from moving from the lab to commercial markets? What specific steps can Federal agencies take to address these shortcomings? Please specify whether these changes apply to academic labs, government labs, or both.

12/09/11: James G. Ryan, [redacted] Founding Dean, Joint School of Nanoscience and Nanoengineering, Greensboro, North Carolina

Comment #5a: **On Nanomanufacturing at the Joint School of Nanoscience and Nanoengineering**

The bold vision to develop a joint graduate school required that the universities look beyond traditional academic models and the national goal of maintaining competitiveness in the manufacturing sector requires that we as a nation look beyond traditional models. [See attached document white paper entitled, "**Nanomanufacturing at the Joint School of Nanoscience and Nanoengineering".]**

Recommended Action 5a: We must develop and build "aggressively interdisciplinary" models that integrate education, research, and public-private partnerships to enable innovative manufacturing technologies. Technologies alone are not enough. We also need to promote methods of commercialization that take ideas from the lab to the factory floor in more efficient ways to assure leadership in advanced manufacturing. Key factors include innovative approaches for: Educational outreach and workforce training, nanomanufacturing science and technology research, and improved commercialization, through effective public-private partnerships that collaboratively leverages the expertise of key stakeholders.

12/09/11: Daniel J.C. Herr, [redacted] Chair - Department of Nanoscience, Joint School of Nanoscience and Nanoengineering, Greensboro, North Carolina

Comment #5b: On policy barriers to achieving a bioeconomy

In 1996, Semiconductor Research Corporation and the National Science Foundation launched a joint Engineering Research Center for Environmentally Benign Semiconductor Manufacturing. The process for selecting and managing this center addressed the core needs of the key stakeholders, especially with respect to conflict of interest concerns. While jointly funded by SRC and NSF, this ERC served as a flagship program and a best practice for true public-private partnership. The Focus Center Research Program and the Nanoelectronics Research Initiative represent additional examples of successful and highly valued SRC public-private partnerships [PPP] with DARPA and NIST, respectively.

In the bioelectronics arena, there appears to be a policy barrier that prevents NIH and industry from developing a true strategic research partnership, which seems to be based on a perceived concern for potential conflicts of interest. Currently, the NIH foundation can accept money from an industrial 'partner'. However, it is my understanding that NIH will not engage these 'partners' in defining the call for proposals, selecting the projects to be funded, or assessing the progress of the funded research. In this model, the partnership consists of industry throwing money over the fence. Unfortunately, this approach presents a barrier to leveraging the expertise of each stakeholder and to exploring true convergent opportunities between government, academic, and industrial sectors. For example, the direct collaboration between the biotechnology and nanoelectronics communities could open new markets, create significant job opportunities, and revolutionize the delivery of health care, while avoiding conflicts of interest and maintaining appropriate transparency.

Recommended Action #5b: Develop a set of best practices for successful and effective public-private partnerships between government funding agencies and strategic industrial sectors. A simple, standard, and open process for government and industry to work together as partners would catalyze innovation, drive biological discovery research into the market, and create jobs for the bioeconomy.

12/09/11: Christopher Kepley, [redacted] Associate Professor, Department of Nanoscience, Joint School of Nanoscience and Nanoengineering, Greensboro, North Carolina

Comment #5c: On barriers to and opportunities for transitioning biological research discoveries from labs to commercial markets?
A key barrier is the lack of support for the tidal wave of novel, proof-of-principal nanotechnology-based diagnostic, therapeutic, and theranostic systems emerging in academic and government labs. In some cases, perceived toxicity concerns, based on little data, can block a novel and meritorious technology from receiving the critical support needed to realize its potential and address key health challenges.

Recommended Action #5c: Consider developing vehicles for accelerating the investment in and assessment of high risk options that exhibit high potential impact and benefits, while maintaining appropriate checks and balances to protect public health.

(6) What specific changes to Federal Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs \http://www.sbir.gov/\ would help accelerate commercialization of federally-funded bioeconomy-related research?

(7) What high-value data might the government release in the spirit of its open government agenda that could spur the development of new products and services in the bioeconomy?

(8) What are the challenges associated with existing private-sector models (e.g. venture funding) for financing entrepreneurial bioeconomy firms and what specific steps can agencies take to address those challenges?

Workforce development: Investment in education and training is essential to creating a technically-skilled 21st century American bioeconomy workforce.

(9) The majority of doctorate recipients will accept jobs outside of academia. What modifications should be made to professional training programs to better prepare scientists and engineers for private-sector bioeconomy jobs?

12/09/11: Daniel J.C. Herr, [redacted] Chair - Department of Nanoscience, Joint School of Nanoscience and Nanoengineering, Greensboro, North Carolina

Comment #9: On preparing and sustaining scientists and engineers for private sector bioeconomy jobs.

Recommended Action #9a: Integrate entrepreneurship training programs within graduate level curricula

Recommended Action #9b: Bring continuing educational programs to the workers, such as through on-line Professional Masters Programs. This will make it easier for private sector scientists and engineers to remain current and adapt to a dynamic bioeconomy.

(10) What roles should community colleges play in training the bioeconomy workforce of the future?

(11) What role should the private sector play in training future bioeconomy scientists and engineers?

(12) What role might government, industry, and academia play in encouraging successful entrepreneurship by faculty, graduate students, and postdocs?

12/09/11: Daniel J.C. Herr, [redacted] Chair - Department of Nanoscience, Joint School of Nanoscience and Nanoengineering, Greensboro, North Carolina

Comment #12: On encouraging successful entrepreneurship

Recommended Action #12: Provide seed corn support for SBIR-like graduate level professional development classes, for developing and exercising entrepreneurial skills in faculty, graduate students, and postdocs.

Reducing regulatory barriers to the bioeconomy: As President Obama has stated, our regulatory system must ``identify and use the best, most innovative, and least burdensome tools for achieving regulatory ends'' and ``protect public health, welfare, safety, and our environment while promoting economic growth, innovation, competitiveness, and job creation."

(13) What specific regulations are unnecessarily slowing or preventing bioinnovation? Please cite evidence that the identified regulation(s) are a) slowing innovation, and b) could be reformed or streamlined while protecting public health, safety, and the environment.

12/09/11: Ethan Will Taylor, [redacted] Senior Research Professor, Department of Nanoscience, Joint School of Nanoscience and Nanoengineering, Greensboro, North Carolina

Comment 13a: On reducing regulatory barriers
For nanobiobiotechnology and related areas such as "Synthetic Biology" to reach their full potential, which I believe is vast, there will have to be a concerted effort to avoid the accumulation of crippling regulations based upon earlier stages of the science, when the fear of the unknown can lead to regulations airing on the side of great caution.

Specifically, as chairman of the UNCG IBC, and having seen what goes down here as a microcosm of other institutions, I am thinking of regulatory procedures surrounding the use of recombinant DNA. These date back to the mid-1970s when DNA splicing and cloning were first invented, and there was great fear that the technology could lead to the creation of "chimeras": literal monsters that could wreak great havoc on the planet when unleashed, very similar to some of the current fears that we've heard about nanotechnology.

As the decades have gone by, recombinant DNA and cloning have become ubiquitous, and commercialized in a vast number of available cloning vectors, bioassay kits, etc., and we are even seeing the emergence of a synthetic biology “hacker” home/garage lab movement, as recently reported in Wired magazine. It is now understood that the original fears from the 1970s that shaped the regulatory environment were substantially overblown, and a very large amount of work that is done in this area is routine to the point of boredom, often having been taken over by companies, which perform many of the services up to and including the creation of complex expression vectors optimized for your organism of choice, and even high school students are now trained in basic DNA manipulations in more progressive locations.

Yet in the academic environment in particular, any institution which aspires to get NIH grant funding has to have an “Institutional Biosafety Committee”, which is charged to review all novel recombinant DNA experiments and constructs prior to their implementation. The same committee deals with review of the use of biohazardous organisms, leading to a further association between the idea of biological hazard and manipulations of DNA.

Despite the creation of certain "exempt" categories, which nonetheless required disclosures on protocol forms and some sort of streamlined committee approval, if the full rigor of the intended process were to be applied, a needless amount of disclosure and review, and inhibition of fully creative experimentation, would descend upon labs across the country. In reality, in many cases a minimal nod to the regulatory process is given, only a subset of experiments are documented, and novel manipulations proceed despite this process. I would venture to speculate that in a majority of research institutions, a substantial percentage of recombinant DNA and synthetic biology research, routine and otherwise, is probably going on in technical violation of the disclosure and protocol review process. Pressure on institutions to attain more compliance by research faculty may lead to more protocols being disclosed, but may also lead to a dampening of the creative spirit. An atmosphere of excessive regulation inevitably leads to those regulations being flouted, accompanied by disrespect for regulations in general, which is undesirable in organizations and in societies.

The fact is, the fundamental building blocks of biochemistry have been perfected over several billion years of evolutionary time, and provide us with tools and prototypical self-assembling nanomachines of astonishing efficiency and diversity, from which there is the potential to engineer new types of hybrid devices based upon a biomimetic concept, such as that applied in the "BioBricks" approach to synthetic biology. We will have no choice but to learn to use these tools in the most creative ways possible, if we are to maintain a global competitive edge.

The current regulatory environment could be compared to a situation in which engineers with a collection of screws, nuts, bolts, metal beams, rods, motors and an entire collection of building blocks, were told they could not create any new device with these components unless the design was submitted for approval by a committee of experts. Within their set of materials and tools, there may exist hazardous components; such as razor blades, high-voltage devices, toxic adhesive solvents, etc. It is reasonable to expect guidelines for the use of these particularly hazardous tools and materials. But to expect to regulate and review, in advance, the designs for every prototype and novel concept for electromechanical machines, even as those designs are being tried out and modified during optimization of an invention, would be unreasonable.

Recommended Action #13a: Define a large subset of the biological building blocks as fundamentally low risk, focus on particularly hazardous components such as specific genes for toxins and pathogenic mechanisms, and simplify the regulatory process so that practitioners of creative synthetic biology, in the broadest sense, will not be required to justify and wait for committee approval for every new idea for every new experiment they devise.

12/09/11: Marinella Sandros, [redacted] Assistant Professor, Department of Nanoscience, Joint School of Nanoscience and Nanoengineering, Greensboro, North Carolina 27402

Comment #13b: On reducing regulatory barriers
What are the barriers preventing biological research discoveries from moving from the lab to commercial markets? What specific steps can Federal agencies take to address these shortcomings? Please specify whether these changes apply to academic labs, government labs, or both.

The biggest barrier is limited access for academic scientists to collaborate with industrial companies, due to IP issues. I think having a non-profit private entity that can bridge academia and industry together will overcome these issues.

Recommended Action #13b: I believe if the government can modify some of the restrictions on how tax dollars can be used, I think we can encourage [collaboration, innovation, and job creation] as we are trying to do at JSNN. I believe that there are few models like this in the US. I truly believe if we can have closer relationships with industry we can move biological innovations much quicker to commercial markets...

(14) What specific steps can Federal agencies take to improve the predictability and transparency of the regulatory system? (Please specify the relevant agency.)

(15) What specific improvements in the regulatory processes for drugs, diagnostics, medical devices, and agricultural biotechnology should federal agencies implement? What challenges do new or emerging technologies pose to the existing regulatory structure and what can agencies do to address those challenges?

Public-private partnerships: The Administration is interested in serving as a catalyst for public-private partnerships that build the bioeconomy and address important unmet needs in areas such as health, energy, agriculture, and environment.

(16) What are the highest impact opportunities for public-private partnerships related to the bioeconomy? What shared goals would these partnerships pursue, which stakeholders might participate, and what mutually reinforcing commitments might they make to support the partnership?

12/09/11: Daniel J.C. Herr, [redacted] Chair - Department of Nanoscience, Joint School of Nanoscience and Nanoengineering, Greensboro, North Carolina

Comment #16: On Public-Private Partnerships: Highest impact opportunities and processes

The highest impact PPP opportunities for the bioeconomy are:

1. Personalized medical devices and monitoring
2. Prosthetics and implantable devices
3. Bioimaging, i.e. from in vivo-intracellular imaging to high resolution, high throughput full body scans.

[For more information, please see the reports from Semiconductor Research Corporation's two recent Bioelectronics Roundtables that focused on prioritizing win-win bioelectronics opportunities between the biotechnology and nanoelectronics communities within government, academia, and industry.]

Recommended Action #16: Regarding "What shared goals would these partnerships pursue, which stakeholders might participate, and what mutually reinforcing commitments might they make to support the partnership", please see Daniel Herr's comments and recommendation for Question #5, above.

(17) What are the highest impact opportunities for pre-competitive collaboration in the life sciences, and what role should the government play in developing them? What can be learned from existing models for pre-competitive collaboration both inside and outside the life-sciences sector? What are the barriers to such collaborations and how might they be removed or overcome?

Please contact any of the contributors listed above, if you have any questions or would like additional information.

Compiled and edited by Daniel J.C. Herr, [redacted]
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Nanomanufacturing at the Joint School of Nanoscience and Nanoengineering:

A White Paper submitted to the Advanced Manufacturing Partnership Steering Committee

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Background

The Joint School of Nanoscience and Nanoengineering (JSNN) is a collaboration of North Carolina A&T State University (NC A&T SU) and The University of North Carolina at Greensboro (UNCG). NC A&T SU is an Historically Black University with strong programs in the basic sciences and engineering. UNCG, the former Woman's College of the UNC system, has a strong tradition in the liberal arts and has built considerable capabilities in the basic sciences. NC A&T SU and UNCG have come together to create this new joint school in order to reach far beyond what either could have achieved alone. The core values of JSNN include collaboration, innovation and cooperative, technology-driven problem solving. JSNN is one of only two schools in the U.S. to have both nanoscience and nanoengineering degree programs. Although NC A&T SU awards the Nanoengineering degrees and UNCG awards the Nanoscience degrees, the joint nature of the school enables students to take classes from both universities and gain a true interdisciplinary perspective. The bold vision to develop a joint graduate school required that the universities look beyond traditional academic models and the national goal of maintaining competitiveness in the manufacturing sector requires that we as a nation look beyond traditional models. We must develop and build "aggressively interdisciplinary" models that integrate education, research, and public-private partnerships to enable innovative manufacturing technologies. Technologies alone are not enough. We also need to promote methods of commercialization that take ideas from the lab to the factory floor in more efficient ways to assure leadership in advanced manufacturing.

Proposal

The United States is a leader in the development of nanotechnologies of all kinds, but due to the enabling aspects of nanotechnology, many countries have entered the race to develop new "nano" products and applications. Nanotechnologies are integral to industries critical for national defense, energy independence, health care and economic development. Many "nano" products and applications are plagued by limited volumes and high costs caused by nanomanufacturing difficulties. Leadership in nanomanufacturing will determine leadership in many business sectors in the coming years and is a critical enabler for national priorities such as defense. In order to build an integrated program that assures leadership, a multi-pronged approach must be developed to build a foundation for nanomanufacturing featuring workforce training, manufacturing science and technology research, and improved commercialization approaches through public-private partnering models. Many U.S. manufacturing companies see their foreign competitors enabled by their governments and although true partnerships between Academia, Government and Industry are difficult to achieve, U.S. nanomanufacturing entities will need the leverage provided by such partnerships in order to implement innovative ideas.

Workforce Training

Workforce training begins with outreach to high schools and particularly with the teachers. It is important that teachers and guidance counselors understand the career options in fields like nanomanufacturing. In order to address these issues, JSNN has provided Guilford County high school science teachers with "nano-training" through our K - 12 outreach programs with a goal of producing students who will be able to make more informed choices regarding careers and degree options.

Formal workforce training in aspects of nanomanufacturing should take place in Associate, Bachelor's and Graduate degree level programs. Typically, community colleges already focus on workforce training for technician level personnel, often in collaboration with local employers. What is lacking is direct experience with leading-edge technologies requiring extensive infrastructure. JSNN has initiated co-op programs with Guilford Technical Community College and Forsyth Technical Community College employing community college students at JSNN so that they gain hands-on experience with leading-edge infrastructure and equipment

Graduate level education in "nano" at universities is primarily directed at producing R&D personnel. JSNN trains research personnel (through its Ph.D. programs) as well as nanomanufacturing personnel (through its Professional Master of Science in Nanoscience degree program). The Professional Master's program involves Nanoscience and Business courses combined with an internship in order to produce graduates who could work in nanomanufacturing or other fields where a combined science and business background is needed.

Currently, the missing element in JSNN's workforce training strategy is at the Bachelor's degree level. Expertise at JSNN's parent institutions combined with JSNN's "nano" competency could produce unique undergraduate curricula emphasizing nanomanufacturing. For example, a collaboration between JSNN and UNCG's Bryan School of Business could develop a B. S. in Nanomanufacturing Science degree program. Philosophically, it would be patterned after the existing Professional Master of Science in Nanoscience and would combine undergraduate science (emphasizing either Physics, Chemistry, or Biology) and business classes (emphasizing subjects such as Finance, Logistics, Entrpreneurship, Manufacturing Operations, etc.). It is anticipated that the degree program would approach the number of credits for a double major. At NC A&T SU, the School of Technology has initiated discussions with JSNN on a Bachelor's in Nanomanufacturing Technology. This degree would contain undergraduate nanoengineering courses such as Nanomaterials and Principles of Nanoengineering in a curriculum with Engineering Technology courses emphasizing critical elements in building nanomanufacturing capabilities including facilities, equipment, nanomaterials safety and nanodevice operation. The total credits in the Nanomanufacturing Technology major would also be similar to a double major in engineering and technology. These undergraduate programs could also serve as feeder programs for JSNN's advanced degree programs.

Initial funding for expansion of the community college co-op program and undergraduate curriculum planning would be approximately $100K. The ongoing operating expenses of the programs (including hiring one additional faculty in each department to teach in the program and three staff to coordinate program operations) would be ~$900K/year*.

Nanomanufacturing Science and Technology Research

The unique environment of the JSNN serves as a “reactor” for emerging technologies and fosters an environment conducive to discovery. Research underway at JSNN focuses on real-world problems and includes development of new drug delivery methods, nanobioelectronic devices to diagnose traumatic brain injury and nanocomposite technologies that create lighter, stronger materials for the automotive, aircraft and energy sectors.

At JSNN, innovation is encouraged in all areas and we work to make sure that the innovative spirit permeates the organization. Innovation involves (in roughly equal parts) understanding what the key problems are in critical fields, having a team of bright, action-oriented problem solvers who learn from every observation and a culture that encourages not only invention, but also innovation and openness. The problem set and professional team exist in most advanced research facilities, but the culture that encourages people to create solutions to problems (invention) and to take invention to the next step where products and (potentially) wealth are created (innovation) along with a willingness to discuss ideas within the team (openness) is rare. At JSNN we are attempting to build this type of culture through an informal weekly “Inventions and Innovations” meeting where faculty, staff, students, and partners can attend to discuss new ideas. Also, we work to actively extract innovations from research results. Moving the ideas from the labs to factory floors is part of JSNN's partnership strategy (see below).

JSNN's current nanomanufacturing research plan includes three Nanoscience topics and three Nanoengineering topics. The Nanoscience areas include Nanoparticle Manufacturing methods, Nanopore Fabrication and Nanobiomanufacturing . Nanoparticles are included in a variety of products from cosmetics to fighter jets. This broad group of materials includes fullerenes, nanotubes, self-assembled structures, thin films and many others. It is difficult to make the most technologically useful particles in large quantities. For example, fullerene materials find applications in pharmaceutical, defense and structural applications although only lab-scale volumes are available. Nanopore Fabrication is a comparatively new area and has seen genomic research applications, but with recent breakthroughs at JSNN, we believe nanopores will be useful in a variety of purification applications as well. Methods used to form nanopores are relatively slow and productivity improvements are needed before they can be evaluated for large scale applications (e.g. separating and purifying nanoparticles). Improved nanobiomanufacturing techniques are needed for biomolecules used in medical diagnostic and other sensors, chromatographic separation technology and biomedical applications.

The Nanoengineering topics include Nanocomposite Materials Fabrication, Nanobioelectronics and Computational Nanotechnology. Nanocomposites involve the use of nanofibers in combination with conventional materials (e.g. fiberglass, carbon fiber, etc.). Nanocomposite materials may be used in aerospace, wind energy and battery applications. Nanofibers are often made by a technique called electrospinning. Although commercial electrospinning equipment is available, it works well for polymers and some inorganic fibers but is not useful for certain glass and advanced inorganic composition nanofibers. New equipment technology is needed for high productivity electrospinning of TEOS-based glass nanofibers and nanofibers based on materials such as boron nitride (BN). Both TEOS-based glass and BN nanofibers are of great interest to DoD. Nanobioelectronics combines computer chip technology with biotechnology in order to create new diagnostic or medical devices. In general, most industrial cleanrooms are not constructed to be capable of working with biomolecules or bacteria incorporated into the circuitry. New protocols for combined Nano and Bio manufacturing must be developed (JSNN has a cleanroom capable of both nano and bio technologies). Computational Nanotechnology will also be investigated to develop new predictive models for "nanobio" problems.

Although each of these topics is connected to national priorities, two in particular are critical to the Air Force (and DoD in general); Nanoparticle Manufacturing and Nanocomposite Materials Fabrication. JSNN plans to devote significant laboratory facilities to Nanoparticle Manufacturing technologies including the Nanoparticle Synthesis and Nanoparticle Characterization laboratories as well as a portion of the Nanochemistry laboratory. JSNN plans to work with AxNano, Inc. to develop new nanoparticle fabrication and purification methods (see Partnership section below). JSNN's Nanocomposite Fabrication Laboratory combined with the assets in the Nanocomposite Scale-up and Commercialization Laboratory (jointly used by JSNN's partner Advaero Technologies, Inc.) will be used to promote improvements in Nanocomposite Fabrication Technology. In addition, portions of seven other laboratories in JSNN's state-of-the-art facility will be utilized in the nanomanufacturing research effort including its 7000 square foot cleanroom, visualization center, and its extensive characterization and metrology laboratories.

JSNN plans to support this research from its North Carolina state recurring budget and research grants obtained from a variety of sources. These programs can be enhanced and extended with additional federal funding, but if the goal is true acceleration of nanomanufacturing then an infrastructure created for the specific purpose is needed. We propose construction of a 60,000 square foot National Nanomanufacturing Center (NNC) (~$20 Million + ~$2 Million per year of operating funds*) on the Gateway South Campus in Greensboro, NC. The facility would be optimized for prototyping and would enable the integrated nanomanufacturing program of workforce training, manufacturing research and improved commercialization though industrial partnerships.

The facility would contain classrooms and distance learning capabilities in order to reach all interested parties. The research labs would be constructed as large prototyping facilities. The Nanoparticle Manufacturing facility would contain particle synthesis equipment and specialized hoods with appropriate chemical handling, piping and facilities to perform continuous flow separations and extractions. JSNN's Nanopore Fabrication technology might also provide critical capabilities for this effort. JSNN's future partner AxNano, Inc. will work with JSNN personnel to develop high yield, high productivity Nanoparticle Manufacturing methods. The Nanocomposite Fabrication facility will be large enough to permit composite lay-up and testing of large objects such as aircraft parts and windmill blades and still have a portion dedicated to the development of high productivity electrospinning equipment for nanofiber fabrication and automated equipment to fabricate structures containing delicate nanomaterials. JSNN's partner Advaero Technologies will work with the faculty in this space. JSNN's other nanocomposite partners will also be able to gain leverage using this space. Other nanomanufacturing projects would also have prototyping capability in the NNC but will require less space than the Nanoparticle and Nanocomposite thrusts. Facilities such as the proposed NNC have a way of galvanizing attention, attracting corporations and enabling innovation. For example, facilities such as Clemson University's Research Campus have provided significant advantage to the automotive companies in South Carolina and UAlbany's Albany Nanotech has become a center of innovation for the semiconductor industry. The NNC would be able to produce prototypes and focus on commercializing innovation while leveraging JSNN's nearby scientific capabilities for analysis, materials testing and characterization, modeling and specialty syntheses.

<u>Improved commercialization approaches through public-private partnering models</u>

JSNN is located on the Gateway University Research Park (Gateway) South Campus. Gateway is also a collaborative initiative of NC A&T SU and UNCG and is responsible for building and tooling the $64.3M JSNN facility using funding from the North Carolina General Assembly. Together, JSNN and Gateway work to attract industrial partners, with JSNN offering leading-edge education and research programs and Gateway offering advanced facilities to support new ventures with commercial partners. Shared infrastructure is critical for collaboration. Universities, governments and industries have different business models but all need the same scientific/engineering infrastructure to be successful. JSNN and Gateway (as with any successful burden sharing organization) strive to enable each participant to get what they need from the common infrastructure.

JSNN's partners are a combination of start-up and well-established companies. Partners or potential partners for each of the nanomanufacturing thrusts are shown below in parenthesis. JSNN has either completed contracts or entered negotiations with each entity.

- Nanoparticle Manufacturing (AxNano, Inc.)
- Nanopore Fabrication (Carl Zeiss SMT)
- Biomanufacturing Techniques (Horiba)
- Nanocomposites for Wind energy (Advaero Technologies, Xanofi)
- Nanobioelectronics (MEMSCAP)
- Computational Nanotechnology (TBD)

Gateway and JSNN have also developed collaborations with companies such as RF Micro Devices and Agilent Technologies and are currently pursuing potential partnership opportunities with over twenty high technology firms. Although access to facilities is an attraction for companies, the biggest attractive force often involves equipment. In order to attract large entities with complex nanomanufacturing problems, a budget for investment in equipment must be developed. In order for the NNC to attract partners, ~$2 Million per year* would be requested to purchase equipment. The costs of a proposed partnership program are identified before an agreement is executed including labor, consumables, maintenance and capital equipment. As a general rule, total program costs are equally divided but in our model, Gateway would own and maintain the equipment and make it available to all partners.

To date, JSNN/Gateway co-location model has created 192 jobs at an average salary over of $70,000. The economic impact of the JSNN/Gateway model on the Piedmont Triad region is conservatively projected to be approximately one-half billion dollars over a ten year period but more needs to be done to build a strong 21st century manufacturing-oriented economy. The NNC will initially create numerous construction jobs, but more importantly, it will create more than 200 nanomanufacturing R&D jobs on the Gateway campus and more than 500 jobs in the Piedmont Triad as well as provide a prolific job creation engine for the knowledge-based nanomanufacturing sector so critical for American competitiveness.

* Proposed funding amounts are estimates intended to show approximate "opportunity cost". More detailed proposals with detailed budgets would be developed upon request.