

## **Interdisciplinary Graduate Education Program in Sustainable Nanotechnology (SuN)**

### Colleges

College of Engineering

College of Natural Resources and Environment

College of Science

### Departments

Civil and Environmental Engineering

Materials Science and Engineering

Wood Science and Forest Products

Geosciences

### Faculty

Peter Vikesland, PI, Civil and Environmental Engineering, [pvikes@vt.edu](mailto:pvikes@vt.edu)

Amy Pruden, co-PI, Civil and Environmental Engineering, [apruden@vt.edu](mailto:apruden@vt.edu)

Sean McGinnis, co-PI, Materials Science and Engineering, [smcginn@vt.edu](mailto:smcginn@vt.edu)

Maren Roman, co-PI, Wood Science and Forest Products, [maren.roman@vt.edu](mailto:maren.roman@vt.edu)

Scott Renneckar, co-PI, Wood Science and Forest Products, [srenneck@vt.edu](mailto:srenneck@vt.edu)

Michael Hochella, co-PI, Geosciences, [hochella@vt.edu](mailto:hochella@vt.edu)

## Introduction

The earth is at a tipping point and its fate and that of humanity hangs in the balance. Twenty-five years ago only 4.9 billion people inhabited the planet, but the population will exceed 8.6 billion within the next twenty-five years. This historically unprecedented 80% increase in population is provoking systemic global calamities such as climate change, water resource limitations, and the re-emergence of many infectious diseases. In the recent past, solutions to problems of similar magnitude have been achieved via technological breakthroughs that were heavily reliant on what was perceived to be an unlimited supply of resources such as oil, coal, and precious metals. Unfortunately, supplies of these materials are not unlimited and as has been recently reported in the popular press, we have now entered an era where access to many resources may be severely restricted.

Similar to the industrial and medical revolutions that preceded it, nanotechnology has been suggested as a means for society to address the challenges of the future. Across the nanotechnology field there are developments in nanomedicine, electronics, and material production that promise to improve people's lives and partially address many of the systemic issues noted above. A challenge that nanotechnology faces, however, is that many existing nanotechnologies are not sustainable on account of their dependence on non-renewable resources, their energy intensive manufacturing processes, and their potentially hazardous impacts to humans and the environment. **The focus of the SuN IGEP is to develop a new paradigm wherein the sustainability of a given nanotechnology is considered during its entire life cycle.** This IGEP builds upon the existing infrastructure of the ICTAS VTSuN Center of Excellence, the NSF/EPA supported Center for the Environmental Implications of Nanotechnology (CEINT), and the EIGER NSF IGERT and the Green Engineering programs at Virginia Tech. Collectively these interdisciplinary efforts provide the intellectual focus and background for our IGEP group.

*Educational Goals.* The primary educational goal of the SuN IGEP is to produce doctoral graduates that have the skills and expertise to provide leadership in the interdisciplinary field of sustainable nanotechnologies. The program will initially consist of a new graduate certificate in sustainable nanotechnology, requiring a minimum of nine graduate hours from a list of courses on topics that include environmental sustainability, environmental nanotechnology, interdisciplinary research methodologies, and life cycle analysis. This planned certificate program is intended as the first step towards the development of an interdisciplinary degree program in sustainable nanotechnology. Although the focus of the SuN IGEP is on the scientific aspects of sustainable nanotechnology, this interdisciplinary degree will be broader in scope and will encompass social and human aspects.

*Research Goals.* The primary research goal of the SuN IGEP is to incorporate sustainability concepts into all aspects of nanotechnology, including raw material choice, manufacturing processes, and disposal. This is an ambitious long-term goal that will be achieved via completion of shorter-term, highly focused efforts that will provide insights with broad applicability. The initial research focus will be on the potential environmental impacts of nanocellulosic materials, such as cellulose nanocrystals and nanofibrillated cellulose. These plant-derived nanomaterials have a wide range of potential applications; however, at present their potential toxicity and environmental implications are virtually unknown. Ph.D. students in the SuN IGEP will examine the life cycle of nanocellulose from cradle to grave, considering its cellular and organismal toxicity, and its environmental fate and transport. Such analyses are critical inputs for decision making regarding the potential benefits and risks of nanotechnology and its products.

## Description

There is considerable interest in the development of sustainable nanotechnologies; however, at present there are few groups within the world that collectively possess the skills necessary to evaluate what makes a given nanotechnology truly sustainable. SuN at Virginia Tech is one such group. Within SuN are faculty from Civil and Environmental Engineering (*Vikesland, Pruden*) with expertise in the environmental implications of nanomaterials and cellulose biodegradation; faculty from Materials Science and Engineering (*McGinnis*) with expertise in green engineering, sustainable manufacturing, and life cycle analysis; faculty from Wood Science and Forest Products (*Roman, Renneckar*) with expertise in nanocellulose production and application; and faculty from Geosciences (*Hochella*) with expertise in nanogeoscience. The collective capabilities of this group, coupled with the support of ICTAS, CEINT, and EIGER, provides a firm foundation to advance our understanding of sustainable nanotechnology principles using nanocellulose as an idealized model. The research results obtained via this IGEP will provide support for the ultimate development of future interdisciplinary research efforts (e.g., IGERT and GAANN proposals) and a graduate degree program in sustainable nanotechnology. We emphasize that although our existing collaborative research efforts have been well funded (> \$5 million in federal funds) that these funding successes DO NOT overlap with what is proposed herein. **The SuN IGEP is a NEW, CRITICAL addition that badly needs to be developed, and our group's track record indicates that we collectively have the capacity to develop it into a new, major program that will be amongst the first in the highly important area of sustainable nanotechnologies.**

*Research Focus.* **The primary research goal of the SuN IGEP is to facilitate the incorporation of sustainable design concepts in the nanotechnology field.** The sustainability of a particular technology is often an afterthought in the design process; however, because nanotechnology is still in its infancy there is significant potential to proactively direct the field towards sustainable design. Achievement of this ambitious goal will require substantial long-term effort and a range of expertise that incorporates not only scientists and engineers, but also economists and social scientists. In the short-term it is necessary to firmly establish SuN as a player in the science of sustainable nanotechnology and we will collectively focus our efforts on the evaluation of the sustainability of one particular type of nanomaterial: nanocellulose. Because of its natural origin, nanocellulose production is often considered to be sustainable and intrinsically safe for the environment. However, nanocellulose is highly modified with respect to its crystallinity and surface chemistry relative to the natural cellulose found within plants and there is growing concern about its environmental implications. Across the SuN group, we will collectively evaluate the sustainability of nanocellulose production, nanocellulose toxicity, and nanocellulose transport in the environment in the context of a life cycle assessment (Figure 1). Students funded by this effort will be co-advised by faculty from different departments due to the highly interdisciplinary nature of this proposed activity.

*Educational Development.* **The primary educational goal of SuN is to produce doctoral graduates that have the expertise to provide leadership in the interdisciplinary field of sustainable nanotechnology.** To ensure SuN graduates possess the necessary skills to attain this goal, the students will not only conduct directed research in the sustainability of nanocellulose, but will also be required to obtain a graduate certificate in sustainable nanotechnology. To receive this certificate, students will at minimum complete 9 graduate course hours in Environmental Nanotechnology (CEE 5984), Interdisciplinary Research (GRAD 5134), and one other course whose nature is dependent upon a student's research focus area. Courses in

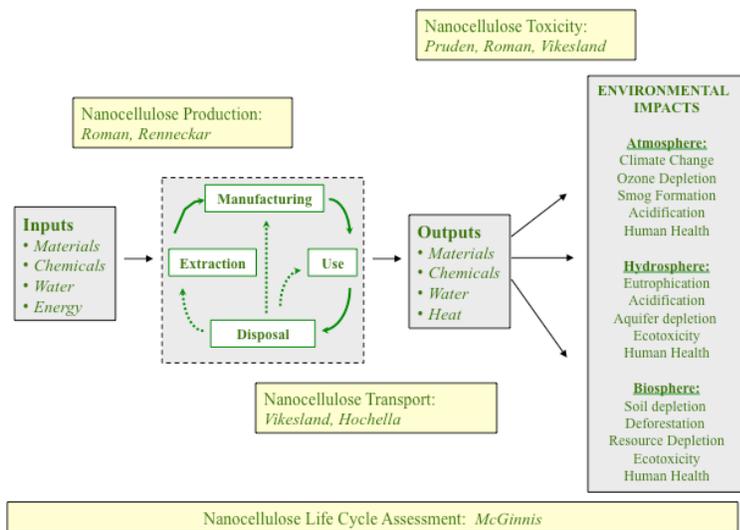


Figure 1 Research thrust areas of the SuN IGEP.

Polysaccharide Chemistry (WOOD 5424), Environmental Sustainability (CEE 4124), Fundamentals of Surface Science and Interface Behavior (GEOS 6604), Environmental Engineering Microbiology (CEE 5194), Constructing Sustainability (NR 5014), and Life Cycle Analysis (ENGR 4134) are currently available. At its outset, the SuN IGEP program relies exclusively on existing courses; however, as the program matures, educational gaps will be identified and new graduate courses will be offered as resources permit. In addition to their research

and classroom activities, SuN students will play an integral role in the recently approved College of Science undergraduate program in Nanoscience and Technology. This new degree program will be initiated in Fall 2011 and SuN affiliated students will be asked to develop and teach individual laboratories and lectures for the undergraduate students enrolled in this exciting new program. This latter activity provides SuN students with exposure to undergraduate teaching and the lectures and laboratories produced by the SuN students will illustrate to the undergraduate population the excitement inherent to interdisciplinary Virginia Tech research.

*Student Recruitment and Retention Plan.* In the first six months following initiation of the SuN IGEP, students will be recruited to the program by the associated faculty and by an informational webpage that describes SuN. Suitable applicants to the graduate programs of the home departments of the SuN faculty will be referred to this new interdisciplinary program and encouraged to apply for IGEP support. A committee of three SuN faculty will review the applicant pool and the most meritorious applicants will be offered admission to the SuN program with IGEP support. Effort will be made to ensure that IGEP support is diverse in terms of home department, gender, and ethnicity. Students not selected for IGEP support, but that have support from other sources will be encouraged to join SuN at their own discretion and with the permission of their advisors. Once the initial cohort of IGEP funded students is in place, additional students will be recruited pending the availability of extramural and IGEP funds.

*SuN Student Support Mechanism.* Funds acquired via the IGEP program will be used to initiate four separate research projects amongst the core faculty. These funds will provide one guaranteed year and the potential for six additional months (pending the availability of funds and student need) of support for each IGEP student. It is the intent of SuN that the research projects initiated by each IGEP funded student should facilitate collection of the preliminary data necessary to develop highly competitive proposals for federal and institutional support.

*Development of the SuN Community.* An important aspect of any planned interdisciplinary research and educational activity is the development of a functioning community of scholars. Every discipline has its own language and social mores that can hinder collaboration between disciplines. As a group established with support from ICTAS, the SuN faculty are familiar with one another. Pruden, Renneckar, and McGinnis recently collaborated on a proposal to NSF,

*Vikesland* and *Roman* are planning experiments to evaluate nanocellulose uptake by the invasive clam *Corbicula fluminea*, and *Hochella* and *Vikesland* are core members of the ICTAS funded Environmental Nanotechnology Laboratory and the EPA/NSF funded CEINT. With IGEP support these existing interactions will be augmented by a planned seminar series wherein SuN faculty and students present their research to one another and learn to speak one another's disciplinary languages. This seminar series will regularly include speakers from the social-science focused *Engaging Sustainability* group at Virginia Tech that is preparing a parallel IGEP proposal. The two groups are highly complementary to one another and intend to work together.

*Plans to Secure Funds for Assistantships and Attain a Steady-State Program Size.* IGEP funds will be used as seed funding to support the development of highly competitive proposals. **A major focus of the SuN IGEP will be the development of large interdisciplinary proposals for the NSF IGERT and the DOE GAANN programs.** Co-PI *Hochella* previously was the PI on successful IGERT and GAANN proposals and will provide expert advise as to how to properly prepare proposals for these highly competitive programs. In addition to these large grant opportunities, the SuN PIs will collaborate on smaller proposals to fund specific aspects of the SuN research program. Recently co-PIs *Pruden*, *Rennecker*, and *McGinnis* submitted a proposal to NSF that would support two graduate students to examine nanocellulose interactions with microorganisms in wastewater treatment. At steady-state, it is expected that the SuN program will have 10-20 graduate students supported with 8-10 faculty advisors involved.

*Program Assessment and Outcome Plan.* Given their complex nature it has historically been a challenge to quantitatively assess the success of interdisciplinary graduate research and education programs. Recognizing these challenges, we have developed a multi-tiered approach to evaluate the SuN IGEP program. This program will continually be refined and updated.

1. Integration of Sustainability. **A critical aspect of the SuN IGEP is that graduates should possess the capacity to synthesize and integrate sustainability concepts into traditional science and engineering focused research efforts.** To assure that all SuN IGEP graduates achieve such a capacity, we will require that each funded student include at least one (and preferably more than one) chapter in their dissertation that examines the sustainability of nanocellulose in the context of the results that they and their SuN colleagues have obtained.
2. Quantification of Success. Readily quantifiable outcomes of the SuN IGEP will be tabulated and reported. These outcomes include: the number of graduate theses funded by the program, the total number of peer-reviewed publications, and the number of funded research proposals derived directly from SuN IGEP support. Proposals and publications from multiple members of SuN will be a particular focus since these will reflect true interdisciplinary outputs.
3. SuN IGEP Advisory Board. An external advisory board consisting of five individuals that are familiar with sustainability, nanocellulose production and use, and environmental nanotechnology will be developed. This advisory board will be given the charge to provide outside guidance regarding the SuN IGEP educational and research efforts and their significance to the developing field of sustainable nanotechnologies. Dr. Pedro Alvarez (Rice University), Dr. Krista Rule Wigginton (University of Maryland) and Dr. William T. Winter (State University of New York College of Environmental Science and Forestry; SUNY-ESF) have agreed to serve on this planned committee. Dr. Alvarez is Chair of Civil Engineering at Rice University and is an expert in environmental nanotechnology. Dr. Wigginton is a 2008 graduate of Virginia Tech and will provide advice regarding potential student perceptions of SuN. Dr. Winter is the Director of the Cellulose Research Center at SUNY ESF. Two additional scholars will be added to the committee following the funding of the SuN IGEP.



December 6, 2010

Dr Karen P. DePauw  
Vice President and Dean of the Graduate School  
235 Graduate Life Center at Donaldson Brown  
Virginia Tech

Dear Dr DePauw,

The College of Science and the Department of Geosciences are delighted to enthusiastically support the proposed Interdisciplinary Graduate Education Program in Sustainable Nanotechnology (SuN). We wish to point out that this proposal has grown out of an already existing, long-term, highly productive faculty collaboration within the Environmental Nanotechnology Laboratory, and the Sustainable Nanotechnology Institute within ICTAS. This extensive lab and institute includes all of the faculty in the IGEP SuN proposal. They have a rapidly growing funding base and a growing cohort of exceptional graduate students. Therefore, we feel that you can be assured that the IGEP SuN program, if funded, will be assured of success, and in fact very quickly gain a national and international reputation. We hope that you agree.

This IGEP program within the College of Science will be coordinated by UDP Mike Hochella. Mike is deeply committed to this project under IGEP PI Peter Vikesland and the rest of the SuN team in the Colleges of Engineering and Natural Resources. Mike is directing the ICTAS nano-sustainability efforts and is Thrust Leader of ICTAS Nanotechnology.

Thank you very much for considering this IGEP program for funding.

Yours sincerely,

Nancy Ross  
Associate Dean, College of Science

Kenneth Eriksson  
Professor and Department Chair, Geosciences



**TO:** Karen P. DePauw, Vice President and Dean of the Graduate School

**FROM:** Richard C. Benson, Dean of Engineering and Torgersen Chair

and

W. Samuel Easterling, Montague-Betts Professor and Department Head,  
Charles E. Via Jr. Department of Civil and Environmental Engineering

and

David E. Clark, Professor and Department Head, Materials Science and Engineering

**DATE:** December 6, 2010

**SUBJECT:** Interdisciplinary Graduate Education Program in Sustainable Nanotechnology (SuN)

Both the College of Engineering and the Department of Civil and Environmental Engineering fully support the proposed Interdisciplinary Graduate Education Program in Sustainable Nanotechnology. The program has been developed by a group of faculty, comprising faculty from this college and department, as well as from three other departments and two other colleges. No additional department or college resources are required to offer this graduate education program.

Sincerely,

Richard C. Benson  
Dean of Engineering and Torgersen Chair

W. Samuel Easterling  
Professor and Department Head  
Civil and Environmental Engineering

David E. Clark  
Professor and Department Head  
Materials Science and Engineering

*Invent the Future*



VirginiaTech

Institute for Critical Technology and  
Applied Science

**ICTAS**

Stanger Street, Suite 410 (MC 0193)  
Blacksburg, Virginia 24061  
540/231-2597 Fax: 540/231-0970  
[www.ictas.vt.edu](http://www.ictas.vt.edu)

December 3, 2010

Karen P. DePauw, Vice President and Dean of the Graduate School  
235 Graduate Life Center at Donaldson Brown  
Virginia Tech

Dear Dean DePauw,

It is a pleasure for me to inform you of my enthusiastic support for the proposed Interdisciplinary Graduate Education Program (IGEP) in Sustainable Nanotechnology led by PI Peter Vikesland. As you may be aware, Peter is a core faculty member in our Environmental Nanoscience and Technology Laboratory within ICTAS, and also one of the founding members of the ICTAS-lead and funded Sustainable Nanotechnology initiative. ICTAS is obviously deeply committed to both the “greening” of nanotechnology, and its long-term, reduced environmental impact. Further, I have been committed to expanding the role of ICTAS in graduate education while we strongly promote programs such as our prestigious ICTAS Doctoral Scholar program. ICTAS and your new IGEP program should be natural partners, as both have been founded based on interdisciplinarity. Finally, ICTAS Nanotechnology Thrust Leader and UDP Mike Hochella is an integral part of Peter’s team, solidifying this important connection.

If any questions arise, please feel free to contact me.

Best regards,

Roop L. Mahajan  
Tucker Chair Professor of Engineering  
Director, Institute for Critical Technology and Applied Science

*Invent the Future*



**MEMORANDUM**

**DATE:** December 3, 2010  
**TO:** Karen P. DePauw, Vice President and Dean of the Graduate School  
**FROM:** Paul M. Winistorfer, Dean and Professor, College of Natural Resources  
and Environment

and

Audrey Zink-Sharp, Professor and Interim Department Head, Department  
of Wood Science and Forest Products

**SUBJECT:** Interdisciplinary Graduate Education Program in Sustainable  
Nanotechnology (SuN)

Dear Dean DePauw:

Both the College of Natural Resources and Environment and the Department of Wood Science and Forest Products fully support the proposed Interdisciplinary Graduate Education Program in Sustainable Nanotechnology. The program has been developed by a group of faculty, comprising faculty from this college and department, as well as from three other departments and two other colleges. No additional department resources are required to offer this graduate education program.

Sincerely,

Paul M. Winistorfer  
Dean and Professor

Audrey Zink-Sharp  
Professor and Interim Department Head

*Invent the Future*

## Appendix – Desired Criteria

*Plan for Securing Extramural Funding Over Time.* We will seek institutional and federal funding to provide long-term support of the SuN IGEP program. Both large-scale and small-scale grant opportunities will be pursued. At the large-scale, both the NSF IGERT (next submission window expected spring 2011) and the Department of Education GAANN (next submission window expected late 2011) programs regularly provide funds for interdisciplinary efforts such as SuN. **IGEP funding will facilitate collection of the preliminary scientific results necessary for successful proposals of large magnitude and will provide logistic support in the form of the planned IGEP staff person.** At the smaller-scale, NSF regularly has grant opportunities in 1) Environmental Health and Safety of Nanomaterials, 2) Environmental Sustainability, 3) Environmental Chemical Sciences, and 4) Polymers that have historically funded studies in the general areas of nanomaterials, sustainability, and nanocellulose. Other federal agencies such as EPA, USDA, and the DOE also have programs that will be considered as funding avenues for SuN.

*Plan to Reach Across the Disciplinary Landscape to Incorporate Disciplines.* The SuN IGEP effort has been purposely designed around a small group of individuals that have existing on-going collaborative interactions. This core group has sufficient breadth to conduct interdisciplinary studies on the environmental sustainability of nanocellulose production, use, and disposal; however, the social and economic aspects of nanocellulose usage and disposal are outside of our realm of expertise. Acknowledging this deficiency, the SuN faculty have begun discussions with the Engaging Sustainability group led by *Dr. Bruce Hull* (Forest Resources and Environmental Conservation). Engaging Sustainability is interested in the political, economic, and social aspects of sustainability and is developing a parallel IGEP proposal to fund efforts in these areas. Based upon the discussions between the groups it is clear that there are significant overlaps between them and that further dialogue will enhance our collective understanding of the complexities of sustainability. To ensure the continuation of this dialogue, we intend to co-develop our proposed seminar series such that faculty and students from SuN and from Engaging Sustainability readily meet with one another and learn from each other. Each group will promote classes offered by the other group as options for their respective Certificate Programs.

*Plan to Develop a New Interdisciplinary Degree Program.* One desired outcome of the SuN IGEP and its associated graduate certificate is the future development of a degree program in sustainable nanotechnology. One challenge that often hinders interdisciplinary research and education efforts is the requirement that the students engaged in the effort have ‘home departments’ with their own degree requirements. Given the number of credit hours associated with attaining a degree from the ‘home department’, it is difficult for an interdisciplinary program to require the breadth of courses necessary to produce true ‘interdisciplinary scholars’. To ameliorate this situation, we intend to build upon the groundwork laid by the SuN IGEP to develop a new degree program in sustainable nanotechnology. This interdisciplinary degree will be broad in scope and will encompass not only the scientific aspects of sustainable nanotechnology, but also the social and human aspects. Students completing the 90 credit hour Ph.D. program will take a mix of courses (at minimum 32 credit hours) in the science and engineering of sustainable nanotechnologies as well as in the social and human aspects of sustainability. **Graduates with this degree will have the capacity to consider not only the scientific and engineering aspects of sustainable nanotechnology, but also the social and economic issues that affect their development and use.** Such a degree program would be amongst the first of its kind in the world and would place Virginia Tech at the front of the field.