Title of area: Synergy at the Nanoscale: Biomedicine, Energy and Materials

Participating Disciplines/Academic Units/Departments:

Department of Chemistry (College of Liberal Arts and Sciences)
Department of Physics and Optical Science (College of Liberal Arts and Sciences)
Nanoscale Science Ph.D. Program (College of Liberal Arts and Sciences)
Department of Biological Sciences (College of Liberal Arts and Sciences)
Department of Civil and Environmental Engineering (College of Engineering)
Department of Electrical and Computer Engineering (College of Engineering)

Leadership:

Juan Vivero-Escoto, Ph.D.; Department of Chemistry
Michael Walter, Ph.D.; Department of Chemistry
Christopher Bejger, Ph.D.; Department of Chemistry

Target category: Areas of Existing and Emerging Excellence

Keywords: Nanotechnology, Biomedicine, Energy, Nanomaterials, Environment

Executive Summary

Synopsis of the thematic area. The field of nanoscale science addresses the understanding and harnessing of novel phenomena that occur at the nanoscale – about 100,000 times smaller than the width of a human hair. Nanoscale science is driving a revolution in the fabrication of new materials, devices, and structures needed to solve worldwide problems involving energy, the environment, and human health, among others. The development of COVID-19 vaccines based on nanoparticle delivery systems is a compelling example of how nanoscale science is being used to address critical global needs. For over a decade, the Nanoscale Science Ph.D. program has enabled UNC Charlotte to attract innovative, collaborative researchers in nanoscale science to our campus. These and other campus researchers have formed productive, synergistic partnerships among chemists, physicists, biologists, and engineers that have garnered federal funding and produced exciting results and publications in the fields of biomedicine, renewable energy, and materials. *Synergy at the Nanoscale: Biomedicine, Energy and Materials* describes an existing area of excellence on our campus that is poised to claim a greater presence on the national and world stages.

Research at UNC Charlotte in the above-mentioned fields involves the development of nanoscale-based solutions for major health, energy and environmental issues impacting our society. For example, we are developing nanosensors for clinical diagnosis of COVID-19. Our team is applying innovative techniques, using nanoparticles, to eliminate antibiotic resistant pathogens. We are using nanotechnology to improve current methods for the effective diagnosis and treatment of cancer. The members of our team are also developing novel organic molecular dyes and polymers for use in solar energy conversion. We are generating unique inorganic nanomaterials to fabricate efficient energy storage devices. Our group has also developed green, sustainable methods to create materials that are effective in removing contaminants from water.

Summary of evidence supporting the nomination. *Synergy at the Nanoscale* is a research area of excellence at UNC Charlotte that involves a team of outstanding established and emerging researchers with national and/or international reputations. During the past five years, faculty in this area have garnered over $16.8M in total funding (NORM 02/20/2016-02/20/2021), obtained 28 patents, and published over 246 papers (Google scholar and PubMed). Our campus has developed this area strategically during the past thirteen years through the interdisciplinary Nanoscale Science Ph.D. program, with guidance from University leadership. The three main topics included in the nomination - *Biomedicine, Energy and Materials* - address some of the most critical societal issues of our time. Faculty research in this area of excellence is making major impacts in the diagnosis and treatment of various diseases, as well as the development of renewable energy technologies, new electronic devices, and sustainable methods for water purification. These research fields align perfectly with the national priorities included in the President's 2021 budget, which requests over $1.7 billion for the National Nanotechnology Initiative (NNI). Overall, we have an outstanding team of agile, collaborative faculty colleagues from multiple disciplines who support this nomination, who are dedicated to solving critical problems affecting our society, and who have an established track record of working together and securing major federal funding. *Synergy at the Nanoscale* is clearly an area of existing and emerging excellence that will provide a solid foundation for the future strategic growth of our University.

Evidence of Strength and Excellence

Biomedicine: Our leadership in this area is highlighted by the productivity of two members of the team: Dr. Kirill Afonin (Chemistry) and Dr. Jerry Troutman (Chemistry). Dr. Afonin is one of the global leaders in the burgeoning field of RNA nanotechnology. He is a founding council member and Vice President of the International Society of RNA Nanotechnology and Nanomedicine. He has received over $3.5M in federal funding, including a highly prestigious MIRA R35 ($1.7M) from the National Institutes of Health (NIH). In the last five years he has published 43 papers, 7 book chapters, edited two books, filed six patents and licensed two technologies to Sixfold Bioscience, Inc. His research has been widely publicized in media such as *EurekAlert! AAAS* and *Nanowerk*. Dr. Afonin works closely with Dr. Ian Marriot (Biological Sciences) in evaluating immunological properties of RNA nanoparticles. Dr. Troutman is another accomplished investigator whose work has been supported continuously by the NIH for the past nine years ($1.7M total). His research is in the field of glycoscience, with a focus on the biosynthesis of polysaccharides found on the surfaces of bacteria. These polysaccharides are important to the bioactivity of pathogens and symbiotic bacteria in the gut, and therefore offer great potential in the treatment and prevention of disease, including the elimination of antibiotic-resistant pathogens. Other scholars in the biomedicine area (Drs. Shunji Egusa, Swarnapali De Silva Indrasekara, Ian Marriot, Pinku Mukherjee, Mariya Munir, Juan Vivero-Escoto and Michael Walter) have also earned national and/or international reputations for their work, including major federal funding (NIH, National Science Foundation (NSF), Department of Defense (DOD)) and publications in top-tier peer reviewed journals, including *Cancer Research*, *ACS NANO* and *Nature Methods*. Synergistic initiatives among these researchers are tackling critical issues in health using interdisciplinary approaches. Drs. Indrasekara and Munir are together developing an optical nanosensor for COVID-19 detection in wastewater. This work, which is part of a project to develop analytical tools for clinical diagnosis and community-wide surveillance of COVID-19, promises to alleviate some of the major problems found in early diagnosis of COVID-19. Dr. Egusa is developing novel nanotechnologies for the precise delivery of drugs to treat acute myeloid leukemia. Dr. Vivero-Escoto is working with Drs. Munir, Troutman and Afonin to develop light-based nanotechnology-enabled approaches to eliminate antibiotic resistant bacteria/genes and cancer. In collaboration with Dr. Mukherjee, Dr. Vivero-Escoto has also secured federal funding to investigate the use of silica-based nanomaterials for the effective treatment of cancer through chemotherapy. Dr. Walter has been developing novel biomedical sensors and is collaborating with Drs. Indersakara, Troutman, and Afonin on applications of highly fluorescent dyes for biomedical sensing and imaging technologies.

Energy: Faculty in this area (Drs. Thomas Schmedake, Michael Walter and Yong Zhang) have received over $850K in collaborative grants from federal agencies (NSF, DOD - Army Research Office) and published in high-impact journals such as the *Journal of the American Chemical Society*, *Journal of Materials Chemistry A* and *Chemical Communications*. Dr. Walter is developing novel organic molecular dyes and polymers for use in solar energy conversion and, in collaboration with Dr. Schmedake, is also developing high efficiency organic light-emitting diodes (OLEDs). Dr. Schmedake has expertise in the development of inorganic-organic hybrid nanostructured materials for energy, environmental, and sensor applications and is a frequent collaborator with Drs. Walter, Bejger, and Zhang. Dr. Bejger is a rising star in this field with recent funding (>$500K) from NSF and from the Department of Energy (DOE), Office of

Electricity. He has a background in the design and synthesis of redox-active molecules and molecular clusters with applications in grid-scale energy storage. His group is developing new, environmentally benign compounds for use in aqueous redox-flow batteries (RFBs). Dr. Bejger also collaborates with Dr. Walter on new materials for energy storage.

Materials: Scientists in this field (Drs. Christopher Bejger, Jordan Poler, Rosario Porras-Aguilar, Thomas Schmedake, and Michael Walter) are well-funded with recent federal funding exceeding $2M, including two NSF CAREER awards, NIH, and EPA grants. Dr. Bejger's CAREER grant focuses on crystalline polymers comprising transition metal chalcogenide (TMC) molecular clusters, which are important materials for catalysis, energy storage, and electronic devices. The Bejger laboratory uses preformed, nanoscale fragments of TMCs to assemble new polymers with high surface areas and predictable structures. These materials are relevant to the study of high surface area nanoelectronics and improved charge storage devices. Dr. Porras-Aguilar's research explores the development of active imaging systems using optical nanomaterials. With her CAREER grant, she is studying the unique effect of these materials on light propagation to implement novel active imaging systems and optical metrology. Dr. Poler is utilizing nanoscale and colloid science to understand the synthesis, characterization and performance of new materials for water treatment to improve our ecosystem and human health. He has developed green, sustainable methods to create novel materials that interact strongly with waterborne contaminants. His work has been patented with the goal of commercialization in the near future. Dr. Schmedake is co-founder of Light and Charge Solutions, a start-up that has raised over $500K in non-diluting funds, and which is partnering with researchers from industry and Argonne National Laboratory in developing inorganic-organic hybrid materials to improve the performance and slash the price of large-scale flexible electronic devices, including OLEDs.

Additional Resources: Resources needed to build the success of this team include: faculty hires (some senior hires) in areas such as polymer chemistry, spectroscopy, drug delivery, and electronic devices; research space, start-up funding, and graduate students for new hires; state-of-the-art instrumentation (e.g. electronic and optical microscopes); and increased graduate assistantship support (more lines and more competitive stipends).

Education: Our team has had a major impact on the education and training of doctoral students through the Nanoscale Science Ph.D. program. Launched in 2007, our program is the second doctoral program in Nanoscience in the country, and the first of its kind in North Carolina. With the leadership of Dr. Donovan-Merkert, the program has graduated 23 students in the past five years. Our alumni are employed at academic institutions, in industry, and at national laboratories. Through the NSF AGEP-NC program, we are developing improved strategies to educate, train and mentor our doctoral students, particularly those from underrepresented minority groups.

Broader impacts: Our team has done much to build the STEM pipeline. The NSF NanoSURE summer research program has hosted over 120 students and received renewal funding three times. Members of our team have helped plan and have participated in the annual UNC Charlotte Science and Technology Expo, which attracts to our campus thousands of students of all ages from the Charlotte region to experience hands-on science activities. ACS Project SEED provides paid laboratory research opportunities to high school students from economically disadvantaged backgrounds. Faculty have also mentored CMS teachers through the Charlotte Teachers Institute.

Alignment with Regional and National Priorities

At the beginning of the 21st century the United States government recognized the fields of nanoscience and nanotechnology as critical areas to be explored and developed to maintain worldwide leadership in science and technology in the future. Therefore, in 2001 the National Nanotechnology initiative (NNI; https://www.nano.gov/) was launched. Since then, nanotechnology is steadily moving from the laboratory to the marketplace with impact on a variety of sectors such as clothing, electronics, clean energy technologies, and automobiles. As a more recent example of the relevance of nanotechnology to tackle key issues in our society, two of the vaccines developed to treat COVID-19 (Pfizer-BioNTech and Moderna) use lipid-based nanoparticles to efficiently deliver the mRNA technology that inoculated the COVID-19 virus. The NNI consists of federal departments, commissions and eleven independent agencies (e.g. NSF, NIH, DOD, DOE, USDA,…) that work together with the vision of *"a future in which the ability to understand and control matter at the nanoscale leads to a revolution in technology and industry that benefits society."* As clear evidence of how the NNI is a national priority, the President's 2021 budget requests over $1.7 billion for this initiative (https://www.nano.gov/sites/default/files/NNI-FY21-Budget-Supplement.pdf). Five Federal organizations with the largest investments (96% of the total) are NIH, NSF, DOE, DOD, and DOC/NIST. These agencies are relevant to this nomination because members of *Synergy at the Nanoscale* team have already obtained funding from them. Nanotechnology Signature Initiatives (NSI) focus on topics of national importance; in particular the members of our team are/will be targeting the following initiatives: Innovative Research in Cancer Nanotechnology (NIH), Glycoscience (NIH), Sensors for Nanotechnology (NIH, DOD, NSF, USDA), Water sustainability through Nanotechnology (NSF, NASA, DOE), Nanoscale Interactions (NSF), and other mechanisms for foundational research at NSF, DOE, and DOD (https://www.nsf.gov/crssprgm/nano/; https://www.nano.gov/DOE; https://www.nano.gov/DOD).

At the state level, the Roadmap for Nanotechnology in North Carolina's 21st Century Economy (https://files.nc.gov/nccommerce/documents/NC-Science--TechnologyGrants-Management-Documents/SciTech/Resources/NCNanotechTaskForceReportFinal.pdf) has paved the way for the establishment of a variety of initiatives such as the Research Triangle Nanotechnology Network (RTNN), the Carolina Institute for Nanomedicine (CINM), the Center for the Environmental Implications of NanoTechnology (CEINT), and others.

This nomination supports the mission of UNC Charlotte *"to offer internationally competitive programs of research and creative activity, exemplary undergraduate, graduate, and professional programs, and a focused set of community engagement initiatives"* through the excellent research team that has demonstrated global recognition in the area of nanoscale science, in particular in the three research topics mentioned above, and by supporting our Nanoscale Science program that educates and trains graduate students. Moreover, through the specific research members of this team are conducting, this nomination also supports the commitment of our University *"to addressing the cultural, economic, educational, environmental, health, and social needs of the greater Charlotte region"* in particular with environmental, economic and health issues.

Supporting Documents

Dr. Kirill Afonin (Associate Professor, Chemistry)	Nucleic acid nanoparticles for biomedical applications. Research field: Biomedicine
Dr. Christopher Bejger (Assistant Professor, Chemistry)	Inorganic-organic hybrid materials and redox flow batteries. Research field: Energy and Materials
Dr. Bernadette Donovan-Merkert (Professor, Chemistry)	Electrochemistry and electron-transfer reactions. Director of Nanoscale Science program
Dr. Shunji Egusa (Assistant Professor, Physics and Optical Science)	New mechanisms and methodologies for the synthesis and applications of nanomaterials in cancer (leukemia) treatment. Research field: Biomedicine and Materials
Dr. Swarnapali De Silva Indrasekara (Assistant Professor, Chemistry)	Plasmonic nanomaterials and development of bioanalytical tools for disease diagnosis. Research field: Biomedicine
Dr. Ian Marriot (Professor, Biological Sciences)	Activation and propagation of peripheral immune responses and inflammation within the central nervous system (CNS). Research field: Biomedicine
Dr. Pinku Mukherjee (Belk Distinguished Professor, Biological Sciences)	MUC1 biology and its oncogenic signaling in adenocarcinomas, and in developing combination immune-therapies. Research field: Biomedicine
Dr. Mariya Munir (Assistant Professor, Civil and Environmental Engineering)	Microbial water quality and public health issues. Detection, removal and inactivation of emerging biological and chemical contaminants in water and wastewater systems. Research field: Biomedicine
Dr. Jordan Poler (Professor, Chemistry)	Synthesis and characterization of nanomaterials using green and environmentally-sustainable reagents and processes. Research field: Materials
Dr. Rosario Porras-Aguilar (Assistant Professor, Physics and Optical Science)	Development of active imaging systems using optical nanomaterials. Research field: Materials
Dr. Thomas Schmedake (Professor, Chemistry)	Inorganic-organic hybrids for energy and sensor applications. Director of the NanoSURE REU program. Research fields: Energy and Materials

Dr. Jerry Troutman (Associate Professor, Chemistry)	Biosynthesis of complex polysaccharides by symbiotic intestinal microbes that are important for normal immunological functions of mammals. Research field: Biomedicine
Dr. Juan Vivero-Escoto (Associate Professor, Chemistry)	Fabrication, characterization and evaluation of nanomaterials for biomedical applications. Research field: Biomedicine
Dr. Michael Walter (Associate Professor, Chemistry)	Synthesis of novel organic molecular dyes and polymers for use in solar energy conversion, biomedical sensors, and electronics. Research fields: Biomedicine, Energy and Materials
Dr. Yong Zhang (Bissell Distinguished Professor, Electrical Engineering and Computer Science)	Organic-inorganic hybrid nanomaterials for electronic, optical properties of semiconductors and energy. Research fields: Energy and Materials