Reports from AC/GPA Subgroups

Discovery Subgroup Report

The Committee concluded that there has been significant achievement for the Discovery outcome goal.

Introduction

The Discovery Subgroup of the Advisory Committee for GPRA Performance Assessment was charged with the task of assessing whether the NSF has demonstrated significant achievement for the Discovery goal outlined in the NSF Strategic Plan (2006-2011) to "foster research that will advance the frontiers of knowledge, emphasizing areas of greatest opportunity and potential benefit and establishing the nation as a global leader in fundamental and transformative science and engineering."

Process Followed and Criteria Used

Members of the Discovery Subgroup reviewed 600 out of a total of 1362 highlights submitted by the NSF staff. The specific highlights reviewed were selected using a random list generator and divided evenly among the 10 Discovery Subgroup members. Each subgroup member was assigned 60 highlights to review but was provided with access to all of the 1362 highlights. Subgroup members were asked to select at least five highlights that exemplified the accomplishments of the Foundation in the area of Discovery and discuss how they address the following criteria:

Research Grants

- Strengthen fundamental research across the full spectrum of science and engineering through support for NSF's core disciplinary programs.
- Foster discoveries that have the potential to transform disciplines or fields of science, engineering, or education research.

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- Investigate the human and social dimensions of new technology and knowledge.
- Advance the fundamental knowledge base on learning.
- Foster research that improves our ability to live sustainably on Earth.
- Support outstanding junior faculty who exemplify the role of teacher-scholars through integration of education and research (CAREER Program).
- Promote innovation and partnerships with industries to stimulate the development of new technologies and processes to further U.S. economic competitiveness and benefit the nation.
- Support international research collaboration among U.S. investigators and partners in other countries and regions.

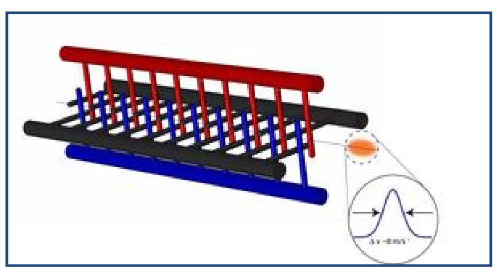
Centers

- Enable academic institutions and their partners to integrate discovery, learning, and innovation on scales that are large enough to transform important science and engineering fields and interdisciplinary areas, and stimulate increased innovation.
- Provide unique opportunities for students to broaden their research horizons.
- Provide opportunities for industrial partners to be actively involved in center research and interact with top academic researchers.

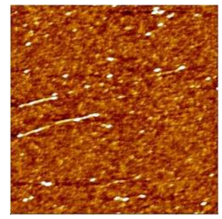
Analysis Overview

Based on our analysis of highlights, the subgroup concluded that the NSF has demonstrated significant achievement in meeting the goals of the strategic plan in the area of Discovery. There was clear evidence that NSF has served to strengthen fundamental research across the full spectrum of science and engineering through support of NSF's core disciplinary programs. The research supported spanned multiple scales – from new studies carried out by young investigators funded by the Faculty Early Career Development (CAREER) Program to extensive collaborations of many investigators at centers, from examination of single molecules to the study of climate interactions at the planetary scale. The highlights capture just a few examples of the diverse and innovative science supported by NSF.

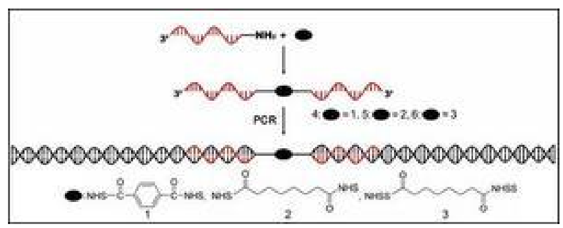
A stellar example of research at the smallest dimension was an award to a young investigator. Heather Lewandowski of the University of Colorado has developed a new method for slowing the speed of molecules in a beam: a critical step required to understand the control of chemical reactions on a microscopic level ***(Precision Control of Molecules;*** *Highlight 18477, Award 0748742)*. It is extremely difficult to observe the dynamics of chemical reactions, such as breaking one chemical bond



and forming another, at a microscopic level because molecules are in constant motion. The ideal way to observe such reactions would be to have the molecule stand still and allow another molecule to approach it. Although this has not been achieved, the new method by Lewandowski uses a Stark decelerator to produce a beam of molecules that are moving in one direction and at the same velocity by rejecting molecules that deviate from the central velocity. This research has enormous potential to impact the future of chemistry and atmospheric science. The CAREER award integrates education with research through discovery-based laboratory courses to mimic a research environment, introduce middle school age girls to experimental science, and develop a new graduate level course that emphasizes experimental measurement.

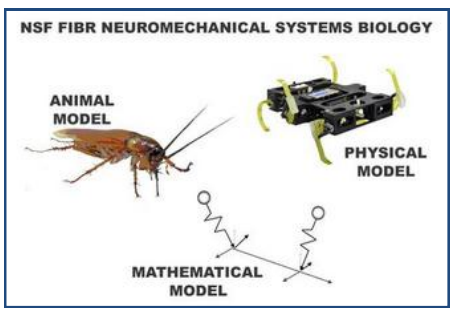


Another example of progress in the science of small things is a Nanoscale Interdisciplinary Research Teams (NIRT) award to Zhenan Bao at Stanford University ***(Towards Single Molecule Electronics**; Highlight 17969, Award 0507296**)***. Understanding and potentially controlling individual molecules is fundamental to developing molecular scale devices for computing, telecommunications, medicine, and other applications. The goal of this research is to construct a metal-single organic molecule-metal structure, which could then become the foundation for the design of organic electronic devices, including organic transistors, solar cells, and light emitting devices. This research has made significant advancement toward this goal by using DNA as a template to connect molecules having specialized chemical connectors at each end. By providing a metal–molecule interface, this research is enabling study of fundamental details of single molecule electronics and is providing the basis for fabricating nanostructures with specified optical or electrical characteristics.

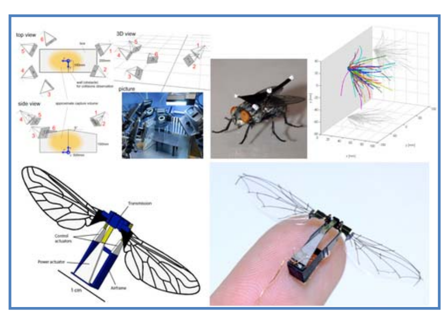


We also found numerous examples of research with the potential to transform disciplines or fields of science. Some of the most striking examples of transformative research came in the form of the potential for one field of science to influence another. For example, there are many funded projects addressing an engineering challenge that use biological examples to solve a mechanical problem. There were also examples of research in cognitive science that could be transformative to the field of artificial intelligence. Although center funding or the funding of interdisciplinary programs was responsible for some of these breakthroughs, some of the most striking examples involved single investigator research through core programs or young investigators funded by CAREER awards. Thus, NSF has succeeded in encouraging a new generation of scientists and engineers to look beyond disciplinary boundaries for their inspiration to solve core disciplinary problems.

Several examples of interdisciplinary research related to robotics illustrate the potential that the funding of fundamental research has to transform fields of science and engineering. In these examples biological models have been used to design machines. In some cases the primary objective was to understand more about a biological system by building mechanical or mathematical models. In others the objective was to use a living organism to provide clues to ways to solve mechanical problems. Robert Full from the University of California Berkeley led a team of researchers funded by the Frontiers in Integrative Biological Research Program to investigate systems-level models of how animals move reaching from neurons to muscles to the skeleton, to the whole body. ***(The Science of Motion;*** *Highlight 16936, Award* ***0425878)***. The approach used by Full's team was to integrate direct experimentation on an animal model (the cockroach) with a physical model (a hexipedal robot) and mathematical models. Cockroaches provide a tractable model because their nerves and muscles are easily monitored and they produce force patterns indistinguishable from other legged animals such as humans, horses, lizards, and crabs. Results from the experiments demonstrate that cockroaches do not change the neural signals to their leg muscles unless they encounter obstacles or crevices more than three times the height of their hip. Mechanical control of normal leg movement does not require active adjustments from a brain. Although this research was aimed at providing a better understanding of neural control of movement, the results have the potential to inspire novel controllers in engineering or lead to the development of artificial muscles.



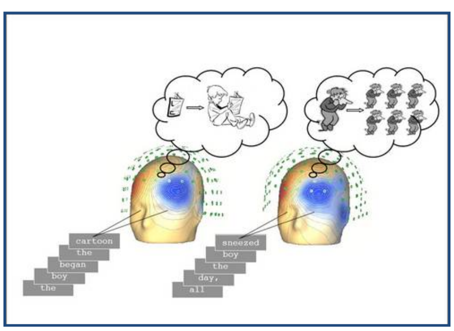
Robert Wood from Harvard University used data obtained from observing the movement of a fly wearing a motion capture suit to help design control methods for robotic flight. ***(The Harvard Microbiotic Fly: Design of a Bio-Inspired Insect-like Robot;*** *Highlight 17733, Award* ***0746638)*** High speed video and analysis of three dimensional positioning and orientation data tracked the response of the fly to obstacles and provided the fly's response to landings and collision events. The data were used to design electromechanical control actuators for robot flight that function like those found on a fly's thorax. The research provides the foundation for faster and more efficient control systems for robots. Robotic insects could be used to perform tasks that are too dangerous for humans such as searching for survivors of natural disasters or exploring hazardous environments. Flying robots also have the



potential to perform high fidelity environmental monitoring, or pollinate crops. This research resulted from a CAREER award to a young investigator.

There are other examples of biological models inspiring the field of engineering. Material properties of organisms often hold clues for manufacturing new types of materials. Researchers at the Materials Research Science and Engineering Center (MRSEC) at the University of California, Santa Barbara, have discovered the mechanical properties of jumbo squid beaks ***(Squid Beaks Use Novel Materials Trick to Prevent Detachment;*** *Highlight 17223, Award 0520415****)***. The squid beak is one of the hardest organic materials known; its extreme rigidity at the tip allows the squid to cut through its prey like butter. However, squid are gelatinous plankton, composed mostly of soft tissue; the mystery has been why the beak does not tear off from stress induced at the junction of materials with greatly differing mechanical properties. By creating a stiffness gradient of two orders of magnitude between beak tip and base, the beak becomes softer and more flexible as it approaches the soft muscle tissue. The research findings have implications for engineering of mechanically mismatched materials.

In another example, the field of cognitive linguistics has the potential to inspire new research in computer science. Research on the ***Neural Bases of Semantic Interpretation (****Highlight 17446, Award 0545186****)*** from Liina Pylkkanen at NYU provides a new understanding of how the human brain solves complex problems of language interpretation and could have important implications for the study of artificial intelligence. Pylkkanen used magnetoencephalography (MEG) to noninvasively measure changes in magnetic fields caused by electrical activity in the brain while subjects were reading semantically complex sentences. By comparing MEG results from complex sentences to parallel expressions involving no hidden meaning, the researchers identified the area of the brain responsible for the interpretation of ambiguous phrases or sentences. This research establishes a starting point for studying the brain bases of semantic composition in healthy individuals as well as in a wide variety of neurological and developmental disorders involving semantic impairment, such as aphasias, schizophrenia, autism, Alzheimer's disease, and semantic dementia. Although the fundamental goal of this research was to address important questions in neural linguistics, it has potential benefits to the study of artificial intelligence and machine learning. Understanding how the human brain solves complex problems of language interpretation could result in more efficient algorithms



for automated processing of language, which in turn has useful applications for web search engines or military intelligence.

Because of the enormous investment that the National Science Foundation has made in encouraging interdisciplinary research, we suggest that the AC/GPA continue to follow the long term effects on the culture of how science is conducted. Are young investigators who have been trained in a world with fewer disciplinary boundaries more likely to reach beyond their borders for inspiration? Has the blurring of disciplinary boundaries resulted in the convergence of disciplines?

Last year the Discovery subgroup of this committee asked that we specifically address research that investigates the human and social dimensions of new knowledge and technology. Our review identified numerous examples that address this question. A CAREER award to Charles Schweik from the University of Massachusetts Amherst ***(Understanding Factors Leading to Success or Abandonment in Open Source Software 'Commons';*** *Highlight 18338, Award 0447623****)*** resulted in a greater understanding of "technology mediated" forms of collaboration through analyzing the success or abandonment of open source software projects. Open source software projects are distributed over the internet to others without any monetary cost. Open source licensing has resulted in teams of collaborators who organize themselves in "commons" to work on software. The research has resulted in a book entitled The Collaborative Principles of Open Source Software Commons, currently under review with MIT Press. Understanding what makes open source software projects succeed could help improve the efficiency of collaborative problem solving.

Kathryn McKinley at the University of Texas, Austin ***(Next Generation Automatic Memory Management;*** *Highlight 17061, Award 0429859****)*** also seeks to understand how humans interface with technology. The PI and her collaborator at the Australian National University have provided a fundamental new building block for memory management algorithms with outstanding performance characteristics that have the flexibility to handle diverse workloads. This algorithm, the first new building block for memory management in over 25 years, has the potential to change the way modern automatic memory management systems are built. This is a significant achievement because memory management is an essential part of every runtime system for managed programming languages, such as Java, C plus, Ruby, and Python. Because this research contributes to systems that execute software, i.e., software infrastructure, and almost all aspects of modern life now depend on software running correctly and with high performance, it is likely to have a significant impact on how humans interface with computers.

Several examples of investigations of the human and social dimensions of new technology explore the use of technology as a collaborative tool for learning or to advance the fundamental knowledge base on learning. A CAREER award to William Tomlinson at the University of California-Irvine ***(An Agent-Based Approach to Human-Computer Interaction for Systems of Collocated Devices;*** *Highlight 18626, Award* *0644415)* resulted in the EcoRaft project, a multi-device museum exhibit that helps children learn about restoration ecology. The project demonstrates novel mechanisms for people to use multiple nearby computing devices that work together while enabling children to learn about global environmental issues and effective science-based ways to address them. The Program supports an effort that impacts the groundwork for a wide range of potential applications involving multiple people and multiple devices cooperating to perform a task, whether for business, communication, or learning. More important, the rich connections between devices help to create an environment conducive to collaborative, discovery-based learning. In another example, Alexander Renkl (University of Freiburg), Vincent Aleven, and Ron Salden (Carnegie Mellon University) have discovered a way in which artificially intelligent computer tutors can be improved ***(Faded Examples Improve Cognitive Tutors;*** *Highlight 19328, Award* *0354420)*. Prior research had shown that "Cognitive Tutors" improve students' math achievement over typical classroom instruction. The current work presents the students with "solved example problems" and "fades out" problem steps as the students demonstrate progress. The researchers found that adding faded examples in this manner improves students' learning outcomes and they performed better on tests that were administered several weeks after the learning phase was conducted. For their work, the researchers were awarded the Cognition and Student Learning Prize by the Institute of Education Sciences. This work has the potential to increase learning so that students across a range of populations have a better chance of succeeding in STEM disciplines.

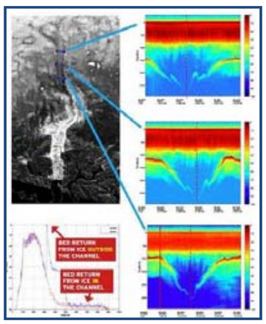
Thomas DeFanti and colleagues at the University of Illinois at Chicago (UIC), through a grant provided by NSF's International Research Network Connections (IRNC) program, used the evolving global optical network infrastructure (IRNC's TransLight/StarLight network) to create a virtual classroom between UIC and Louisiana State University (LSU) in order to teach videogame design ***(Sharing Data on a Global Scale;*** *Highlight 19181, Award* *0441094)*. For this class, they took advantage of high-definition video-conferencing and online discussion groups for class instruction and team

projects. Through this process, they also sought to understand how to make the subject matter compelling and effective over distance, and to learn how students work together in teams separated by time and space. The success of this endeavor has resulted in interest from international collaborators at Moscow State University in Russia and Masaryk University in the Czech Republic.

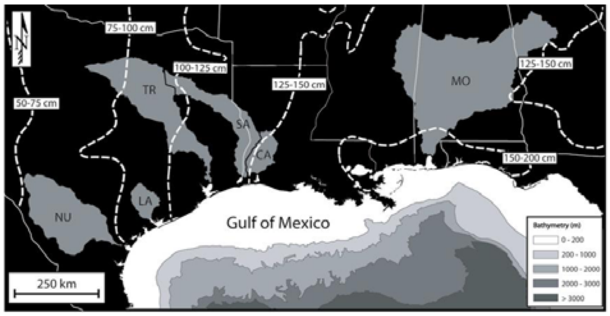
Last year the Discovery subgroup of this committee also asked that we specifically address research that improves our ability to live sustainably on earth. The highlights that we reviewed had numerous examples of projects that address important questions in energy and climate change research. An example of research that addresses challenges in storing energy also involves an industry partnership. Small Business Innovation Research (SBIR) funding to Christopher Rhodes of Lynntech, Inc. has developed an innovative, low-cost nano-structured composite electrode for high energy and power density asymmetric electrochemical capacitors ***(High-performance, Low-cost Hybrid Electrochemical Capacitors;*** *Highlight 17293, Award 0750183****)***. This project demonstrated the material's improved performance compared with existing technologies, and designed a low-cost manufacturing process. The availability of low-cost and high energy density storage devices of any kind will go a long way to absorb large amounts of intermittent sources of electricity (e.g., wind and solar) into the electric power grid, thus encouraging the development of green sources of power, which reduce the country's carbon footprint and dependency on imported fossil fuel. Since this was an SBIR grant, the researchers are expected to be driven by their commercial instincts to bring this low cost storage technology to the marketplace soon rather than leaving this as an academic exercise that sometimes take a long time to come to fruition. Having this storage technology commercialized sooner rather than later will help U.S. competitiveness in a fast growing market for low cost, high efficiency, and non-polluting storage devices for application in commercial and residential buildings.

One of the most globally important issues of our time is climate change and understanding human impacts. The Intergovernmental Panel on Climate Change (IPCC) 2007 concluded that global warming is occurring now, and that human contributions from greenhouse gas emissions are involved. The impacts of climate change in the Arctic and on the Antarctic Peninsula regions have been clearly seen from rapid melt and demise of ice shelves over the recent decade. New results published in Nature and the Proceedings of the National Academy of Sciences show that most of Antarctica is warming now, although to a greater degree in the West Antarctic ice sheet than the East Antarctic ice sheet. ***(New Data Reveal Recent Antarctic Warming,*** *Highlight 17984, Awards 0126161 and 0440414****)***. In addition, the research team led by Ed Brook at Oregon State

has used evidence from gases trapped in ice cores to clearly show that during abrupt climate change events, atmospheric carbon dioxide rose each time that Antarctica has warmed significantly in the past ***(Gas from the Past Gives Clues about the Relationship Between Climate and Ocean Circulation,*** *Highlight 17987, Awards 0337891 and 0602395****).*** Natural abrupt warming events in Greenland and Antarctica between 10,000 to 100,000 years ago have occurred in opposite patterns, due to changes in ocean transport of heat. Models predict that carbon dioxide is released from the deep ocean in times when Antarctica warms significantly. If that were to occur, a natural release of carbon dioxide from the deep ocean would add to anthropogenically-induced rise in the greenhouse gas, accelerating climate change. In another example, new sensitive radar technologies are being used by the Center for Remote Sensing of Ice Sheets to understand the impact of bed geometry under a glacier on its discharge rates ***(STC-II: Channel Geometry under Jakobshavn Isbrae, West Greenland from Airborne Rader Sounding,*** *Highlight 19130, Award 0424589****)***. This glacier has been showing variable but accelerated rates of flow and discharge since 1995. The melting of the Greenland ice sheet is contributing to sea level rise due to global warming. Improving estimates of future sea level rise is a primary goal of the center. In three grants grouped under the heading, ***Melting on the Arctic Express*** *(Highlight 18536, Awards 0531026, 0531173, and 0632130)* researchers were able to determine the amount of melting at the top and bottom surfaces of the sea ice cover. Their observations indicate that there was an extraordinarily large amount of bottom melting of the ice in the summers of 2007 and 2008 and that solar heating of the upper ocean was the primary heat source. Their calculations seem to confirm that solar heating in the open water was sufficient in magnitude and in timing to produce the observed bottom melting. This is a very significant discovery given the many instances of loss of Arctic sea ice cover that have been reported recently in the scientific press. When the issues of global warming and climate change are capturing the headlines globally, it is necessary to have such data and models to help separate fact from fiction.



In addition to global sea level rise from climate change, by comparing data from the geological record, researchers discovered that local, relative increases in sea level rise in estuaries of the upper Gulf Coast are occurring, most likely due to oil and gas extraction and/or sediment starvation at the mouth of the Mississippi River. ***(Response of Upper Gulf Coast Estuaries to Holocence Climate,*** *Highlight 17459, Awards 9905230, 0002807, and 0107650).* The accelerated sea level rise in this region of the U.S. is likely to lead to rapid and dramatic reorganization of estuarine environments, coastal erosion, and wetland loss, as global sea level rise continues in the next few centuries.

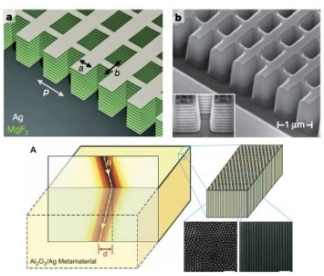


An award to Juan Valdes at the University of Arizona ***(Initiation of a Prototype Ecohydrologial Observatory at the Valles Caldera National Preserve,*** *Highlight 19094, Awards 9876800)* demonstrates the importance of large scale ecological research to address environmental challenges. Water availability in the western states is primarily determined by high mountain hydrology, yet current information about actual processes is limited. Research at the Center for Sustainability of Semi-Arid Hydrology and Riparian Areas combines environmental instrumentation of a watershed at a scale sufficient to collect meaningful data with fine-resolution modeling of hydrologic processes and water partitioning vegetation, runoff, and groundwater discharge. Data were collected over an annual cycle on a basin scale; as a result, researchers are able to better quantify the processes that govern flood and drought flows in western rivers. This research was conducted at an NSF Science and Technology Center. Because the research was carried out on a sufficient spatial scale, the results make a substantial contribution to management and preservation of western water resources, an essential commodity for ecosystem and human sustainability.

NSF has also funded projects to develop environmental modeling tools to help biologists and ecologists address important questions with applications to global climate change and the corresponding impetus on sustainable practices for environment-related activities ***(Networked Infomechanical Systems (NIMS),*** *Highlight 18846, Award 0331481)*. Researchers funded by this project have created NIMS, a Networked Infomechanical Systems robotic sensor technology that combines working, embedded computing, and electromechanical systems to monitor environments with spatio-temporal dynamics efficiently. NIMS is a breakthrough in sensing technology since it provides autonomous and precise control of sensors in complex environments while exploiting the existing infrastructure available in-field. NIMS has been used successfully in both terrestrial (rain forests in La Selva, Costa Rica; White Mountains, California; and San Jacinto confluence zone, California) and aquatic (Lake Epecuen, Argentina; Lake Fumor, California; and San Joaquin confluence zone, California) environments. NIMS has been used and adopted by biologists and ecologists to address critical problems including characterizing light distribution. NIMS provided unprecedented, high resolution data for critical environmental monitoring applications that were not possible before.

The above selected projects include several interesting examples of center-level research. However, there are many other highlights that illustrate specific mechanisms that NSF centers have used to enable academic institutions and their partners to integrate discovery, learning, and innovation on scales that are large enough to transform important science and engineering fields and interdisciplinary areas and stimulate increased innovation. NSF centers provide unique opportunities for students to broaden their research horizons and also provide opportunities for collaboration with industrial partners.

Transformative research that manipulates light at the nanoscale from two groups of researchers at the Center for Scalable and Integrated Nanomanufacturing at the University of California Berkeley puts us a step closer to the possibility of "invisibility cloaking" or making a material invisible ***(Bending Light Backward Towards Invisibility;*** *Highlight 16944, Awards 0751621).* These projects using two very different fabrication methods each resulted in the first demonstrations of a bulk material designed to bend light. Metamaterials are composites that have extraordinary optical properties and can negatively refract light. One of the metamaterials being studied is a novel composite with a fishnet structure. The second is made with silver nanowires embedded in an alumnia matrix. This work is significant because it is the first demonstration of negative refractive index and optical negative refraction of bulk optical materials. The exploration of optical phenomena associated with zero and negative refraction indices could lead to applications such as new ways to create novel high powered optical lenses or increased storage capacity in optical media. This research involved the collaboration of an interdisciplinary team of mechanical engineers, physicists, and chemists from three UC campuses (UNCC, UCLA, and Berkeley). Because of the transformative potential, the research has attracted industrial support from Hewlett Packard, Boeing, and Northrop Grumman.



Research at the Center for Environmentally Responsible Solvents and Processes at the University of North Carolina at Chapel Hill *(Highlight ID 18479, Award 9876674)* resulted in the ***Lemelson-MIT Prize to PI Joseph M. Simone***. This project has led to groundbreaking solutions in green manufacturing, producing applications in gene therapy and drug delivery, as well as in medical device design and manufacture. This project uses supercritical fluids, which are a special phase of matter that has both gas and liquid properties. Supercritical fluids produce a class of high performance plastics known as flouropolymers. This breakthrough impacts environmentally sustainable manufacturing. Fluoropolymers are used in wire and cable insulation, flexible tubing, and industrial films – applications that span the fields of data communications, electricity storage, and automotive design. “DuPont has licensed this breakthrough fluorpolymer-creation process, and we have built commercial facilities based on the technology, leading to unique products and more environmentally sustainable manufacturing,” said Nandan S. Rao, Global Technology Director, DuPont Fluorproducts. This work has also been applied to the medical device field. Dr. Rao, working with Duke University and Synecor LLC, is developing a fully bioabsorbable stent, and progress is being made to eliminate the need for permanent prosthetics in opening blocked or closed blood vessels. Work is underway utilizing fabrication processes from the microelectronics industry to create tiny drug carriers.