# CYBER-ENABLED MATERIALS, MANUFACTURING, AND SMART SYSTEMS (CEMMSS)

## Overview

In response to the Administration's Materials Genome Initiative (MGI), Advanced Manufacturing Partnership, and the National Robotics Initiative (NRI), the Cyber-enabled Materials, Manufacturing, and Smart Systems (CEMMSS) framework aims to integrate a number of science and engineering activities across the Foundation – breakthrough materials, advanced manufacturing, robotics, and cyber-physical systems. Through deployment of new cyber-enabled paradigms, materials with unique properties and functionality will be discovered and developed more reliably and efficiently. Further, using advanced manufacturing strategies, new materials can be fashioned into artifacts and systems embedded with computational intelligence, thereby transforming today's static systems, processes, and edifices into adaptive, pervasive smart systems.

The smart systems of tomorrow and the materials from which they will be composed will vastly exceed those of today in terms of adaptability, autonomy, functionality, efficiency, reliability, safety, usability, recoverability, and recyclability. These advances have the potential to accelerate scientific discoveries to address key national and societal challenges critical to U.S. security and competitiveness.

**Total Funding for CEMMSS**
(Dollars in Millions)

| FY 2012 Actual | FY 2012 Enacted/ Annualized FY 2013 CR | FY 2014 Request |
|---|---|---|
| **$144.32** | **$141.65** | **$300.42** |

## Goals

Goal 1: Science and Engineering

Establish a scientific basis, a codified knowledge base, and shared approach that advance cyber- and data-enabled principles for discovery, design, development, and production of new classes of advanced materials. Develop and deploy advanced manufacturing methods to produce artifacts and systems with superior functionality, including embedded intelligence to make them smart, responsive, and adaptive. Develop the core science needed to engineer systems that build from and depend upon the synergy of computational and physical components in real-world contexts. The goal is integrated programs across CEMMSS research areas, for example, in cyber-manufacturing, materials informatics, and smart systems.

Goal 2: Education, Workforce Development, and Community Building

Create integrated research communities from incongruent disciplines. Educate a cadre of high caliber disciplinary and interdisciplinary researchers with a wide range of skills, including skills in the use of cyber- and data-enabled approaches to science and engineering. Engage the support of related research and education programs at the National Science Foundation (NSF), such as Engineering Research Centers; Materials Research Science and Engineering Centers; and Science, Technology, Education, and Mathematics (STEM) education programs. Partner with other government agencies, international funding organizations, and industry. The goal is to build a thriving CEMMSS ecosystem.

Goal 3: Research Infrastructure Development

Develop the critical research infrastructure – cyber and experimental – to be used to discover, develop, test, refine, and validate the advanced materials, design, manufacturing, and development methods as well

as to enable the transition to practice of smart systems from the lab to the field. In the short-term, the goal is cyberinfrastructure for advanced manufacturing, cyber-physical systems, robotics, and materials. The longer-term goal is to stitch together disparate testbeds for explorations at the CEMMSS frontiers.

**Approach**

The CEMMSS framework of bringing together researchers focused on breakthrough materials, advanced manufacturing, robotics, and cyber-physical systems is expected to increase collaboration and communication among these research communities, leading to enhanced disciplinary and interdisciplinary research. These efforts will transform static systems, processes, and edifices into adaptive, pervasive smart systems with embedded computational intelligence that can sense, adapt, and react. Success in CEMMSS will drive transformations that address the pressing technological challenges facing the Nation, promoting U.S. economic competitiveness.

Programmatic

To generate new capabilities with meaningful impact, NSF is developing a portfolio that coordinates and synchronizes activities across four main research areas – breakthrough materials, advanced manufacturing, robotics, and cyber-physical systems – and encourages interdependencies and common research elements to surface and be exploited at each subsequent stage of the evolution of the program.

Organizational

CEMMSS leadership is shared across the relevant division directors in the Directorate for Computer and Information Science and Engineering (CISE), the Directorate for Engineering (ENG) and the Directorate for Mathematical and Physical Sciences (MPS). The CEMMSS coordination team is comprised of program directors from CISE, ENG, MPS, and the Directorate for Biological Sciences (BIO). This group is charged with developing CEMMSS activities and implementing the suite of activities over the next four years. The team will also work with internal and external program evaluation experts to help develop a set of metrics by which program progress can be evaluated over time.

Scope

Numerous CEMMSS interdisciplinary connections already exist at NSF. Many are pairwise and expanding, such as robotics and manufacturing; materials and manufacturing; cyber-physical systems and robotics; cyber-physical systems and manufacturing materials; and robotics and the biological sciences. NSF has sponsored and will continue to hold community-building workshops and will request white papers to contribute to the development and evolution of CEMMSS. The intention is to go beyond these two-way collaborations and drive research in new directions. This will be achieved through a combination of new solicitations and Dear Colleague Letters (DCLs). CEMMSS currently includes many interagency activities; new cross-agency partnerships are continuously being developed. Industry partnerships also are a key element in CEMMSS's success; industry and venture capital groups will be invited to workshops and principal investigator (PI) meetings. NSF also expects that international activities will become increasingly relevant over the period of time that CEMMSS is an NSF-wide investment area. CEMMSS presents a unique opportunity to accelerate integrative research and educational activities. The interaction of research ideas that is promoted by CEMMSS multiplies their impact across multiple research communities.

**Investment Framework**

**CEMMSS Funding by Directorate**
(Dollars in Millions)

| Directorate | FY 2012 Actual | FY 2012 Enacted/ Annualized FY 2013 CR | FY 2014 Request |
|---|---|---|---|
| Biological Sciences | $3.00 | $3.00 | $5.00 |
| Computer and Information Science and Engineering | 50.50 | 50.50 | 103.00 |
| Engineering | 56.00 | 56.00 | 126.42 |
| Mathematical and Physical Sciences | 34.82 | 32.15 | 66.00 |
| **Total** | **$144.32** | **$141.65** | **$300.42** |

Totals may not add due to rounding.

**FY 2012 – FY 2013**

Science and Engineering
In 2012, NSF jumpstarted CEMMSS's science and engineering activities through a suite of activities, including DCLs, solicitations, and Early-concept Grants for Exploratory Research (EAGER) projects. These activities promoted smart systems by focusing on advanced manufacturing, robotics, cyber-physical systems, scalable nanomanufacturing, and advanced materials.

In FY 2013, the program is emphasizing mid-scale team-based interdisciplinary research that will build the knowledge necessary to make progress in CEMMSS, including opportunities for transitioning discoveries into practice. Investments will continue to build pair-wise programmatic activities across CEMMSS focus areas to develop the next generation of robots, cyber-physical systems, cyber-manufacturing tools, and advanced materials. For example, pilot programs will further integrate materials science and engineering with processing, design, and manufacturing research, including Designing Materials to Revolutionize and Engineer the Future (DMREF), NSF's premier program in support of MGI involving CISE, MPS, and ENG.

Education, Workforce Development, and Community Building
To foster and accelerate the building of integrated research communities among various disciplines, in FY 2012, NSF held technical workshops, design sessions, focused meetings, and panels about advanced manufacturing, MGI, and cybersecurity for cyber-physical systems. An organizational meeting was held with representatives from academic and industrial organizations to discuss collaborative work in health applications of emerging robotics technologies. NSF also continued to support the cyber-physical systems (CPS) Virtual Organization. Among the awards given in FY 2012, NRI funded the use of robotics to facilitate and motivate STEM learning across the K16 continuum. In addition to co-chairing the National Science and Technology Council Subcommittee for MGI and the CPS Senior Steering Group (SSG), NSF participated in interagency award meetings to structure a balanced NRI portfolio across agencies. NSF has worked to enhance CPS cooperation with other agencies through the NITRD program and has developed memoranda of understanding (MOUs) with Department of Defense agencies related to MGI.

In FY 2013, the associated big data and cyberinfrastructure components necessary for making advances in CEMMSS will be identified. NSF will continue to co-chair and/or participate in interagency NSTC Subcommittees, SSGs, and working groups. Each focus area will develop curriculum and new education

programs. In the area of advanced manufacturing, a program is being started with industry to provide support for undergraduate laboratories to use existing cyber-manufacturing infrastructure in project work. NSF has developed an MOU for interagency cooperation in CPS with the Department of Transportation

Research Infrastructure Development

In FY 2012, there were initial pilot investments in testbeds and prototypes for cyber-enabled materials, manufacturing, and smart systems. The NRI solicitation funded the development of co-robot testbeds for technology testing, demonstration, and validation. Pilot investments at Purdue University were utilized to integrate the NSF-funded HubZero cyberinfrastructure with the Department of Commerce-led National Digital Engineering and Manufacturing Consortium. Purdue has now launched ManufacturingHub.org, and is using this cyberinfrastructure to link manufacturers to state-of-the-art computational modeling and simulation tools to solve real world manufacturing problems more accurately and rapidly.

In FY 2013, NSF will build upon successful pilots and expand development of cybermanufacturing assets and link academic and government-furnished tools to industry needs and opportunities. NSF is also encouraging the development of new, or the use of existing, testbeds to evaluate advances in cyber-physical systems. DMREF plans to build an integrated network of platforms that develop and utilize advanced computational and experimental tools to accelerate the discovery, synthesis, and deployment of new materials as well as their transfer to the manufacturing sector.

**FY 2014 Request**

To advance the science and engineering goal in FY 2014, the focus will be on evolving a comprehensive, integrated program across the focus areas to encourage new connections, discoveries, and/or emerging fields of science and engineering. Investments will be made in advanced manufacturing ($159.73 million), including investments in scalable nanomanufacturing ($10.0 million); cyber-physical systems ($50.0 million); core programs that integrate materials science and engineering with processing, design, and manufacturing research ($36.0 million); DMREF/MGI ($42.0 million); and NRI ($31.50 million). A workshop is planned to bring together communities engaged in materials research on sensors and detectors with those in manufacturing and cyber-physical systems. This will enhance community building and identify science and engineering challenges for this new community. In addition, CEMMSS will conduct the first round of challenges and contests.

To advance the Education, Workforce Development, and Community Building goal, NSF will continue its role in interagency Subcommittees, SSGs, and working groups and will develop further partnerships with other agencies as well as with the European Union. Interagency MGI activities specific to DMREF will include evaluation methods for cross-agency projects, development of a strategic plan for MGI, and program assessment and planning meetings for subsequent solicitations. NSF will also expand its use of MOUs to share cyber and experimental facilities operated by interagency partners. NSF will continue to support the CPS Virtual Organization, which is a broad community of interest for CPS researchers and developers. There will be workshops and PI meetings in all four focus areas. For example, CPS/CEMMSS education workshops will address graduate curricula, undergraduate courses, and strategies for the new NSF Research Traineeships (NRT) program in CPS. Also, a workshop that will bring together the DMREF community will invite industry as well as venture capitalists to attend part of the workshop.

The Research Infrastructure Development goal will involve all four focus areas. The CPS solicitation will include a focus area on testbeds and will seek partnerships among CISE, ENG, and interagency partners. DMREF will invest in data sharing, analysis, and visualization capabilities to enhance data-driven material discovery, assessment, and deployment. The challenges and contests conducted as part of NRI in FY 2014 will highlight cyberinfrastructure goals by making four awards based on the following criteria: current cost to manufacture, expectation of broader impact, innovation of integrated solution, and ease of

transition to other projects and/or industry.

**FY 2015 – FY 2017**

To further develop the foundational science and engineering basis of CEMMSS, NSF will develop several integrated programs in cyber-manufacturing, advanced materials, and smart systems. The long-term goal is to build a thriving ecosystem of cyber-enabled systems and advanced materials. There will be a continued focus on bringing communities together by engaging students, teachers, and educators in cybermanufacturing workshops as well as workshops on other topics that cross the four areas, and by participating in working groups. NSF will expand partnerships with other agencies, international organizations, and industry. These will be grounded in the collaborations NSF has already initiated. To date, NSF has worked with other agencies, such as the National Institute of Standards and Technology, the National Institutes of Health, the National Oceanic and Atmospheric Administration, U.S. Department of Agriculture, and the Departments of Transportation and Defense, which are currently building and deploying smart systems of all kinds (e.g., underwater sensor networks; autonomous vehicles that swim, fly, crawl up walls; portable energy efficient storage devices, etc.). Combining mission agency investments with the basic science and engineering funded by NSF could have a significant impact on future U.S. critical infrastructure by embedding computational intelligence in the underlying systems and the materials from which they are composed.

Solicitations will emphasize a call for high impact solutions integrated across the CEMMSS disciplines, especially those that enhance manufacturing processes, and utilize advanced materials and computational intelligence. CEMMSS will also promote high-risk, breakthrough applications and testbeds in order to continue to push the boundaries of discovery in advanced materials, cybermanufacturing, and smart systems. In FY 2015, the CEMMSS coordination team will engage external contractors to conduct portfolio analysis, for example, identifying gaps and opportunities for further interagency, industry, and international cooperation in cyber-enabled materials, manufacturing, and smart systems.

**Evaluation Framework**

At the end of FY 2012, NSF contracted with the Science and Technology Policy Institute (STPI) to develop a framework for assessment and a set of program-specific metrics to be available for use within ten to eleven months.

STPI will assist with identifying metrics to measure progress across the three goals. Possible indicators include:

- For science and engineering – increases in the number and quality of breakthrough discoveries; the emergence of new fields; increasing agency, industry, and international partnerships; and increasing transition of discoveries into practice (i.e., patents, start-ups, new products);
- For education – increases in the number of smart systems courses offered, faculty recruited, and students graduating from academic programs; and
- For cyberinfrastructure – the development of de facto standards for interoperability; increased use of shared data analytic, simulation and modeling tools, and common software platforms; and the growth of computer-integrated and cyber-based manufacturing across the U.S.

The preliminary work to set out a baseline for these metrics will be carried out in FY 2013, allowing program evaluation to be deployed during FY 2014. Yearly program assessments will be carried out by the CEMMSS coordination team and presented to NSF senior management.