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

$256,950,000
+$25,490,000 / 11.0%

Overview

The Cyber-enabled Materials, Manufacturing, and Smart Systems (CEMMSS) investment aims to integrate a number of science and engineering activities across NSF, including breakthrough materials, advanced manufacturing, robotics, and cyber-physical systems (CPS), in response to the Materials Genome Initiative (MGI), Advanced Manufacturing Partnership (AMP), and National Robotics Initiative (NRI). Through CEMMSS-funded research, materials with unique properties and functionality are being discovered and developed more reliably and efficiently via the integration of theory, modeling and simulation, data analytics, and experiments. These new materials can in turn be fashioned into objects, structures, and systems embedded with computational intelligence, thereby transforming today's static systems, processes, and edifices into adaptive smart systems through the use of advanced manufacturing strategies also supported through CEMMSS.

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 and engineering discoveries to address key national and societal challenges critical to U.S. security and competitiveness.

Total Funding for CEMMSS
(Dollars in Millions)

FY 2014 Actual	FY 2015 Estimate	FY 2016 Request
$255.94	**$231.46**	**$256.95**

Goals

Goal 1: Science and Engineering

CEMMSS will establish a scientific base, a codified knowledge base, and shared principles for designing, manufacturing, and deploying cyber-enabled smart engineered systems and advanced materials.

Goal 2: Education, Workforce Development, and Community Building

CEMMSS investments will lead to the education of a cadre of high-caliber disciplinary and interdisciplinary researchers and develop a vibrant workforce so as to ensure a pipeline of talent and a growing community in these critical areas.

Goal 3: Research Infrastructure Development

CEMMSS will develop the critical research infrastructure that can be used to discover, test, refine, and validate the advanced materials, designs, and manufacturing and development methods so as to enable the deployment of smart systems.

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. This will lead to enhanced disciplinary and interdisciplinary research. CEMMSS funds research that couples modeling and theory with experimentation, thereby shortening the time and resources required for the discovery and understanding of new materials. Such efforts will aid in the transformation of static systems, processes, and edifices into

adaptive, widespread 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

CEMMSS is developing a portfolio that 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 Computer and Information Science and Engineering (CISE), Engineering (ENG), and Mathematical and Physical Sciences (MPS) directorates. The CEMMSS coordination team is comprised of program directors from the CISE, ENG, MPS, and Biological Sciences (BIO) directorates. This group is charged with developing and implementing the suite of CEMMSS activities. The team is also working with internal and external program evaluation experts to help develop a set of metrics by which program progress can be assessed 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; cyber-physical systems and advanced biomanufacturing; manufacturing and the biological sciences; robotics and the biological sciences; and advanced manufacturing and technician education. NSF has sponsored, and will continue to hold, community-building workshops. The intention is to drive new research directions. This will be achieved through a combination of new solicitations and Dear Colleague Letters (DCLs). CEMMSS currently includes many interagency activities, and 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 2014 Actual	FY 2015 Estimate	FY 2016 Request
Biological Sciences	$4.75	$4.99	$5.48
Computer and Information Science and Engineering	85.00	89.00	94.11
Education and Human Resources	0.30	-	-
Engineering	97.79	96.81	107.52
Mathematical and Physical Sciences	68.10	40.66	49.84
Total	**$255.94**	**$231.46**	**$256.95**

Totals may not add due to rounding.

FY 2014 – FY 2015

The specific CEMMSS investments in Advanced Manufacturing, CPS, Designing Materials to Revolutionize and Engineer our Future (DMREF), and NRI continued to focus on increased integration of the highest priority areas, such as those related to materials and manufacturing, and developing smart systems.

Biomanufacturing emerged as an important emphasis research area in the overall portfolio of advanced manufacturing research. ENG and BIO jointly funded a National Academy of Sciences (NAS) study on the Industrialization of Biology that focuses on the research, education, and infrastructure needs to enable advances in biomanufacturing; a final report is expected by the end of FY 2015. NSF and the National Institute of Standards and Technology (NIST), along with the European Commission, are holding a workshop in FY 2015 on the development of standards that will enable data sharing and automation in advanced biomanufacturing and engineering of biology. In FY 2014, ENG and BIO collaborated on a DCL that solicited new Industry/University Cooperative Research Centers (I/UCRC) in the area of advanced biomanufacturing, and the first planning grant under this DCL will be funded in FY 2015.

In FY 2014, the CPS program solicitation was updated to incorporate results from a gap analysis of the program's portfolio as well as community feedback. Additionally, the CPS solicitation included, for the first time in FY 2014, the Department of Homeland Security (DHS) and the Department of Transportation (DOT), and the program is continuing to expand its agency partners in FY 2015. Over 40 projects were supported by CPS in conjunction with DHS and DOT in FY 2014.

The DMREF program developed a multi-directorate solicitation in FY 2014 that is supporting awards in FY 2015 that integrate theory, simulation, and/or cyber-enabled data analytics with synthesis and characterization experiments in an iterative manner. These awards will accelerate new materials discovery and understanding, design, and innovation.

The NRI solicitation emphasized a call for solutions integrated across the CEMMSS disciplines, especially those that enhance manufacturing processes, and those that have the broadest impacts. CEMMSS will increase the use of the "transition to practice" option (e.g., through the interagency CPS solicitation). NSF will continue to work with other agencies, as well as with industrial/commercial organizations, in support of NRI challenges and contests programs that foster the implementation of systems and devices to achieve real-world tasks in unconstrained environments.

CEMMSS programs continue to hold technical workshops to advance research goals. For example, CPS efforts were informed by a series of FY 2014 community workshops exploring foundational research challenges in key national priority areas, including energy, transportation, and medical devices. CPS will hold a workshop in FY 2015 exploring the role of CPS in Internet of Things (IoT)-enabled smart city applications.

DMREF held joint workshops with the Department of Energy (DOE) in areas of critical importance to the development of the field. Some of these workshops were co-organized with other agencies as addressed in the recent MGI Strategic Plan.[1] To spotlight opportunities for mathematical sciences research in connection with DMREF, MPS will support a Symposium on Mathematical and Computational Aspects of Materials Science in March 2015.

NRI-related workshops have focused on: a) Opportunities in Robotics, Automation, and Computer Science; b) Robot Planning in the Real World: Research Challenges and Opportunities; and c)

[1] www.whitehouse.gov/sites/default/files/microsites/ostp/NSTC/mgi_strategic_plan_-_dec_2014.pdf

Advancement of Field Robots for Ebola Response (organized by the Office of Science and Technology Policy (OSTP) as part of the Adminstration's response to Ebola). In FY 2015, NRI will convene a workshop titled, "Locomotion and Manipulation: Why the Great Divide?," encouraging collaboration between the research communities of locomotion and manipulation, particularly in areas of planning, control, perception, and design. Additionally, CISE will hold a workshop in FY 2015 to bring together researchers in robotics and cyber-physical systems to develop a set of foundational problems common to the two communities.

CEMMSS programs held annual meetings of NSF-funded researchers as a means to build the CEMMSS research community. Additionally, these meetings of principal investigators (PI) allow researchers to describe research advances and identify emerging directions, form new collaborations, learn about new funding opportunities across the federal government, and interact with stakeholders from other NSF programs and federal agencies. The following PI meetings occurred (or are planned) during FY 2014–2015:

- CPS held its annual PI meeting in fall 2014, and plans for its fall 2015 PI meeting to include a session with representatives from NSF center-scale activities (e.g., Engineering Research Centers, Science and Technology Centers, and I/UCRC).
- DMREF held a joint PI meeting with the DOE MGI meeting of grantees in January 2015.
- NRI held its second annual PI meeting in fall 2014 to advance cross-project interaction and collaboration; establish safety standards and risk metrics; and plan for project transitions to include additional partners.

As mentioned earlier, interagency and industrial partnerships are important to the success of CEMMSS. These interagency activities include: a) recruitment of additional government agencies; b) development of evaluation methods for cross-agency projects; c) implementation of smart systems challenges and contests; and d) program assessment and planning meetings for subsequent solicitations.

In response to the Advanced Manufacturing Partnership 2.0 (AMP 2.0), NSF and the Department of Commerce (DOC) launched a new manufacturing technology consortium in FY 2014 to ensure the federal government maintains leading-edge insight into emerging manufacturing technology trends. In FY 2015, NSF plans to fund up to two new I/UCRC or clusters in advanced manufacturing to help address key technological gaps on cross-cutting manufacturing technologies – advanced sensors, digital manufacturing, and composites – that the AMP highlighted as critical for U.S. competitiveness. Additionally, NSF will identify opportunities for utilizing supplemental awards to CEMMSS grantees to enable direct collaboration with at least two of the newly created Institutes for Manufacturing Innovation (managed by DOD and DOE) and/or DOC's Investing in Manufacturing Communities Partnership (IMCP) initiative. NSF will continue to participate in, or host, interagency-supported workshops to provide insight on opportunities, needs, and scientific barriers facing the broader advanced manufacturing sectors. NSF will use the results of these events to connect ongoing NSF research activities to related mission agency efforts, and to help set research agendas for FY 2016 and beyond.

Through the National Science and Technology Council (NSTC) Subcomittee for Networking and Information Technology Research and Development (NITRD) CPS Senior Steering Group (SSG), NSF co-leads a multi-agency, multi-sector comprehensive approach to solving the most difficult cross-cutting R&D challenges. The CPS SSG provides leadership across the government in CPS R&D, and allows NSF to cooperate with other agencies on research portfolio development. NSF also explored partnerships with mission agencies to establish linkages between NSF-funded projects and mission agency-funded contracts/cooperative agreements to further the development and deployment of smart systems. For example, these activities led to additional agencies partnering on the CPS program solicitation, as described above.

In addition, through participation in the NSTC Subcomittee on the Materials Genome Initative (SMGI), NSF helped develop an interagency strategic framework for MGI in FY 2014. As was noted above, NSF organized technical workshops with other federal agencies based on this framework.

Education and workforce development are essential to this emerging field. In FY 2014, the Education and Human Resources (EHR) directorate, through its Advanced Technological Education (ATE) program, supported a collaborative center that provides technical support to grantees of the Department of Labor's Trade Adjustment Assistance Community College and Career Training (TAACCCT) program. NSF conducted internal and external portfolio analyses of its education investments at the technician, undergraduate, and graduate levels to identify gaps and opportunities for further cross-directorate and interagency cooperation related to education and workforce development in CEMMSS.

Based on this gap analysis and portfolio evaluation, NSF is developing a broad CEMMSS education framework in connection with the Improving Undergraduate STEM Education (IUSE) agency-wide framework, and the NSF-wide Strategic Plan for Graduate Education which is under development. A key aspect of this analysis is a NAS study on CPS education; initially funded in FY 2013; a final report is anticipated in FY 2015.

In FY 2014, NSF held a first-of-its-kind workshop aimed at upper-level graduate students and recent Ph.D. graduates focused on the CPS community. Given the success of this activity, NSF will hold a similar workshop in FY 2015. The objectives of this workshop are to identify new paradigms, challenges, and opportunities that will define future research directions for CPS; facilitate advances in closely related disciplines such as energy, transportation, and healthcare; and nurture and grow the CPS field by fostering new collaborations among young researchers. CPS will hold another workshop to discuss challenge problems in cyber-physical systems with an aim to engage secondary and undergraduate students. The NRI solicitation for FY 2014 and FY 2015 included language encouraging activities involving the participation and training of students and requesting reviewers to assess the potential for involvement of motivated young roboticists in accomplishing the research goals of the proposed projects.

Research infrastructure is also essential. NSF focused on solidifying plans for data and software infrastructure with an emphasis on engaging the community in a discussion on requirements and incentives for use. Pilot investments in data and software infrastructure will be made. NSF will hold a community workshop on CPS testbeds in FY 2015 to help identify the most pressing needs and most promising sectors for CPS. NSF works with the CPS Virtual Organization (VO) to distribute testbed software, including simulation and other tools. CPS will also fund at least two projects focused on community testbeds/infrastructure.

FY 2016 Request

- In FY 2016, NSF expects to build toward a cyber-manufacturing program to enable research on the networked integration of manufacturing machines, equipment and systems into an increasingly accessible manufacturing service infrastructure. This program will leverage exsiting core programs within ENG, including Design of Engineering Material Systems (DEMS), Manufacturing Machines and Equipment (MME), and Manufacturing Enterprise Systems (MES), as well as cross-directorate activities including CPS and NRI.
- NSF plans to support research in advanced biomanufacturing. This research will focus on studying theories and technologies of design, engineering, and manufacturing of bio-related (natural or synthetic) products, such as cells and cell-based therapeutic products (i.e. individualized tissues and organoids), or devices with biomaterials and/or cells as components. It will leverage the Biomedical Engineering and Biotechnology and Biochemical Engineering programs in ENG, and build on groundbreaking discoveries, many of which have been supported by NSF in the past, such as 3D additive manufacturing, genome editing, systems and synthetic biology, stem cell biology,

computational modeling, micro- and nanofabrication, and tissue engineering and regenerative medicine. The program holds the promise of enabling the manufacturing of products for low-cost therapeutic research, personalized therapeutic products, and high-value chemicals and materials.

- In FY 2016, NSF expects to continue its interagency collaborations in the area of engineering biology related to advanced biomanufacturing. ENG and BIO will continue to collaborate in funding a new I/UCRC in the area.
- With an interagency CEMMSS program established, CPS will increase its focus on Transition To Practice (TTP) as part of its strong foundational program. This will include funding another I/UCRC in CPS, and a session at the annual CPS PI meeting describing programs that enable TTP and showcasing successful CPS TTP efforts.
- Annual workshops for DMREF PIs will be held to build the community and to identify challenges and successes associated with the integrated and iterative approach to DMREF projects. Industrial participants, venture capitalists, and representatives of professional societies will be invited. Joint workshops with DOE PIs will be continued.
- Joint meetings will be held of co-robot and autonomous robot scientists and engineers from industry and academe to facilitate the application and transfer of known technologies in each domain that satisfy the constraints of the other.
- NSF expects to continue to work with other federal agencies as well as industrial/commercial organizations in support of NRI challenges and contests that foster the implementation of systems and devices to achieve real-world tasks in unconstrained environments.
- Additionally, the NRI solicitation will be updated to encourage the engagement of projects in cross-disciplinary workforce development (academic and industrial) as a key consideration in addressing the broader impact criteria.
- On the basis of the NAS report on CPS education anticipated in FY 2015 as described above, NSF will hold a workshop with the goal of jumpstarting activities and funding EArly-Concept Grants for Exploratory Research (EAGER) awards to members of the community.

FY 2017 – FY 2018

As CEMMSS makes significant progress, NSF will develop several comprehensive, integrated programs across the focus areas, e.g., in cyber-manufacturing, advanced materials and smart systems, to encourage new connections, discoveries and/or emerging fields of science and engineering. Progress towards CEMMSS goals will show evidence of: 1) an integrated and thriving ecosystem of cyber-enabled systems and advanced materials; 2) improved interdisciplinary education based on longitudinal study of education outcomes; and 3) advanced research infrastructure used by CEMMSS scientists and engineers. Through workshops and studies, NSF will regularly perform gap and opportunity analyses of emerging research areas to prioritize new CEMMSS programs.

NSF expects to continue to grow the cyber-manufacturing program, building upon CPS, NRI, and ENG core programs. CPS expects to continue funding CAREER awards, developing partnerships with other agencies, and supporting a transition to practice option in its solicitations. Awards that address the research infrastructure needs of the DMREF research community will also be made. NSF will hold annual PI meetings and workshops, and invite industry experts, venture capitalists, and representatives of professional societies to participate. Through NRI, safety standards and manufacturing performance for co-robots will be evaluated and validated. NSF will also host joint meetings of robot scientists and engineers from industry and academia to facilitate the transition of discoveries into practice.

As interagency partnerships mature, it is expected that hands-on research opportunities for NSF-sponsored students will increase (e.g., in the Manufacturing Innovation Institutes, and IMPC initiatives). NSF also expects to implement some of the recommendations included in the NAS study on CPS Education.

Evaluation Framework

NSF engaged the Science and Technology Policy Institute (STPI) in FY 2012 to assist with the development of a plan for an impact assessment of the CEMMSS initiative. This formulation has entailed discussions with CEMMSS management, including division directors, as well as CEMMSS program directors. Along the way, these discussions are also helping to formulate appropriate synergistic working groups, spanning NRI, CPS, Advanced Manufacturing, DMREF, and other related CEMMSS activities. The approach outlined below is being followed for CEMMSS program evaluation and assessment:

- A portfolio analysis was conducted to understand the scope and scheme of the overall CEMMSS initiative. The first step entailed gathering information and understanding the baseline portfolio, stakeholders, and related activities that NSF currently supports in the CEMMSS area. This included examining the current state of research in the research subfields and analyzing the various recommendations from federal advisory boards and the stakeholder communities on how future investments in CEMMSS areas should be focused.
- A logic model was developed to help NSF track progress toward the major scientific, educational, and infrastructure objectives of CEMMSS.
- Based on the results of the related activities described above, NSF will develop a plan for assessing progress across the CEMMSS science, engineering, education, and cyberinfrastructure activities.

By mid-FY 2015, the framework for the impact assessment will be developed. A report, including an implementation plan and metrics to measure success, will be submitted to the CEMMSS Coordination Team by the end of FY 2015.

The progress of the implementation of CEMMSS also was monitored and reviewed quarterly as part of a performance goal in FY 2014 and FY 2015. For more information about monitoring key program investments, see the FY 2014 Annual Performance Report in the Performance chapter.