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 (CPS). Through CEMMSS-funded research, materials with unique properties and functionality will be discovered and developed more reliably and efficiently via the integration of theory, simulation, data analytics, and experiments. Further, using advanced manufacturing strategies, new materials can be fashioned into objects, structures, and systems embedded with computational intelligence, thereby transforming today's static systems, processes, and edifices into adaptive 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 2013 Actual	FY 2014 Estimate	FY 2015 Request
$181.43	**$230.05**	**$213.20**

Goals

Goal 1: Science and Engineering

Establish a scientific basis, a codified knowledge base, and an integrated experimental and computational approach for discovery, design, development, and production of new classes of advanced materials, advanced manufacturing methods to produce networks and systems with superior functionality, and the core science needed to engineer systems that build from and depend upon the synergy of computational and physical components in real-world contexts.

Goal 2: Education, Workforce Development, and Community Building

This initiative requires the creation of integrated research communities from disparate disciplines. Additionally, a transformation in how scientists and engineers are educated is needed, especially in terms of the introduction of computational- and data-enabled approaches. Partnerships with other government agencies, international funding organizations, and industry will be leveraged as well. Workforce development will extend across the research communities to promote acceptance of new approaches.

Goal 3: Research Infrastructure Development

Develop the critical research infrastructure – computational 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. Initially CEMMSS will focus on scientific developments and cyberinfrastructure for advanced manufacturing, cyber-physical systems, robotics, and materials. In the longer-term it will focus on connecting 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, 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 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 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 CISE, ENG, MPS, and the Directorate for Biological Sciences (BIO). This group is charged with developing CEMMSS activities and implementing the suite of activities. 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. 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 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/Office	FY 2013 Actual	FY 2014 Estimate	FY 2015 Request
Biological Sciences	$4.50	$4.75	$4.50
Computer and Information Science and Engineering	64.80	85.00	81.50
Education and Human Resources	-	0.30	-
Engineering	75.00	95.00	90.00
Mathematical and Physical Sciences	37.13	45.00	37.20
Total	**$181.43**	**$230.05**	**$213.20**

Totals may not add due to rounding.

FY 2013 – FY 2014

To jumpstart the CEMMSS activity within the research communities, several agenda setting and community-building workshops were sponsored. The CEMMSS programs also made new awards to seed promising new approaches. For example:

- In FY 2013, NSF posted the fifth Cyber-Physical Systems (CPS) solicitation, and the total investment in the CPS program was over $31.0 million. The FY 2013 awards included two "Frontier" center-scale projects, ten small "breakthrough" projects, and a National Academy of Sciences (NAS) study on educational needs for developing CPS researchers and practitioners. Additionally, CISE signed a memorandum of understanding (MOU) with the Federal Highway Administration (FHWA), allowing for co-funding of CPS proposals in the area of smart highway infrastructure. In FY 2014, NSF will sign additional MOUs and will issue a joint solicitation with the Department of Homeland Security (DHS) and the Department of Transportation (DOT). NSF funded the second year of NRI with an increased priority for collaborative projects.
- In FY 2013, NSF posted the second NRI solicitation and made 41 awards with a total investment in the NRI program of approximately $30 million. NRI foundational workshops were held in the areas of: a) Research Challenges and Opportunities in Robot Planning in the Real World (October 2013); and b) Cloud and Real-time Robotics (February 2013). NRI also supported two other workshops to address barriers to adoption and impact on national priorities:
  - Challenges and Opportunities in Utilizing Robotics in Small and Medium Manufacturing Enterprises (October 2013); and
  - The IEEE International Symposium on Safety, Security, and Rescue Robotics (October 2013).
  - Workshop reports for each have been published or are in the process of being generated by the meeting organizers.
- CPS and NRI received an increased number of proposals related to advanced manufacturing. Sixteen awards, totaling approximately $6.0 million, were made.
- In ENG, core research programs in advanced manufacturing made over 65 new research awards in FY 2013, representing more than $28.0 million in funding.
- Nine awards were made in Scalable Nanomanufacturing in FY 2013. Combined with core research program in nanomanufacturing and related projects, Scalable Nanomanufacturing was funded at approximately $22.50 million.
- A new core program within ENG, Design of Engineering Material Systems (DEMS), that supports fundamental research intended to lead to new paradigms of design, development, and insertion of advanced engineering material systems, was inaugurated in FY 2013. DEMS made three awards for approximately $1.25 million.

- A joint Designing Materials to Revolutionize and Engineer our Future (DMREF) DCL was issued in December 2012. A collaboration between MPS, ENG, and CISE, DMREF will further the goals of the MGI by accelerating the discovery and deployment of new materials with a specific and desired function or property through integration of theory, computation, experiments, and systematic use of materials data. Eighteen projects were funded in FY 2013. A new version of this Foundation-wide DCL, coupled with directorate-specific DCLs to further alert interested research communities to the initiative, was issued in January 2014.
- NSF sponsored a workshop, *The Materials Genome Initiative: The Interplay of Experiment, Theory and Computation*[1] the results of which were released in June 2013.
- In September 2013, NSF held a community-building meeting for DMREF grantees to identify challenges and successes associated with an integrated and iterative approach to DMREF research.

As mentioned earlier, interagency and industrial partnerships are important to CEMMSS' success. Through participation in the National Science and Technology Council Subcommittee on the Materials Genome Initiative (NSTC/SMGI), NSF is working on an interagency strategic framework for MGI. As part of the NSTC/SMGI activities, NSF worked with the Department of Energy (DOE) and the National Institutes of Standards and Technology (NIST) to hold two workshops to identify the Grand Challenges associated with implementing a MGI approach to the discovery and design of materials.

Through the NSTC Subcommittee for Networking Information Technology Research and Development (NITRD) CPS Senior Steering Group (SSG), NSF co-leads a multi-agency, multi-sector comprehensive approach to resolving the most difficult cross-cutting R&D challenges in CPS. The CPS SSG advocates for joint, coordinated and independent but collaborative research solicitations across the member agencies. The first MOU between NSF and DOT was signed in FY 2013.

To further NRI partnerships, interagency program assessment and planning meetings for subsequent solicitations were held. For example, government researchers from several agencies (e.g., Agriculture, NIST, the Defense Advanced Research Projects Agency [DARPA],) met monthly to develop the community of researchers and program managers across agencies and to discuss the challenges being faced in robotics science and technology. The goal was to promote interagency problem-solving approaches and inform planning for needed research solutions over multiple timeframes. One outcome was a three-year grant to fund a common software infrastructure for developing open source software for robot operating systems to be shared across the agencies. In total, six interagency NRI meetings were held, each emphasizing the programs and particular technological challenges of the host agency with the goal of leveraging one another's R&D programs and mission requirements.

CEMMSS emphasizes opportunities for transitioning discoveries into practice. All PIs from NRI-funded projects participated in a grantee meeting held in October 2013 jointly with industry and government participants. The meeting was to discern gaps and promote exchange in research collaborations related to manufacturing. A small number of robot manufacturers have established special NRI pricing for certain robotic systems to facilitate code and device exchange among researchers. NSF is considering supplemental grants enabling additional acquisition of justified systems. A DMREF grantee workshop held in late FY 2013 connected researchers with industry and venture capitalists to showcase DMREF research activities.

FY 2015 Request

Investments will be made in advanced manufacturing ($150.70 million), including investments in scalable nanomanufacturing ($27.05 million); cyber physical systems ($38.00 million); core programs that integrate materials science and engineering with processing, design, and manufacturing research ($11.77

[1] https://docs.google.com/file/d/0B06HLhCFL05NcVNtRk1MSGRmNVU/edit?usp=sharing&pli=1

million); DMREF/MGI ($22.00 million); and NRI ($28.50 million). CPS, NRI, DMREF, and Advanced Manufacturing will continue to focus on increased integration of the highest priority areas such as those related to materials and manufacturing, and developing smart systems. Annual PI meetings and workshops will continue to help build the community by bringing together researchers from across the respective communities. For example, CISE will hold a workshop or Ideas Lab, bringing together researchers in robotics and cyber-physical systems to develop a set of foundational problems common to the two communities. DMREF will hold workshops in areas of critical importance to the development of the field. A joint DMREF/DOE MGI meeting of grantees is planned for the fall of 2014.

An updated CPS solicitation will incorporate results from a gap analysis of the CPS portfolio as well as community feedback. For example, CPS will build on a series of FY 2014 community workshops exploring the foundational research challenges for CPS in key national priority areas, including energy, transportation, and medical devices. CPS will hold its annual PI meeting, which will include a session with representatives from NSF center-scale activities (e.g., Engineering Research Center, Science and Technology Center, and Industry & University Cooperative Research Program). NSF will also hold a workshop specifically aimed at those who have attempted but have not been successful in obtaining CPS funding. The goal of this workshop will be to educate potential CPS researchers on the priorities of the program and components of successful research projects.

A third annual NRI PI meeting will be held to: a) advance cross-project interaction and collaboration; b) establish safety standards and risk metrics; and c) plan for project transitions to partners, other projects and industry. Other NRI workshops will focus on: a) Real-Time Contingency Handling and Failure Recovery; b) System Learning of Behaviors, Strategies and Heuristics; and c) Energy Efficiency in Smart Cooperative Systems. CPS and NRI will seek proposals for centers and jointly fund at least one such project.

NSF will continue to build on its established interagency partnerships in FY 2015. Interagency activities will 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. 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, DOE) and/or the Department of Commerce's Investing in Manufacturing Communities Partnership (IMCP) initiative. NSF will 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 set future research agendas and connect ongoing NSF research activities to related mission agency efforts. NSF will also continue to co-chair the CPS SSG and cooperate with other agencies on research portfolio development. Through the CPS SSG, NSF will also explore 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.

Education and workforce development are essential to this emerging field. NSF will conduct internal and external portfolio analyses to identify gaps and opportunities for further interagency cooperation related to education and workforce development. Based on this gap analysis and portfolio evaluation, NSF will develop a broad CEMMSS education framework. Using the findings of a NAS study on CPS education, NSF will hold a workshop with a goal to jump start activities and fund EArly-Concept Grants for Exploratory Research (EAGER) awards to members of the community. NSF will also hold a first-of-its-kind workshop aimed at upper-level graduate students and recent Ph.D. graduates. The objectives of this workshop will be 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 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 high-school and undergraduate students. Additionally, the NRI solicitation will be updated to suggest engagement of projects in cross-disciplinary workforce development (academic and industrial) as a key consideration in evaluating the broader impact criteria.

Research infrastructure is also essential. NSF will focus 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 to help identify the most pressing needs and most promising sectors for CPS. NSF will work with the CPS Virtual Organization (VO) to distribute testbed software, including simulation and other tools. CPS will fund at least two proposals in community testbed/infrastructure.

Subsequent NRI solicitations will emphasize a call for solutions integrated across the CEMMSS disciplines, especially those that enhance manufacturing processes, and those that have the broadest impacts. NSF will hold a joint academic-industry-government workshop to propose next-generation Grand Challenges in light of available and prototyped technologies. CEMMSS will increase the use of the "transition to practice" option (e.g., through the interagency CPS solicitation). NRI challenges and contests programs will be defined to require the implementation of systems and devices to achieve real-world tasks in unconstrained environments by partnering whenever possible with industrial/commercial organizations.

FY 2016 – FY 2017

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.

For example, NSF expects to develop a cyber-manufacturing core program, building upon CPS and advanced manufacturing results to date. ENG through its DEMS program will continue to invest in both unsolicited and CAREER awards. CPS expects to continue funding CAREER awards, developing partnerships with other agencies, and supporting a transition to practice option in its solicitations. DMREF will continue to support awards that integrate theory, simulation, or cyber-enabled data analytics with experiments in an iterative manner. These awards will address the research infrastructure needs by the DMREF research community. NSF will hold annual workshops and invite industry participants, venture capitalists, and representatives of professional societies to participate. Through NRI establish safety standards suitable for OSHA machinery compliance and validate manufacturing co-robot performance in real world environments. 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

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.

STPI assisted with identifying metrics to measure progress across the three goals. Indicators include:

- For science and engineering – increased number and quality of breakthrough discoveries in CEMMSS, as evidenced by new journal articles and conference presentations/proceedings in field-specific and interdisciplinary journals and conferences; the emergence of new fields, as evidenced by new journals and conferences, as well as citations therein; increasing agency, industry, and international partnerships, as measured by new collaborations among investigators, new partnerships formed among institutions, and new joint funding programs established; and increasing transition of discoveries into practice, i.e., number of patents granted, technologies licensed, start-ups formed, and new products commercialized and marketed;
- For education – number of existing courses, curricula, and degree programs modified to emphasize interdisciplinary CEMMSS foci; number of new courses, curricula, and degree programs in interdisciplinary CEMMSS areas; increases in the numbers of CEMMSS courses being offered, faculty being recruited and/or trained, and students entering and graduating from academic programs, particularly graduate-level programs; number of new student internships/traineeships in industry or government labs; and the formalization and dissemination of best practices for interdisciplinary CEMMSS education; and
- For cyberinfrastructure – the development of de facto standards for interoperability; new databases, modeling and simulation tools, software/software platforms, and other testbeds developed and deployed; increased use of shared data analytic, simulation and modeling tools, common software platforms, and other testbeds; 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 was carried out during FY 2013, allowing program evaluation to be deployed by early FY 2015. Yearly program assessments will be carried out by the CEMMSS coordination team and presented to NSF senior management and other stakeholders.