NIST Three-Year Programmatic Plan, FY 2014-2016

1 Introduction

The National Institute of Standards and Technology (NIST) promotes U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in a range of strategic areas critical to the nation's economy. The America COMPETES Act (Pub. L. 110-69, 121 Stat. 572) outlines major roles for NIST in promoting national competitiveness and innovation, and also calls for NIST to submit a three-year programmatic plan concurrent with the submission of the President's budget request to Congress. This document summarizes the focus of NIST programs for use in planning and prioritizing investments over this three-year period. NIST will continue to refine this plan as it works with the Administration to address national priorities.

This Plan, first, describes NIST's mission and goals as well as an overview of its major structural areas. Second, this Plan outlines the strategic framework upon which NIST defines its priorities: relevancy to national priorities and research and technical capacity optimization.

2 NIST Overview

Since 1901, NIST (known as the National Bureau of Standards until 1988) has developed and maintained key standards for the Nation, a role that the U.S. Constitution assigns to the Federal government, and has been supplying the measurements and tools to help U.S. industry compete. As a non-regulatory agency in the U.S. Department of Commerce, an experienced partner of industry, and the Federal research agency specifically focused on promoting U.S. economic competitiveness, NIST is well-positioned to accelerate and promote innovation and advanced technologies through its laboratory programs and its Innovation and Industry Services Programs.

2.1 NIST Mission and Goals

> **Mission**: To promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve the quality of life.

The following goals aim to ensure that NIST retains the technical capabilities and adaptability necessary to carry out its key role in the Nation's innovation ecosystem:

Goals:

- **Strengthen NIST's laboratories and facilities to ensure U.S. leadership in measurement science**. The strength and vitality of the NIST laboratories are crucial to meeting the complex and demanding measurement and standards challenges associated with new technologies. NIST will continue to invest in the high-performing facilities, equipment, infrastructure, and personnel.

- **Fortify U.S. advanced manufacturing capabilities.** The Nation's long-term competitiveness relies on its global leadership in advanced manufacturing capabilities. NIST will develop and deploy unique tools to support U.S. advanced manufacturing through programs including the Hollings Manufacturing Extension Partnership, the Advanced Manufacturing Technology Consortia Program, and the National Network for Manufacturing Innovation.
- **Maximize NIST's impact through effective collaboration and coordination.** NIST's research and development activities have the greatest impact when the knowledge and technology generated is transferred to industry, universities, standards organizations, and other government agencies. NIST will continue expanding its efforts to pursue partnership opportunities with other organizations through multiple technology transfer mechanisms including delivery of measurement solutions to industry and other government agencies, providing access to unique measurement capabilities through its user facilities, participation in standards-setting organizations, convening consortia, licensing of intellectual property, and continued attraction and training of high quality research associates.
- **Develop world class operations and support.** NIST's activities are most efficient and effective when supported by exceptional business practices, strategic planning, and operational offices. NIST will improve its practices to enhance the business of NIST.

2.2 Delivering On the NIST Mission

NIST's mission to promote innovation and industry competitiveness is best served when we support activities throughout the research and development pipeline, from the most basic science to the deployment of advanced technologies. NIST programs are designed to span this pipeline, enabling organizational excellence for institutions from non-profits and universities to manufacturers, supporting advanced manufacturing by facilitating pre-competitive and applied research as well as technology deployment, and performing world-class metrology and technology research and services.

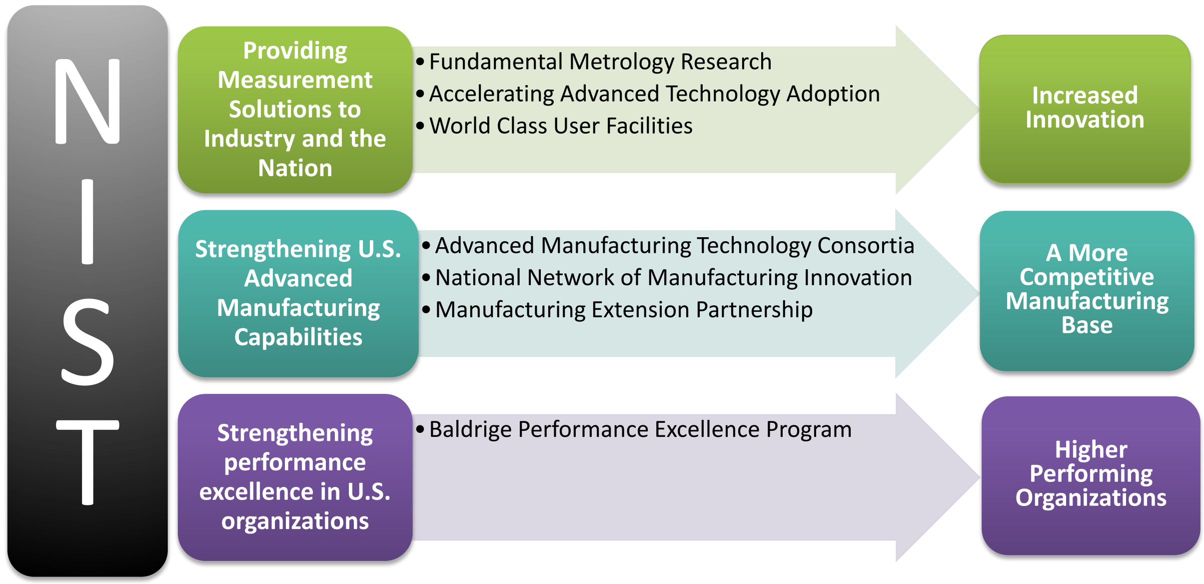

Figure 1 Delivering on the NIST mission

2.2.1 The NIST Laboratories

The NIST laboratory programs work at the frontiers of measurement science to ensure that the U.S. system of measurements is firmly grounded on sound scientific and technical principles. Today, the NIST laboratories address increasingly complex measurement challenges, ranging from the very small (nanoscale devices) to the very large (vehicles and buildings), and from the physical (renewable energy sources) to the virtual (cybersecurity and cloud computing). As new technologies develop and evolve, NIST's measurement research and services remain central to innovation, productivity, trade, and public safety.

The NIST laboratory programs provide industry, academia, and other federal agencies with:

- Scientific underpinnings for basic and derived measurement units, international standards , measurement and calibration services, and certified reference materials;
- Impartial expertise and leadership in basic and applied research to enable development of test methods and verified data to support the efficient commercialization and exchange of goods and services in industry and commerce;

- Expertise and support for the development of consensus-based standards and specifications that define technical and performance requirements for goods and services, with associated measurements and test methods for conformity; and
- Unique, cutting-edge user facilities that support innovation in materials science, nanotechnology discovery and fabrication, and other emerging technology areas through the NIST Center for Neutron Research, which provides world-class neutron measurement capabilities to the U.S. research community, and the NIST Center for Nanoscale Science and Technology, which supports the U.S. nanotechnology enterprise from discovery to production by providing access to world-class nanoscale measurement and fabrication methods and technology.

Driving Innovation through Measurement

NIST creates the infrastructure necessary to measure the performance and quality of products and services. In close cooperation with industry, academia, and other federal agencies, NIST continually advances measurement science, develops standard protocols and test methods, and evaluates and generates data. These critical tools, which the private sector cannot provide due to the high cost and unique skills needed, are the foundations for interoperability between products and systems, enabling global trade.

Industry relies on NIST for the physical measurements and standards needed to enable advanced manufacturing, to develop and test new materials, to enable innovation, and to ensure compliance with regulations. NIST measurement research facilitates the diffusion of precision metrology into industry in a number of ways. Frequently, NIST researchers will develop next-generation measurement techniques that are adopted by industry and integrated into commercially available devices, including scanned probe microscopes, mass spectrometers, and other high precision devices.

In addition, NIST provides measurement and calibration services via its Standard Reference Materials®, calibration services, and Standard Reference Data programs. Standard materials are sold to industry, academia, and government to assure the accuracy of measurements made daily throughout the United States. NIST calibration services enable customers to achieve the highest measurement quality and productivity. NIST Standard Reference Data are well-documented numeric data used in technical problem-solving, research, and development. Looking to the future, NIST is working to develop a suite of portable, highly-precise devices that could provide customers with in-place precision measurements to keep pace with ever-accelerating product development cycles. These chip-scale devices could be directly integrated into equipment and products to provide continuous quality control and assurance, freeing manufacturers and customers from complex measurement traceability chains and lengthy calibration procedures

Accelerating the adoption and deployment of advanced technology solutions

Technology is rapidly evolving to integrate new capabilities across the economy, including manufacturing processes, transportation systems, critical infrastructure, and healthcare. While these innovations will contribute to the U.S. economy and quality of life, they have associated challenges in interoperability, security, and resiliency. NIST programs respond to these challenges by employing its expertise in measurements and standards and experience supporting industry to accelerate the transition from world-class basic research to applied solutions. These efforts include developing standards, prototypes, and guidelines that are essential for the adoption and dissemination of new technologies through engagement with government and industry stakeholders. In addition, NIST provides test-beds, testing and validation methodologies, and support for certification to support technology deployment in areas such as smart grid, cybersecurity, cloud computing, cyber-physical systems, and smart manufacturing, to name a few.

NIST's involvement in the smart grid is a prime example of how NIST combines its core research capability with extensive stakeholder engagement to drive technology adoption. The smart grid is a planned nationwide network that uses information technology to deliver electricity efficiently, reliably, and securely. As outlined in the Energy Independence and Security Act of 2007 (Pub. L. 110-140, 121 Stat. 1492), NIST has "primary responsibility to coordinate development of a framework that includes protocols and model standards for information management to achieve interoperability of smart grid devices and systems." NIST initiated the Smart Grid Interoperability Panel (SGIP) to support NIST in coordinating standards development for the smart grid. The SGIP is a public-private partnership that defines requirements for essential communication protocols and other common specifications and coordinates development of these standards, enabling NIST to solicit input and cooperation from private and public sector stakeholders in developing the smart grid standards framework.

World class, unique, cutting-edge research facilities

Industry, academia, and other government agencies have access to unique NIST user facilities that support innovation in materials science, nanotechnology, and other emerging technology areas. The NIST Center for Neutron Research (NCNR) provides world-class neutron measurement capabilities to the U.S. research community, and the NIST Center for Nanoscale Science and Technology (CNST) supports the U.S. nanotechnology enterprise from discovery to production by providing access to world-class nanoscale measurement and fabrication methods and technology. The customer-focused mission of both NCNR and CNST includes the development and application of entirely new measurement and fabrication techniques while ensuring safe and reliable facility operations.

2.2.2 NIST Innovation and Industry Services (IIS)

In support of the Administration's emphasis on serving industry through outreach services, NIST provides two important externally-focused services: The Hollings Manufacturing Extension Partnership (MEP) and the Baldrige Performance Excellence Program (BPEP).

BPEP provides criteria for organizational performance self-assessment and serves as a resource to improve U.S. innovation, entrepreneurship, and competitiveness in businesses/industry, education, health care, and government and other public benefit organizations. BPEP is responsible for managing the Malcolm Baldrige Quality Improvement Act of 1987 (Public Law 100-107), in cooperation with senior U.S. business, education, health care, and nonprofit leaders. The Baldrige Foundation, the private non-profit organization that has supported BPEP for over 20 years with the contributions of the private sector, has agreed to support operations of the Baldrige Program through 2015, while key program partners explore alternative business and funding models to sustain the mission of BPEP in the future.

NIST's MEP provides technical and business assistance to smaller manufacturers through grant-supported partnerships between Federal and state governments and non-profit organizations in all 50 states and Puerto Rico. Field agents and programs in 60 centers nationwide help manufacturers understand, adopt, and apply new technologies and business practices, resulting in increased productivity, better performance, cost savings, waste reduction, and creation and retention of manufacturing jobs. MEP also acts as a strategic advisor to promote business growth and innovation and to connect manufacturers to public and private resources essential for expanding into new markets, developing efficient processes, and training an advanced workforce. To enable future profitable manufacturing growth, the long-term focus of NIST's MEP Program will be on encouraging cultures of continuous improvement, accelerating the adoption of new technology to build business growth, responding to evolving supply chains, implementing environmentally sustainable processes, and establishing and enabling a strong workforce.

FY 2013–15 Priority Update: Technology Transfer and Commercialization

Technology transfer is the overall process by which NIST knowledge, facilities and capabilities in measurement science, standards and technology promote U.S. innovation and industrial competitiveness. This broad approach to technology transfer helps focus our programs on outcomes and economic benefits in addition to advancing measurement science.

In response to the October 2011 Presidential Memorandum - "Accelerating Technology Transfer and Commercialization of Federal Research in Support of High-Growth Businesses" and commitments in the NIST Programmatic Plan, NIST created a senior-level committee to review our policies and processes and create an implementation plan to strengthen our approach. Our progress over the past year has included:

- Broadening the NIST definition of technology transfer to address the full range of options available to transfer results and further collaboration
- Revising intellectual property policies to better support U.S. economic growth and introducing licensing programs to facilitate transfer to small businesses
- Streamlining the language in partnership agreements and reducing the time for review
- Reducing the burden on small businesses in our SBIR process and accelerating the time to award
- Creating a more robust set of metrics to measure progress

In addition to improvements in our internal policies, NIST continues to lead the coordination of interagency efforts to improve government-wide technology transfer.

3 The NIST Strategic Framework

To most effectively accomplish its mission, NIST must be capable, relevant, and effective. This means that NIST must be forward-looking in order to build and maintain world-leading scientific capacity in the technology areas that will shape future industries, while at the same time having the situational awareness and flexibility to build programs that apply NIST's technical capabilities to the Nation's most immediate needs. In addition, NIST must continue to strengthen and improve the internal processes necessary to accomplish its mission with the greatest efficiency and effectiveness possible.

To accomplish this, NIST views the possible landscape of activities through the lens of its mission. Through a variety of mechanisms including meetings, workshops, industry visits, objective peer review of its programs, NIST continually collects information on major national issues, shifting trends in science and technology, and the performance of key operational processes. This input is then used to make decisions on where NIST needs to develop specific capabilities, how best to marshal existing resources to address current issues effectively, and how to continually optimize the organization for improved performance.

Figure 2 NIST Strategic Framework

This document introduces the first two strategic perspectives: National Priorities and Long-Term Trends, summarizing NIST activities in areas of current national priority and highlighting where NIST needs to build capacity in the future. The challenges and technology needs enumerated in this plan represent many of the areas important to NIST; however, they may not be fully comprehensive and are subject to continual reassessment.

3.1 Addressing National Priorities

To maximize the value and usefulness of NIST programs, we must apply our technological expertise to those areas critical to U.S. competitiveness and quality of life. By focusing our investments on priority areas including energy, health care, manufacturing, infrastructure, cyber-physical systems, and advanced communications, NIST can be responsive to administration and national priorities. These areas, which have been emphasized by Congress, the Administration, and the President's Council of Advisors on Science and Technology, were selected based on alignment with NIST mission.

3.1.1 Manufacturing

Manufacturing has long been the Nation's economic engine, providing quality jobs to millions of Americans. By themselves, the Nation's manufacturers would rank among the world's 12 largest economies, thanks in large part to the sector's nearly 11 million employees. Though it has one of the most productive manufacturing workforces ever, U.S. industry faces relentless competition that has trimmed the Nation's share of global manufacturing output from 26 percent in 2000 to about 22 percent in 2010.[1]

Our more than 300,000 manufacturing plants must respond quickly and effectively to an ever-changing mix of requirements, risks, and opportunities, from changing energy costs to emerging technologies to competition from global markets. Domestic manufacturing is integral to the innovation cycle, supporting two-thirds of private sector R&D and providing immediate feedback to researchers.

Revitalizing the Nation's manufacturing industries and helping to ensure that they will continue to be engines of innovation and job creation is essential for U.S. competitiveness in an increasingly global economy. To continue to compete in manufacturing, the U.S. must develop and adopt advanced, high-value manufacturing techniques, from modeling and simulation methods that accelerate the deployment of new materials and complex processing routes to environmentally-sustainable practices that save energy and preserve critical resources. Rejuvenating U.S. manufacturing will require the development of measurements that support new, advanced manufacturing techniques.

NIST is strengthening its efforts in Advanced Manufacturing to support the competitive advantage that U.S. manufacturers are poised to hold, as a result of U.S. excellence in areas such as biotechnology, nanotechnology, materials science, cybersecurity, and precision measurement. In an effort to serve its mission to enhance U.S. competitiveness, NIST has a number of activities supporting advanced manufacturing (see box).

[1] World Bank. (2011). "Manufacturing, value added (constant 2000 US$)." *Data of World Bank*. Washington, DC: World Bank.

FY 2013–2015 Priority Update: NIST Advanced Manufacturing Portfolio

Advanced manufacturing is fundamental to our economic strength and national security: it can create high-quality jobs, is an important source of exports, and is a key source of technological innovation. Manufacturing is at the heart of what NIST does. Recognizing this, the NIST 3-Year Programmatic Plan for FY 2013–2015 identified strengthening U.S. advanced manufacturing capabilities as a strategic priority. Through FY2012 and FY2013, NIST has improved its support for advanced manufacturing through a portfolio of programs that spans the spectrum from cutting edge research to services provided directly to manufacturers.

- Research at **the NIST laboratories** develops and delivers measurement science tools that support advanced manufacturing technologies, including materials modeling and simulation, nanomanufacturing, biomanufacturing, smart manufacturing, robotics, and other enabling technologies. Measurement science and standards services developed at NIST provide the basic and applied research underpinnings to support advances in manufacturing. NIST provides the enabling interoperability standards and tools to allow manufacturers and researchers to lower costs and accelerate innovation. Unique, cutting edge user facilities support innovation in materials development and deployment, nanotechnology discovery and fabrication, and other emerging technology areas.
- **The Hollings Manufacturing Extension Partnership (MEP)** is supporting technologies and practices that increase the competitiveness and resilience of our nation's small and medium manufacturing base. A federal-state-local partnership, MEP is enabling future growth with a long-term focus on encouraging cultures of continuous improvement, accelerating the adoption of new technology to build business growth, responding to evolving supply chains, implementing environmentally sustainable processes, and supporting a strong workforce.
- **The Malcolm Baldrige National Quality Program** promotes excellence in organizational performance; recognizes the quality achievements of U.S. manufacturers, small businesses, and other types of organizations; and publicizes successful performance management strategies.
- **The Advanced Manufacturing National Program Office (AMNPO)** serves as the central point of contact for Federal activities and will strengthen strategic coordination among Federal agencies including NIST, NASA, DOD, NSF, and DOE.

Proposed and newly enacted programs specifically focused on supporting advanced manufacturing fill much needed gaps in the U.S. research infrastructure.

- The proposed **National Network of Manufacturing Innovation (NNMI)** is envisioned as a nationwide network of up to 15 Institutes for Manufacturing Innovation to provide the R&D infrastructure needed to support a robust advanced manufacturing sector by filling a critical gap in the U.S. innovation pipeline.
- **Advanced Manufacturing Technology Consortia program (AMTech)** established in FY 2013 will provide funding to establish industry-led consortia to create technology roadmaps to identify and tackle long-term R&D challenges shared by industry.

3.1.2 Cybersecurity

Information technology, especially the ubiquity of mobile computing and the internet, is revolutionizing all areas of the Nation's economy, enabling new products, new business models, and entirely new industries. Each of the national challenges identified for NIST focus will be transformed by this rapid evolution of technology. For example, by linking information technologies with the electric power grid, the smart grid promises many benefits, including increased energy efficiency, reduced carbon emissions, and improved power reliability. Another example is the incorporation of information technology into health care. By making medical information accessible for health care providers without loss or corruption of information and providing instant access to medical histories at the point of care, there

FY 2013–15 Priority Update: Cybersecurity

NIST is a recognized world leader in cybersecurity, with a track record of accelerating the development and deployment of cybersecurity solutions and standards that are reliable, usable, interoperable, and secure, as well as the measurements and standards infrastructure for emerging cybersecurity applications. Recognizing the importance of NIST's leadership in cybersecurity to the competitiveness of the nation, the NIST 3-Year Programmatic Plan for FY 2013–2015 identified advancing the state of the art in cybersecurity solutions as a strategic priority. Over the past year, NIST has taken significant steps to address the Nation's cybersecurity needs.

- The National Cybersecurity Center of Excellence (NCCoE) will encourage the rapid adoption of advanced security technology by bridging the gap between the public and private sectors and provide U.S. companies and government agencies with technical resources for developing, evaluating, and transferring the technology needed to secure their intellectual proper and data. In FY2012, the NCCoE completed several steps towards becoming operational, including the establishment of temporary laboratory and office facilities at the University of Maryland's Institute for Bioscience and Biotechnology (IBBR). The Center identified initial use cases in the areas of healthcare technology and manufacturing and began establishing key partnership with industry to forward the development of solutions in these areas.
- NIST supports the Administration's National Strategy for Trusted Identities in Cyberspace (NSTIC) initiative by facilitating the creation of an Identity Ecosystem that gives participants access to secure credentials and increases the opportunities for trusted on-line transactions. On September 20th, 2012, the NSTIC National Program Office at NIST awarded more than $9 million for five pilot projects in support of the Identity Ecosystem, and anticipates awarding grants for additional pilot programs through FY2016.

Furthermore, the February 13, 2013, Executive Order "Improving Critical Infrastructure Cybersecurity" (E.O. 13636) directs NIST to work with stakeholders to develop a voluntary cybersecurity framework, a set of voluntary standards and best practices to guide industry in reducing cyber risks to the networks and computers that support critical infrastructure vital to the Nation's economy, security and daily life. NIST is taking immediate steps to establish this cybersecurity framework. This NIST-coordinated and industry-led Framework will leverage existing consensus standards, practices, and procedures that have been effective and that can be adopted by industry to protect its digital information and infrastructure from the full range of cybersecurity threats. The prioritized, flexible, repeatable, and cost-effective approach of the framework will help owners and operators of critical infrastructure to manage cybersecurity-related risk while protecting business confidentiality, individual privacy and civil liberties.

will be fewer errors and redundant tests; more efficient and effective reporting, surveillance, and quality monitoring; and quicker detection of adverse drug reactions and epidemics.

However, the increased ability to access information remotely comes with significant concerns over the security of that information. For Information Technology (IT) systems that enable remote operation and modification of physical systems, from power production to manufacturing lines, vulnerabilities in those systems might allow an attacker to penetrate a network, gain access to command and control software, and cause substantial damage. Where the IT system simply incorporates data availability, vulnerabilities in security could present privacy concerns. NIST will apply its security research and standards expertise and proven ability for industry collaboration to enable organizations to improve the efficiency and effectiveness of their cybersecurity trusted credential practices thereby working towards the Administration's mandate to significantly improve the security and interoperability of our Nation's cyberspace infrastructure.

3.1.3 Advanced Communications

Broadband communications networks have become as essential to today's economy as the electrical power grid was to the Industrial Revolution. To compete effectively in this global business environment, communities and companies will need high speed, reliable and secure access to huge amounts of data, available anytime, anywhere. However, the U.S. lacks the technology to ensure adequate capacity to achieve a large-scale network capable of this vision. This network will need to seamlessly integrate wireless and land-based communication technology, and it will rely on revolutionary advances in network architecture. Today's networks are already showing signs of strain.

Services are striving to address the rapid increase in demand, but new technologies and approaches are needed. Considering the many new fields where reliable, efficient, secure, and low-cost networks are critical, such as medicine (e.g., Electronic Healthcare Records and telemedicine), sensor and control networks (e.g., smart grid and environmental monitoring), and information systems (e.g., cloud computing and big data analysis), incremental advances in broadband technology or network capacity will be not be sufficient to meet the future needs of a hyperconnected world. NIST's modeling, measurement science, and experience convening stakeholders to develop common standards and frameworks will enable significant innovation in communications in both the commercial and public safety sectors.

3.1.4 Cyber-Physical Systems

Cyber-Physical Systems (CPS) are hybrid networked cyber and engineered physical elements co-designed to create adaptive and predictive systems that respond in real-time to enhance performance with varying degrees of human interaction. This incorporation of networking and information technology in physical structures and systems presents an opportunity to increase efficiencies across the economy. A number of related concepts come together within a common CPS umbrella, including Industrial Internet, Smarter Planet, Sustainable Cities, Smart Systems, Machine to Machine, and Internet of Things.

Interoperability and cybersecurity standards are key enablers to realize integrated platform architectures for CPS across multiple business sectors and across multiple production, product, system, and system of system platforms. Historically, architectures and standards for communication-centric interoperability, networked industrial control systems, and data-centric analytics have been developed independently and differently. The architectures, standards, and measurement science foundations for CPS will need to address its multitude of unique performance requirements. Robust assessment tools are essential to harmonize the platform architectures and standards for CPS.

CPS makes pervasive use of networked sensors, processors, and actuators that sense and interact with the physical world (including the human users) and employs physics-based computational models and data analysis to optimize real-time operation. At the same time, the effective integration of the cyber with the physical poses a substantial engineering challenge. Dramatic improvements in systems engineering, integration, and testing processes for CPS are needed to meet safety, security, reliability, and performance requirements. NIST has deep expertise in a number of CPS domains and is uniquely positioned to advance CPS through measurement science.

3.1.5 Health Care

Across the health care system—from basic research for the disease diagnosis to the management of patients' records—greater availability of accurate measurement tools and standards can contribute to reducing health care costs and accelerate the application of new discoveries to prevention and treatment. The convergence of advances in biotechnology and information technology is creating opportunities to revolutionize health care from prevention to diagnosis, treatment, and rehabilitation. Prospects for personalized medicine are rapidly beginning to take shape. Knowledge that each person's health status is defined by a unique combination of genetic, environmental, and clinical influences eventually will lead to health-preserving and disease-countering tools custom-tailored to individuals. This approach will require new measurement tools and standards in the areas of medical imaging, advanced biological measurements, and bioinformatics. It will require accurate, reliable measurements at every level of biological detail, from identification of each of the hundreds of proteins in a droplet of blood to whole-body measurements. NIST collaborates extensively with other Federal and private organizations to provide the new measurements and standards methods, tools, and data needed to advance biosciences and health research.

3.1.6 Forensic Science

Forensic science is an essential tool in the enforcement of Federal, State, and Tribal criminal laws and the administration of justice. Techniques used by forensic scientists often serve as the keystone for criminal, atrocity, and homeland security investigations, civil litigation, and mass disaster victim identification. Indeed, forensic science uses cutting edge scientific technology and expertise to discover, expose, and explain physical evidence that identifies culpability, holds criminals accountable, exonerates the innocent, and protects the public from further harm.

The current scientific measurement basis and the state of standardization of forensic science are widely acknowledged as needing significant improvement. Forensic science is intended to provide the justice system with nonbiased, independent scientific evidence analysis and expert testimony: aiding police in catching criminals; understanding crime scenes; identifying suspects; and helping to correctly ascertain guilt or innocence. However, the reliability and scientific validity of forensic science has been called into question, with a number of critical issues identified by scientific and legal communities.

NIST is perfectly positioned to provide measurement science support to the forensic science community through the research and development of traceable standard materials, reference data, and calibration systems. The NIST laboratories have partnerships with professional associations, standards developing organizations, government, industry, and academia, which will enable NIST to strengthen and expand efforts to advance measurement quality for forensic science. The NIST laboratories have complementary expertise that will further enable research to characterize and improve the accuracy and efficacy of many forensic approaches, aiding practitioners by providing tools for crime scene investigation, laboratory analysis, and court room use of this evidence.

3.1.7 Disaster Resilience

U.S. communities can and do suffer catastrophic loss, due to extreme events such as hurricanes, tornadoes, wildfires, earthquakes, and flooding. A large percentage of the Nation's buildings and infrastructure is concentrated in disaster-prone regions. Despite significant progress in disaster-related science and technology, natural and technological disasters in the United States are responsible for an estimated $55 billion in average annual costs in terms of lives lost, disruption of commerce and financial networks, properties destroyed, and the cost of mobilizing emergency response personnel and equipment. As costs continue to rise, there is increasing recognition of the need to move from response and recovery to proactively identifying hazards that pose threats and taking action to reduce the potential impacts. Whether hazards become disasters depends upon the disaster resilience of our structures and communities. This, in turn, depends upon the capacity to prepare for and mitigate the impacts of hazards, preventing them from becoming disasters. Critically needed metrics, tools, and standards to ensure community-level resilience do not exist to enable communities to recover rapidly from these disasters with minimal loss of life, minimal damage to buildings and infrastructure lifelines, and minimal business disruption.

NIST will provide Federal leadership to convene the highly diverse stakeholder interests (planners, designers, contractors, state and local officials, standards development organizations, code organizations, industry organizations, professional organizations, and other agencies) across all infrastructure sectors to develop and adopt a national resilience framework and associated model resilience standards and policies. NIST is well-positioned to contribute to the Nation’s resilience to disaster both through its mission of promoting U.S. innovation and competitiveness by anticipating and meeting the measurement science, standards, and technology needs of U.S. industries, as well as its core competencies in performance of buildings and infrastructure under extreme loads.

3.2 Optimizing Capabilities for Long-Term Trends

NIST is committed to helping the U.S. maintain its leadership in technology and innovation. To be prepared to support U.S. competitiveness in the future, NIST optimizes its capacity based on long-term technology trends. Due to the rapid pace of technological change, NIST constantly reevaluates the alignment between its portfolio of research and technical expertise and the larger innovation landscape. Through workshops, conferences, and planning exercises, NIST has identified a set of emerging issues and technology trends that will significantly impact multiple areas of the economy in the coming decades. These issues currently include biotechnology, modeling and simulation, cybersecurity, big data, systems engineering, and in-place precision measurement. Over the coming years, NIST will be taking steps to build capabilities in each of these areas. A selection of planned efforts in each of these areas is highlighted below.

3.2.1 Biotechnology

Historically of central importance to medicine and health care, biotechnology's influence is now also spreading to other areas of the economy. From using biological systems as inspiration for improved design and engineering to integrating biological organisms into manufacturing processes, the Nation's economy and quality of life have much to gain from innovations in biotechnology. In particular, synthetic biology seeks to create a new manufacturing paradigm using cells as foundries to create new products including new fuels, pharmaceuticals, specialty chemicals, and advanced materials. NIST's expertise in measurement science will be critical to the growth and sustainability of this burgeoning industry.

The innate variability of biological systems presents a challenge for manufacturing, which traditionally requires high degrees of reproducibility. Fundamental measurement science will help these industries identify and manage this variability. NIST is well-positioned to support the development of biologically-based manufacturing of products, with research activities that include:

- A partnership with the Department of Energy National Renewable Energy Lab will determine the thermodynamic properties of the various forms of cellulose for biofuels.
- The creation of well characterized cellulose samples that will enable accurate measurements of the heat capacity and heat of combustion on these samples needed to realize the potential of this class of materials as renewable fuels.
- Programs in high field NMR, mass spectrometry, and sequencing to understand the exact chemical composition of protein biologic drugs.
- Development of reference methods and materials to assess post translational modifications of protein products (such as antibodies used for cancer therapy).
- Development of reliable cell line identification techniques, based upon the same technology as human forensic testing, to provide unambiguous identification of the cell strain used to generate protein therapeutic drugs to improve the consistency of the manufacturing process.
- Development of Reference Materials that mimic the range, size disparity, and optical properties of protein particles and establishment of methods quantitatively measuring the size and concentration of protein particulates that can hamper the efficacy of biologic drugs.
- Development of measurement methods to gauge the efficacy and enable the controlled use of biocatalysts for the production of polymer materials.
- Development of measurements to assess the reliability of bio-based nanocomposites.

In addition, NIST houses unique facilities that can enable innovation in biotechnology. The NCNR's cold neutron source is well-suited to probe the structure and dynamics of biological samples. Since neutrons are sensitive to the positions of the light elements that are of central importance to all biological systems, neutron scattering can provide unique information on the structure and function of biological macromolecules. Moreover the Biomolecular Labeling Laboratory (BL^2), a collaboration between NIST and the University of Maryland, permits tagging of large molecules with different isotopes making them easier to analyze using neutron scattering, nuclear magnetic resonance, and mass spectroscopy. The BL^2 facility should interest drug manufacturers who need details about the structure and behavior of protein molecules that could become new medicines. In addition, many of the cutting-edge techniques to manipulate and characterize materials at the nanoscale available at the CNST can be exploited for research in biological systems.

3.2.2 Modeling and Simulation

Advancements in computing have created new opportunities for modeling and simulation to replace or support physical experiments and design cycles. As processors get faster and less expensive, these techniques become accessible to smaller businesses at the same time that they tackle larger and more complex problems. Modeling and simulation will permeate the vast majority of NIST's activities—from supporting the development of world-class measurement techniques to developing verified and validated models for industry use.

NIST is centrally positioned in the interagency Materials Genome Initiative, which has the goal of significantly reducing the time from discovery to commercial deployment of new materials through modeling and simulation. Similarly, NIST is participating in the interagency Nanotechnology Signature Initiative to create a nanotechnology knowledge infrastructure. Through considerable interactions with industry and academia, NIST will develop and deploy a desperately-needed data infrastructure, including data assessment and validation, data standards, and modeling and simulation tools.

Models and simulation enable the development and deployment of technologies across the economy. Models are critical to designing and operating the power grid at maximum efficiency and reliability. Modeling and simulation allows manufacturers to bypass prototype construction for many types of testing, which dramatically reduces the cost and time to new product design. Among NIST's planned activities incorporating modeling and simulation into technology development and deployment are:

- Development of measurement methods that are tightly integrated with multi-scale models for simulating materials growth, structure, optical and electronic properties, and device performance.
- Creating web-based repositories of modeling and simulation results, standard reference problems and critically evaluated datasets and associated models for use by the materials design community.
- Creating and disseminating tools to integrate predictive multi-scale, multi-disciplinary models and simulations with material properties of reference data.
- Development of measurement standards and protocols for improving the reliability of current and next generation imaging tools.
- Development of models in support of accelerated lifetime and reliability testing of thin films, concentrating PV, and quantum-scale technology.
- Development of modeling and simulation tools for accelerating the transition to "beyond-CMOS" devices.

- Development of models allowing the optimization of nanostructures to improve the efficiency of energy conversion and storage devices.
- Evaluating 3D protein structure modeling, molecular dynamics protocols, and molecular trajectories as surrogates for protein structure, dynamics, and interactions in neurological diseases.

3.2.3 Big Data

Data collected and analyzed from multiple sources like scientific experiments, sensors & instruments, environmental measurements, medical imaging, smart systems such as smart grid and cyber-physical systems, network measurements for cybersecurity, and financial transactions are increasing rapidly in volume and complexity and is creating a transformational shift in our understanding of the universe around us. The persistent presence of data and wide-range impact of the information contained in the data has led to the emergence of a new field called Big Data. Big Data refers to data volume, velocity (data flow rate), and/or variety (complexity) that exceed the capacity or capability to capture, store, collate/combine, analyze, scale, manage, maintain, curate, compress, and/or deliver using available approaches and systems. Big Data is an area that has impacted many segments of the global and U.S. economy. The development of standards and metrics will provide access to the often-hidden information in Big Data and allow for fusion with new and evolving data sources. NIST's expertise convening stakeholders and developing frameworks, standards, and metrics will be invaluable to exploiting the flood of data now available. NIST's activities in the area of Big Data may include:

- Developing a common framework, common definitions, and reference architectures to support and accelerate the use of Big Data tools, technology, measurements, and standards.
- Methods to validate immense sets of domain-specific material, including the chemical and biological data needed by industry to reliably design advanced materials and manufacturing processes.
- Developing tools to facilitate data sharing and extraction of knowledge.
- Promoting interoperability and portability of big data solutions.
- Creating standards, guidelines, best practices, reference materials, metrology test beds, and challenge problems to enable reliability, security, and privacy-protection that will facilitate innovative big data solutions for storage, analytics, knowledge extraction, fusion/integration, usability, and visualization.
- Help to develop/promote best of breed correlation tools and methods to align and map data, both structured and unstructured, from diverse information sources.
- Provide a way to establish uniqueness of individuals, devices, organizations, and events (collectively entities) across large data sets to provide the basis for pattern and use analysis.

3.2.4 Systems Engineering

Economic growth, national security, industrial competitiveness, and quality of life increasingly depend on large, complex systems that use new and innovative technologies, must meet stringent performance, cost, and schedule requirements, and must operate in a trustworthy and fail-safe manner throughout their service lives. Examples of large-scale complex systems are found in every sphere of human endeavor from commercial airliners and weapons systems to the power grid and the Internet.

The trend towards increased system scale and complexity is expected to accelerate rapidly in coming decades. Without properly anticipating and planning for these trends, the development and deployment of future systems could become cost-prohibitive. It also could become difficult, if not impossible, to assure and certify reliable in-service performance of future systems.

The current state-of-the-art of systems engineering is inadequate to provide the scientific foundations needed to develop the systems of the future. These systems will be more autonomous, with greater awareness of their operating norms and variations; more complex in scale, composition, capabilities, networks, and interfaces resulting in unexpected emergent behaviors; composed as a system of systems that each may be designed, built, and operated—independently or as part of the whole system—to meet differing sets of objectives and that also may grow organically over time in scale, complexity, and functionality; and have profound interactions with humans. The science for architecting, designing, analyzing, building, verifying, validating, certifying, commissioning, operating, and maintaining such large-scale complex systems does not exist.

To address the engineering challenges inherent in developing and deploying large-scale complex and to position the U.S. as a world leader in systems engineering, NIST will build new measurement science capability in the following areas:

- Development of metrics, tools, and standards to measure system complexity and the potential for emergent behaviors.
- Development of metrics, tools, and standards to measure scientifically provable composability (such as modularity and state independence) of complex system components and compositionality (can the system as a whole be characterized by characterizing its components and how those components are combined) of the large complex system itself to meet performance requirements; standardization of reference architectures based on such scientific developments in select cases.
- Development of non-conventional mathematical models, tools, and performance metrics to measure, predict, optimally control, quantify uncertainty in, and assure/certify the dynamic performance of large complex systems which are both adaptive and evolving.
- Scientific metrics, tools, and standards to measure the effectiveness and efficiency of the process of designing, building, and integrating large complex systems that combine networks of open and closed subsystems and components.

3.2.5 In-place Precision Measurement

Ever-accelerating product development cycles will benefit from in-place precision measurements directly integrated into equipment and products to provide continuous quality control and assurance, freeing customers from complex measurement traceability chains and lengthy calibration procedures. Such in-place measurement techniques will use quantum physics research methods, including the interaction between atoms and electromagnetic fields, to achieve fundamental advances in measurement science relevant to industry and the technical community. With these technologies, every manufacturing process could be continually referenced to precision standards; every airliner could have continual traceable measurements of electrical quantities, pressure, and temperature to improve efficiency and safety; and every air traffic control radar system could be continually calibrated. Almost any major product or process benefitting from precision physical measurements could employ built-in intrinsic calibration technology.

Providing such “NIST-on-a-Chip” technology would extend NIST’s initial success with devices such as ultraminiature atomic clocks, magnetometers and other devices to a broad range of measurements: electrical quantities, temperature, time, magnetic fields, motion, acceleration, force, gravity, and many other physical measurements. This program leverages NIST’s world-leading strengths in quantum-based measurements and in the science and technology of microfabrication, as well as, NIST’s experience convening university and industry partners. NIST activities in support of in-place precision measurement include:

- Developing chip-scale technologies for precision measurements of electrical quantities, temperature, force, motion, acceleration, gravity, and other quantities.
- Partnering with university and industry researchers to develop new ultraminiature measurement technologies.
- Partnering with university and industry researchers to develop new ways of integrating multiple precision measurement technologies on a single small, robust, low-cost measurement platform that can be deployed almost anywhere.
- Improving technology transfer from NIST to industry for the production, distribution and implementation of in-place precision measurement technologies.