Department of Commerce

National Institute of Standards and Technology

Three-Year Programmatic Plan

FY 2011 – FY 2013

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Introduction

The America COMPETES Act outlines major roles for the Commerce Department's National Institute of Standards and Technology (NIST) in promoting national competitiveness and innovation. The Act 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 presents the NIST programmatic plan covering fiscal year (FY) 2011 through FY 2013. This document is a product of strategic programmatic planning processes at NIST, but it is not intended to serve as a strategic plan. Rather, it aims to summarize the focus and priorities of the NIST programs over this three-year period. NIST will continue to refine this plan as it works with the Administration to address national priorities.

This plan includes the following:

- An overview of NIST's mission and a description of major programs
- Information on NIST's programmatic planning
- Highlights of current major NIST efforts
- Summaries of selected NIST programs currently addressing critical national priorities

NIST: Promoting U.S. Innovation and Industrial Competitiveness

The NIST mission is to promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life. Since 1901, NIST, a non-regulatory agency, has been supplying the measurements and tools—from standardized high-precision gage blocks needed to manufacture interchangeable parts to the world's most accurate atomic clock—to help U.S. industry compete successfully through innovation. Over the last several decades, NIST has been assigned important new roles and responsibilities, including awarding competitive grants to foster development of promising, high-risk technologies; diffusing advanced technologies and business practices to smaller manufacturers; and promoting quality management methods in key sectors. Old and new, all NIST programs support the nation's vast innovation system.

As an experienced partner of industry and as the federal research agency specifically focused on promoting U.S. economic competitiveness, NIST is well positioned to help U.S. industry and government succeed. NIST carries out its mission through the NIST Laboratories and extramural programs. These are described below.

NIST Laboratories

For more than 100 years, NIST has maintained the national standards of measurement, a role that the U.S. Constitution assigns to the Federal Government to ensure fairness in the marketplace. Today, the NIST Laboratories address increasingly complex measurement challenges. For example, NIST develops measurements focusing on the very small—nanotechnology devices—and the very large—skyscrapers, develops methods for characterizing strands of DNA for forensic testing, and tests the performance of walk-through metal detectors.

NIST Mission

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

The high quality of NIST measurement science research is reflected in the award-winning work of NIST scientists and engineers for developing new measurement tools and techniques. An example of the value of this work was given in a recent National Research Council report[1], which described a NIST-developed measurement tool aimed at furthering the development of hydrogen fuel cells as "one of the most significant analytical advances in the membrane fuel cell field realized in decades."

NIST provides the U.S. with unmatched measurement capabilities, tools, and facilities. The NIST Laboratories work at the frontiers of measurement science to ensure that the U.S. system of measurements is firmly grounded on a sound scientific and technical foundation. NIST promotes the use of measurements based on the international system of units (SI). The measurement science research at NIST is useful to all science and engineering disciplines. The NIST Laboratories directly support U.S. innovation and industrial competitiveness by developing new measurement instruments and facilities to address critical barriers to innovation; disseminating validated measurement methods and protocols; providing reference data, reference materials, and calibration services to ensure that industry-performed measurements are traceable to NIST standards; and developing testing protocols and supporting laboratory accreditation programs. NIST works actively with other metrology institutes from around the world to ensure that the global marketplace is supported with sound measurements and standards.

The NIST Laboratories also support the development of written standards and specifications that define technical and performance requirements for goods and services. These standards—also known as documentary standards—are often developed collaboratively with the private sector through an open, consensus-based process. NIST scientists and engineers lend their expertise to these efforts in order to promote standards that are based on sound science and to ensure that the standards are supported by effective measurements and testing for conformity to the standards. In addition, NIST is designated under the National Technology Transfer Advancement Act (NTTAA) as the

coordinator for all federal agencies using documentary standards.

Technology Innovation Program

Launched in 2008, NIST's Technology Innovation Program (TIP) was created by Congress under the America COMPETES Act to support innovative, high-risk, high-reward research in areas of critical national need where the government has a clear interest because of the magnitude of the problems and their importance to society. The merit-based competitive program funds cost-shared[2] R&D projects by individual small or medium-sized businesses as well as joint ventures, which may include institutions of higher education, non-profit research institutes, government laboratories, and other organizations.

TIP's second competition, held in 2009, targeted proposals for physical infrastructure and manufacturing.[3] TIP awarded approximately $41 million for 12 R&D projects in manufacturing that would enable more cost-effective use of advanced materials in innovative products. With a cost share of $43 million, this represents a total R&D investment in manufacturing of $84 million over five years. New and improved materials underlie many product innovations, such as lighter and safer vehicles, higher efficiency gas turbines, higher performance aircraft, and better performing batteries. The 2009 competition addressed improved technologies to produce these advanced materials and to rapidly integrate them into products while maintaining the materials' properties.

The 2009 competition also awarded approximately $30 million for eight physical infrastructure projects in two areas. The first is innovative, cost-effective sensing technologies for non-destructive testing and monitoring of the structural health of major infrastructure components. It emphasizes technologies to detect corrosion, cracking, delamination, and other structural damage in water resources systems such as water and wastewater pipelines, dams, levees, and locks, as well as bridges and roadways. The second area is new technologies for repairing and upgrading existing structures. The emphasis is on practical technologies, including novel materials and cost-effective methods for installing them, that would provide enhanced performance or longer service life than existing materials and practices. With the additional cost share of $32 million, this represents a total potential R&D investment of $62 million over five years.

Hollings Manufacturing Extension Partnership

Through partnerships between federal and state governments and non-profit organizations, NIST's Hollings Manufacturing Extension Partnership (MEP) provides technical and business assistance to smaller manufacturers through a nationwide network in all 50 states and Puerto Rico. Field agents and programs are helping manufacturers understand, adopt, and apply new technologies and business practices, as well as reap the benefits through increased productivity, better performance, cost savings, waste reduction, and creation and retention of manufacturing jobs. MEP acts as a strategic advisor to promote business growth and innovation and to connect manufacturers to public and private resources essential for increased profitability and competitiveness in the global marketplace.

To date, MEP has completed over 400,000 customer engagements, including technical assistance projects, training programs, networking events, and long-term strategic support. In FY 2008, MEP services are estimated to have led to over $1.4 billion in cost savings and nearly $10.5 billion in new and retained sales, while also creating and retaining over 57,000 jobs.[4]

Baldrige National Quality Program

NIST's Baldrige National Quality Program (BNQP) promotes proven performance management practices to strengthen U.S. organizations. The program promotes organizational excellence through education, outreach, and an annual awards program. The Baldrige Award is given to organizations in six categories: manufacturing, service, small business, healthcare, education, and nonprofit. The recent pressures on healthcare and education cost and performance have invigorated improvement efforts in these sectors that are especially important to the nation's economic performance and the quality of life enjoyed by its citizens.

The BNQP is recognized worldwide: more than 40 states and nearly 80 countries participate in programs modeled after the BNQP.[5] The heart of the program—the Baldrige criteria—has been requested or downloaded over 10 million times, and in the view of one chief executive is "probably the single most influential document in the modern history of American business."[6]

NIST Programmatic Planning

Technological innovation drives economic growth, sustains U.S. competitiveness in the global economy, and supplies solutions to critical national needs and global challenges. According to the National Academy of Science, "economic studies conducted even before the information-technology revolution have shown that as much as 85% of measured growth in US income per capita was due to technological change."[7] NIST programs support and enhance the nation's innovative capacity, and help to promote an effective marketplace for technological innovations—new applications and capabilities—by ensuring sound, science-based measurements and standards.

With a more than century-long tradition of collaborating with industry and supplying essential measurement know-how and tools to businesses, universities, and government agencies, NIST is a proven partner strategically positioned to help the nation improve its innovation performance and address national priorities. The America COMPETES Act

recognizes that superior innovation performance has been the primary source of our nation's competitive advantage in the global economy. It also recognizes that NIST is a key component of the nation's innovation infrastructure and outlines major roles for NIST in promoting national competitiveness and innovation.

The breadth of technology in the U.S. economy results in a broad technical portfolio for NIST. The NIST programs must maintain technical leadership in measurement science, while also responding effectively to the rapid pace of technological innovation. To address this challenge, NIST has developed a multi-year planning process supporting NIST's goal of promoting economic prosperity and job creation in a technology-based economy. This goal also includes the following:

- Focus our mission, authorities, and programs for maximum impact
- Apply technology to address critical national needs
- Maximize impact through excellence, leverage, and efficiency.

The planning process involves creating and maintaining programmatic plans with discrete goals, objectives, and performance measures. The programmatic plans address critical topics within a set of investment priority areas (IPA) established by NIST to guide the development of programs and budget initiatives. The IPAs for FY 2010 are Buildings and Physical Infrastructure, Energy, Environment, Healthcare, Information Technology, and Manufacturing. These were selected based on the following criteria:

- Clearly matches NIST's mission and goals
- Addresses urgent national priorities
- Involves a compelling innovation or competitiveness issue

Programmatic planning is a continuous process. To be prepared for tomorrow's needs, NIST must understand future priorities and challenges for each IPA and identify additional IPAs that may emerge. NIST is providing opportunities for earlier and broader involvement of customers and other stakeholders. In FY 2010, NIST is initiating an external needs assessment workshop series so stakeholders can lay out external drivers and opportunities for specific technology areas. The workshops will inform NIST's strategic decision making and programmatic planning activities. The workshop series will be a vehicle for accelerating the most critical measurement solutions to support innovation and technology. The initial workshops in the series will address two key areas: Advanced Solar Energy Technologies and Climate Change.

The table below maps NIST's six IPAs for FY 2010 to selected NIST Programs. Each of the programs, which are described later in this plan, supports one or more IPAs. The table below indicates which IPA has been designated as primary for each program, as well as what other IPAs each program directly affects. The mappings are not intended to be comprehensive, but rather to indicate the strongest connections between programs and IPAs.

NIST Programs by Investment Priority Area
(✪ Primary, ✓ Secondary)

NIST Programs	NIST Investment Priority Areas					
	Buildings and Physical Infrastructure	Energy	Environment	Healthcare	Information Technology	Manufacturing
Advanced Alternative Energies		✪	✓			✓
Net-Zero Energy Buildings		✪	✓			✓
Greenhouse Gas Measurements and Climate Change			✪			✓
Sustainable Manufacturing		✓	✓			✪
Biomedical Measurements to Support Disease Diagnosis and Treatment				✪		
Nanomaterial Environmental Health and Safety			✪	✓		✓
Scalable Cybersecurity for Emerging Technologies and Threats					✪	
Infrastructure Development and Remediation	✪					
Standards for National Priority Critical Infrastructures						
Smart Grid Interoperability		✪	✓		✓	✓
Health Information Technology				✪	✓	✓

The table on the next page provides selected highlights of NIST's current and planned future efforts for the programs listed in the table above. NIST will continue to refine its plans for future years as appropriate, such as responding to emerging national priorities or major scientific and technological advances, and all items listed as examples of planned efforts for FY 2011 through FY 2013 are subject to change.

Current and Future Plans for Selected NIST Programs

Programs	FY 2010	Examples of Planned Efforts		
		FY 2011	FY 2012	FY 2013
Advanced Alternative Energies	No new funds	3rd generation photovoltaics	Solar storage/batteries	
Net-Zero Energy Buildings	Development of measurement tools and methods to enable net-zero energy buildings ($4M in FY 2010); construction of residential test facility ($2M in ARRA funding)	Building system intelligence In-situ performance measurements	Emerging building energy technologies Sustainable building materials Sustainability performance evaluation	
Greenhouse Gas Measurements and Climate Change	Measurements and standards to improve accuracy of point source GHG monitoring and to improve calibration of climate monitoring satellites ($7M in FY 2010)	Calibration testbed Optical remote GHG measurement tools	Traceable Reference Material program Source gap and flux identification	
Sustainable Manufacturing	No new funds	Alternative source materials Energy use reporting	Advanced information infrastructure	
Biomedical Measurements to Support Disease Diagnosis and Treatment	Reference materials and measurement tools to improve laboratory medicine and medical imaging ($5M in FY 2010)	Medical diagnostics Standard Reference Materials Medical imaging Characterization and manufacture of protein-based biologic drugs	Advanced medical devices	
Nanomaterial Environmental Health and Safety	No new funds	Physical and chemical characterization of nanomaterials	Transformation and fate and transport of nanomaterials	
Scalable Cybersecurity for Emerging Technologies and Threats	Support for NIST activities under the CNCI ($5.5M in FY 2010), and support upgrades and improvements to NIST's Security Content Automation Protocol ($5M in ARRA funding)	Cryptographic practices Multifactor authentication Security automation Security isolation	Network data database	Network growth modeling
Infrastructure Development and Remediation	Construction of a National Structural Fire Resistance Lab ($16M in ARRA funding)	Resilience to disasters (NEHRP and other hazards)	Condition assessment Sustainability Infrastructure delivery	
Standards for National Priority Critical Infrastructures	Smart Grid interoperability standards development and testing and validation framework ($5M in FY 2010; $15M in ARRA funding)	Power systems Building interface Industrial interface Cybersecurity Communication		
	Health information technology (IT) standards development and R&D to support testing and validation ($3.7M in FY 2010; $20M in ARRA funding)	Enhanced infrastructure definition Usability standards Telemedicine Testing infrastructure		

Programmatic Planning Priorities

With the aim of promoting U.S. innovation and industrial competitiveness, NIST has established three overarching priorities to guide and align investments in its programs:

1. Strengthen and focus NIST's Laboratories and facilities to ensure U.S. leadership in measurement science and standards.
   - Enhance support of other federal agencies in meeting U.S. Government needs for voluntary consensus standards.
   - Advance the state-of-the-art in measurement science.
   - Enhance the facilities and equipment that enable cutting-edge research.

2. Focus new NIST activities to address critical national priorities.
   - Improve energy efficiency and environmental stewardship.
   - Ensure consumer health, safety, and security.
   - Promote partnership mechanisms with industry and academia through extramural programs.

3. Expand collaboration to leverage NIST capabilities and advance innovation at regional and national levels.

The rest of this document discusses NIST's current efforts and its plans for FY 2011 through FY 2013 related to these priorities.

Strengthen and focus NIST's Laboratories and facilities to ensure U.S. leadership in measurement science and standards

The strength and vitality of the NIST Laboratories are crucial to meeting the ever more complex and demanding measurement and standards challenges associated with new technology. High-performing facilities, equipment, infrastructure, and personnel are crucial to NIST's efforts in maintaining a world-class infrastructure so that the U.S. remains the world's innovation leader.

The sections below describe three major aspects of NIST's current work in this area. First, NIST is providing leadership for other federal agencies to ensure that they have the standards and conformity assessment programs they need to support innovation and competitiveness while ensuring the protection of health, safety, the environment, and interoperability. Second, NIST is promoting measurement research that will be the sources of innovations in measurement science and technology for decades to come. Finally, NIST is enhancing its facilities and equipment, which enable cutting-edge research.

Enhance support of other federal agencies in meeting U.S. Government needs for voluntary consensus standards

Standards are critical to our Nation because they can enhance quality, safety, reliability, efficiency, and interoperability of products and services, as well as providing cost benefits. Standards have been an integral part of the mission of NIST since it was established. NIST works with two types of standards. Fundamental measurement standards, also known as physical standards, are for mass, length, time, substance, and other fundamental physical properties. The second type of standards, documentary standards, specify characteristics of products, processes, and testing. As the Nation's measurement laboratory, NIST participates in both phases of standards development: first, in the research that underpins the standards, and second, in the preparation of the standards documents themselves, typically as participants in national and international standards development organizations.[8]

The National Technology Transfer and Advancement Act (NTTAA) directs all federal agencies to use voluntary consensus standards as a means of carrying out policy objectives and activities. The goal is for federal agencies to adopt private sector standards, wherever possible, instead of creating government-unique, non-consensus standards. This reduces costs for the Federal Government and supports more widespread use of consensus standards. The NTTAA directs NIST to coordinate the use of such standards with other federal agencies, as well as state and local governments.

Because federal agencies are increasingly in need of documentary standards—in areas such as interoperability for healthcare information systems and Smart Grid devices—NIST plans to enhance its support of these agencies. NIST will leverage its knowledge of the documentary standards arena to develop approaches to accelerate the development and adoption of voluntary consensus standards. NIST will also ensure that it is fully ready to lead federal efforts to address future major standards needs, such as coordinating standards development efforts and establishing standards frameworks.

Advance the state-of-the-art in measurement science

NIST leadership in measurement science research ensures that U.S. industry and universities will have the tools they need to remain at the leading edge of innovation and to secure "first-mover advantage" in bringing new technology to market. NIST will invest in high-risk, high-payoff projects that advance the state-of-the-art in measurement science and that focus on critical measurement barriers. Examples of these efforts are described below.

Innovations in Measurement Science (IMS) Program

NIST's Innovations in Measurement Science (IMS) program funds highly innovative and creative measurement science ideas from members of the NIST Laboratories—ideas that support NIST's mission and have the potential to significantly advance NIST's measurement science capabilities.

One current research effort funded through the IMS program is addressing fundamental problems with the essential links between electrical and mechanical units from the International System of Units (SI). The calculable capacitor, a device that realizes the capacitance unit (farad) from the meter, was originally created 40 years ago after many years of research and has been used ever since. With the availability of new technologies, such as modern lasers and digital electronics, it is now possible to build the next generation of calculable capacitors with improved reliability, accessibility, and accuracy. In this project, NIST will use femtosecond laser frequency comb technology to create a new calculable capacitor that would, for the first time, realize an SI electrical unit based directly on an atomic clock. NIST's goal is for its new calculable capacitor to have measurement uncertainties roughly a factor of two lower than those of other calculable capacitors currently being developed around the world.

Quantum-Based Measurements

Our current international system of measuring time, light, mass, length, substance, temperature, and electrical units is based on our intuitive understanding of Newton's classical mechanics. But progress in building ever smaller, more efficient, and more intricate devices has placed increasing

demands on the precision of our measurement system—a system crucial for the quality control, reproducibility, product innovation, and legal metrology essential for robust, advanced manufacturing. At the same time, this progress has brought us into the quantum world—the world at the atomic scale where classical Newtonian mechanics no longer apply.

As an example, precise time and frequency measurements underpin much of modern technology, including navigation by GPS, synchronization of telecommunications networks, and advanced radars. These time and frequency measurements are based on atomic clocks that use the special properties of quantum mechanics to make the most accurate absolute measurement of any quantity, with the uncertainty for time currently approximately one second in 100 million years (3×10^{-16}).

Just as research in quantum mechanics has led to more accurate clocks, so has research on atomic clocks led to the development of new tools for exploiting quantum mechanics. For example, research on precision manipulation of the quantum mechanics of ions to make better atomic clocks led directly to research on the use of those ions for quantum computing, initiating NIST's world-class program on quantum information processing. More recently, NIST has turned the tools and techniques of quantum computing back to research on developing a new type of atomic clock with the potential to be 100 times more accurate than today's atomic clocks. Such accuracy and sensitivity are needed to meet increasing demands in navigation, telecommunication, gravity, and magnetic measurements. NIST's FY 2010 appropriations will provide an additional $3M to support research on quantum-based measurements.

Enhance the facilities and equipment that enable cutting-edge research

State-of-the-art facilities and equipment are essential to the capabilities of the NIST Laboratories. For example, NIST centers in neutron science and nanofabrication serve thousands of researchers each year from industry and universities. NIST capabilities must be maintained at the highest levels of precision and accuracy to meet the increasingly stringent needs of their users. Also, obsolete facilities and equipment reduce safety and productivity. NIST will prioritize efforts to improve and upgrade facilities and equipment to promote the capabilities and safety of the laboratories.

NIST's FY 2010 appropriation includes $80 million for construction, which will support the following facilities projects:

- $12 million for the initial renovation of Building 1 at NIST's Boulder, Colorado site, which will significantly improve productivity and enable new measurements and research to support emerging industry needs.
- $2 million to conduct an in-depth space analysis at NIST headquarters in Gaithersburg, Maryland, which is a necessary step toward systematic renovation of obsolescent facilities.
- $8 million for NIST Center for Neutron Research (NCNR) reliability improvements, which will fund construction fit-up costs associated with configuring and occupying the completed Guide Hall facility and Technical Support Buildings.
- $58 million for Safety, Capacity, Maintenance, and Major Repair (SCMMR) projects that support capacity and safety improvements as well as ongoing, recurring, and preventative maintenance and major repair of the NIST physical plant in Gaithersburg, Maryland; Boulder and Fort Collins, Colorado; and Kauai, Hawaii.

NIST has also received $180 million in American Recovery and Reinvestment Act (ARRA) direct appropriations to "address NIST's backlog of maintenance and renovation and for construction of new facilities and laboratories." Approved in May 2009, NIST's plan for these funds specifies:[9]

- $68.5 million to complete funding for a precision measurement laboratory at NIST's site in Boulder. This includes enhancements in laboratory performance and capacity; construction of a state-of-the-art clean room, essential for the most advanced research in nanotechnology, quantum information, and ultra-precise atomic clocks; and higher-performance outfitting of laboratories tailored to individual projects.
- $39 million to carry out safety, capacity, maintenance and major repair projects that enhance the performance of NIST's aging facilities.
- $16 million for energy- and water-saving support infrastructure for the NCNR Expansion Project.
- $16 million to fund the design and construction of a National Structural Fire Resistance Laboratory, a unique resource that studies how structures can be designed to resist failure in a fire—research that could save thousands of lives and billions of dollars in property damage through innovation in the design of new fire-resistant materials and structures.
- $15 million to fund the design and construction of a facility that will improve the synchronization to NIST time of tens of millions of consumer clocks, watches, and other timepieces.
- $9 million for relocation and consolidation of advanced robotics and logistics operations. A portion of these funds will support a new Robotics Facility that will be devoted to development, fabrication, and testing of robotics systems and components.
- $7.5 million to fund the construction of liquid helium recovery systems for NIST sites in Gaithersburg and Boulder. These systems help conserve an increasingly scarce resource used in low-temperature research.
- $7 million for design and construction of a consolidated Fire and Police Emergency Services Station in Gaithersburg to house the NIST police, fire, and emergency services staff in the same building. These groups are currently dispersed throughout the campus in outdated facilities.
- $2 million for a Net-Zero-Energy Residential Test Facility in Gaithersburg. This will be used to test and

measure state-of-the-art residential building components and technologies, and to develop ways to measure energy flow in a residential building as an entire interconnected system in order to meet the energy requirements of the home.

Focus new NIST activities on critical national priorities

In planning its programs and investments, NIST continually looks across a range of strategic areas important to the Nation's economy and well-being, including energy, environment, healthcare, information technology, manufacturing, and the Nation's infrastructure, targeting areas where NIST efforts in measurement science and standards can have maximal impact in solving critical problems:

- In the area of energy and the environment, NIST programs in Smart Grid, advanced alternative energies, and sustainable manufacturing are improving energy efficiency and environmental stewardship.
- NIST programs focused on healthcare, cybersecurity, and infrastructure development and remediation are critical to ensuring consumer health and safety.

In addressing the Nation's challenges, NIST works to leverage its laboratory capabilities by promoting partnership mechanisms with industry and academia through multiple extramural programs.

The material below provides more information on NIST's plans in these areas for FY 2011-2013.

Improve energy efficiency and environmental stewardship

Current NIST goals for improving energy efficiency and environmental stewardship include the following:

- Help reduce atmospheric emissions from energy production by creating measurement tools and standards needed to develop new and cleaner sources of energy and to improve energy efficiency.
- Help to establish the scientific basis for measurement and monitoring of particular substances in the environment that may negatively impact climate.
- Help improve the competitiveness of U.S. manufacturers through the development and deployment of sustainable technologies and business practices that enhance the ability to rapidly introduce product innovations.

Developing new and cleaner sources of energy while reducing atmospheric emissions from energy production is a priority of the current Administration. This goal is especially challenging, given the Nation's dependence on fossil fuels and projections that U.S. energy demand will grow 29% by 2030.[10] Recognizing this challenge, the Office of Science and Technology Policy (OSTP) and the Office of Management and Budget (OMB) included "promoting innovative energy technologies…" as one of its four science and technology priorities for the FY 2011 budget. NIST's efforts in support of this are focused on creating measurement tools and standards for developing cleaner electrical power and improving energy efficiency. Specific examples include enabling improvements to advanced alternative energy technologies and supporting standards development for Smart Grid and net-zero energy buildings.

The United States and the rest of the world face many challenges today involving the environment and how it negatively impacts the world's climate and the health of its citizens. For example, growing concerns about increased greenhouse gas concentrations in the atmosphere leading to higher global air and ocean temperatures are prompting the drafting of new legislation that would regulate the amount of man-made emissions of greenhouse gases. NIST is helping to address this problem by providing the fundamental measurement science, standards, and reference data needed to accurately quantify sources of greenhouse gases.

Another area of environmental stewardship that NIST is exploring involves manufacturing. The manufacturing sector is of vital importance to the U.S. economy. It

NIST Marine Laboratory Investigates the Cause of Coral Bleaching

Researchers from NIST and five other institutions working at the Hollings Marine Laboratory (HML) in Charleston, South Carolina are studying the metabolic activity of a pathogen shown to cause coral bleaching, a serious threat to undersea reef ecosystems worldwide. Coral bleaching is the whitening of living coral due to a disruption of its symbiosis with tiny photosynthesizing algae. The algae reside within the coral's tissues and provide the coral with up to 90% of its energy. Unfortunately, ecologically valuable coral colonies around the world are being threatened by a bacterium which can become virulent, infiltrate coral, and dislodge the algae, eventually causing the coral to die.

Environmental scientists have shown in laboratory experiments that the virulence of the bacterium is temperature dependent, raising concerns that increasing ocean temperatures may lead to greater risk of widespread coral bleaching. It has been reported that nearly 30% of the world's coral reefs—and the ecosystems they support—have already been severely degraded by bleaching.

The HML research team has been using nuclear magnetic resonance (NMR) to study metabolic changes in the bacterium related to temperature changes. An increase of just three degrees Celsius makes the bacterium virulent, and the research team discovered significant changes in the levels of three small-molecule metabolism-related components that help regulate energy production and osmotic pressure. Future studies are planned to better understand the temperature-dependent mechanism and the potential impact to the coral under changing ecological conditions.

(http://www.nist.gov/public_affairs/techbeat/tb2009_1020.htm)

contributes 12% of the Gross Domestic Product (GDP) and provides 10% of the Nation's workforce with high-paying jobs.[11] Global competition and rapidly-changing market demands are pressing U.S. manufacturers to respond more quickly and efficiently, with innovative products and processes. However, many challenges and barriers currently exist throughout the product realization lifecycle—from design to fabrication to logistics and distribution—that prevent this.

The manufacturing sector, including all buildings used for manufacturing, is the largest consumer of energy (45%)[12], the second largest consumer of mined materials (21%)[13], a major producer of solid waste (10 trillion kg per year)[14], and a significant user of hazardous materials—all of which are implicated in global environmental problems. Increasingly stringent regulatory restrictions, consumer preference for environmentally friendly products, and other factors are forcing manufacturers to pursue more sustainable processes. To address sustainability effectively, manufacturers need to measure, control, and manage sustainability in terms of economic, environmental, and societal impacts across the five major phases of a typical product's life cycle: raw material selection, product realization, distribution, customer use, and material recovery. NIST is supporting this by improving methods and standards for life cycle analysis, material recycling, and integrated design and production.

Current and planned NIST efforts targeting improved energy efficiency and environmental stewardship are focused on five programs:

- Smart Grid Interoperability
- Advanced Alternative Energies
- Net-Zero Energy Buildings
- Greenhouse Gas Measurements and Climate Change
- Sustainable Manufacturing

In FY 2010, increases for energy efficiency and environmental stewardship research are targeted at the following efforts:

- Measurements and standards to support accelerated deployment of an interoperable Smart Grid ($5M)
- Measurements for net-zero energy, high-performance green buildings ($4M)
- Greenhouse gas emissions measurements ($7M)

Future (FY 2011-2012) program areas could potentially include characterization of next generation biofuels; measurements to enable lower energy consumption devices; materials research to improve vehicle energy efficiency; advanced decision support tools and technologies that support the entire life cycle; measurement techniques to accelerate the development of highly energy-efficient green electronic devices; measurement research to enhance remote monitoring of climate change; and carbon dioxide capture and sequestration research, including development of standard reference materials and data, calibration services, and measurement tools and procedures.

Ensure consumer health, safety, and security

Current NIST goals for ensuring consumer health, safety, and security include the following:

- Help reduce the cost and increase the quality of healthcare for all Americans by supporting the establishment of a nationwide health information technology (IT) infrastructure and conducting biomedical measurement research that underlies national efforts in disease prevention, detection, and treatment.
- Establish the measurement science and technology needed to determine the health risks posed by nanomaterials and products that incorporate nanomaterials in their life cycles.
- Ensure U.S. leadership in IT by helping to develop more secure, capable, interoperable, and usable information systems.
- Support the improvement and repair or replacement of our Nation's buildings and infrastructure to increase performance and reliability, thus improving safety.

Improving the Nation's healthcare infrastructure is a key goal of the Administration, with the ultimate objective being reduced cost and improved quality of healthcare for all Americans. The elements of the Administration's healthcare policy best suited for NIST to address include reducing cost through the establishment of a nationwide health IT infrastructure, and advancing biomedical research to enable the prevention, early detection, and effective treatment of disease, with a specific focus on measurement tools that will improve and reduce the cost of medical diagnosis and therapy and contribute to technologies aimed at personalized medicine.

The expanded use of health IT is a key component of improving the cost, quality, and availability of health care in the U.S. The Healthcare Information and Management Systems Society (HIMSS) stated in April 2009 that "lives can be saved, outcomes of care improved, and costs reduced by transforming the healthcare system through the appropriate use of information technology." The Federal Government has committed to improving health IT, and NIST has been given several responsibilities under ARRA for health IT.

In the area of advanced biological research, the Administration's "A Strategy for American Innovation" proposed harnessing science and technology to address a number of "Grand Challenges", including:

- Complete DNA sequencing of every case of cancer
- Smart anti-cancer therapeutics that kill cancer cells and leave their normal neighbors untouched
- Early detection of dozens of diseases from a saliva sample
- Nanotechnology that delivers drugs precisely to the desired tissue
- Personalized medicine that enables the prescription of the right dose of the right drug for the right person

- A universal vaccine for influenza that will protect against all future strains
- Regenerative medicine that can end the agonizing wait for an organ transplant.[15]

Improved measurement capabilities are critical components to successfully meeting these challenges, and NIST is a key player in developing these capabilities.

Another emerging health concern relates to the use of nanomaterials. Nanomaterials are essential to three of the Administration's Science and Technology Priorities: driving economic growth through commercial innovation, promoting innovative energy technologies, and helping Americans live longer, healthier lives. However, the benefits of nanomaterials may never be realized due to public fears of potential hazards to human health and the environment and the reluctance of U.S. industry to invest in potentially harmful technologies. The problem is that nanomaterials and products that incorporate nanomaterials pose unknown risks throughout the stages of their life cycles to people and the environment. Science-based lifecycle risk assessment and management is required to address this problem. This, in turn, requires the development of a measurement and standards infrastructure to establish the essential linkages between physico-chemical properties, exposure, and hazards. NIST is developing the measurement science and technology necessary for identifying, understanding, and quantifying these linkages.

In addition to supporting the health of consumers, NIST is also concerned about their safety and security. A major component of that is the cyber infrastructure, which the Administration has declared a strategic asset and for which the President has established a set of high priority initiatives in the *Cyberspace Policy Review*.[16] NIST has a leading role in the Department of Commerce program of cybersecurity and privacy initiatives that support realizing the potential for ecommerce to foster innovation, bolster U.S. industrial competitiveness, and enhance our economic prosperity and security. In addition to the rapidly growing ecommerce industry (more than $200 billion in transactions in the U.S. alone for 2008), interconnected networks of computers are essential for life-critical functions such as air traffic control, factory operation, and electric power distribution. In the past decade, advances in computing and communications technologies have drastically changed the landscape for commerce and government. IT is an important engine for economic growth, and the push for its adoption in all sectors is overwhelming.

NIST is responsible for cybersecurity research, development of federal cybersecurity standards, establishment of methods and metrics for determining the effectiveness of security controls, and providing technical support to public and private sector implementation of security standards and controls. An example of how NIST is supporting advances in secure IT is conducting research and developing voluntary consensus documentary standards for cryptography practices to safeguard the confidentiality and integrity of information and systems.

Our Nation's physical infrastructure is another major source of concern regarding consumer safety. The U.S. has more than 4 million miles of roads, nearly 600,000 bridges, 5000 airports, and 120,000 miles of urban rail track. Deciding how to prioritize infrastructure investment is not a trivial matter. There are significant barriers to having consistent, objective measurements of infrastructure condition. NIST is addressing these underlying measurement science issues so that work can be better prioritized to maximize performance and return on investment.

There is also a need to more rapidly deliver resilient, sustainable, and cost-effective buildings. The basis for building codes, standards, and practices for buildings is characterized by critical technical gaps. Specifically, there is a lack of measurement science to enhance the resilience of buildings under wind, fire, and earthquake loads; to enable performance-based building codes and standards, including studying disaster and failure events to improve the safety of structures; and to overcome technical barriers hampering the use of more sustainable infrastructural materials. NIST is working on addressing these measurement science challenges.

Current and planned NIST efforts related to providing the measurement and standards framework to ensure consumer health, safety, and security are focused around five programs:

- Healthcare Information Technology
- Biomedical Measurements to Support Disease Diagnosis and Treatment
- Nanomaterial Environmental Health and Safety
- Scalable Cybersecurity for Emerging Technologies and Threats
- Infrastructure Development and Remediation

NIST's FY 2010 appropriation increases target the following efforts in this area:

- Measurement and validation protocols to support the implementation of a nationwide healthcare information infrastructure ($3.7M)
- Measurements and standards to improve the efficacy and accuracy of clinical diagnostics and medical imaging ($5M)
- Measurements and standards necessary for the development and implementation of leap-ahead security technologies for interconnected systems ($5.5M)

Future (FY 2011-2012) research areas could potentially include metrology to support the development of personalized medicine, the qualification and certification of disease biomarkers with improved medical imaging tools, and the development of biomedical interfaces, implants, and sensors being explored for use in nanomedicine; measurement science for the analysis and control of complex systems; and measurement science for enhancing

the resilience and sustainability of structures, including buildings and physical infrastructure.

In the realm of consumer health, safety, and security, NIST is monitoring and evaluating emerging research areas. Two of these, forensic science and food and water safety, are discussed below.

Forensic science is used to provide evidence for criminal and civil cases. Although forensic science is often portrayed in today's culture as being all-encompassing, the reality is that there is much research work yet to be done. This research will result in standards that provide the necessary basis by which forensic analysts provide the scientific results that meet judicial acceptability.

NIST is positioned to play an important role in addressing the challenges identified by the 2009 National Academies report titled "Strengthening Forensic Science in the United States: A Path Forward."[17] NIST can provide the measurement science and standards infrastructure to give a rigorous scientific grounding for the forensic sciences to define uncertainties and validate methods, establish standards and best practices, and develop guidelines for the accreditation of federal, state, and local organizations. NIST has already been making significant contributions to forensic science. For example, NIST has been researching computer forensics, such as the evaluation of investigative software and the identification of electronic files; conducting DNA research and creating biological standard reference materials; and studying bullet and cartridge cases, burn pattern recognition, and measurement and simulation of ignition sources.

Consumer and product safety is an issue that impacts all Americans. For example, microbial and chemical contaminants in food and water can result in illness and, in some cases, death. Episodes can cause an enormous economic and social impact, often many times the magnitude of the health impact. However, testing for food and water contaminants is done more often in response to an incident than to prevent incidents from occurring. Ongoing monitoring is essential to avert the health issues and economic impact that result from contamination, and improved incident-related measurements are needed to manage responses, assign responsibility, and identify necessary corrective actions. A possible role for NIST in addressing this challenge is to establish analytical methods, reference materials, and measurement assurance programs for detecting, identifying, and measuring the levels of harmful microorganisms, food allergens, protein toxins, nanomaterials, and other substances of particular concern in food and water safety.

NIST Analysis of Facility Collapse

On May 2, 2009, the Dallas Cowboys' fabric-covered, steel frame practice facility in Irving, Texas collapsed during a severe thunderstorm. Twelve people were injured, one seriously. Shortly after the collapse, NIST sent a team of structural engineers to assess the failed structure and wind damage in the surrounding area, and to collect relevant data such as plans, specifications, and design calculations.

Using the acquired data, NIST developed a computer model of a typical structural frame used in the facility and then studied the frame's ability to resist force under wind conditions. NIST worked with the National Oceanic and Atmospheric Administration (NOAA) National Severe Storms Laboratory to estimate the wind conditions at the time of collapse, determining that maximum gusts were estimated at 55 to 65 miles per hour, well below the national standard for wind loads.

In October 2009, NIST issued a report on its findings for public comment. "Our investigation found that the facility collapsed under a wind load that a building of this type would be expected to withstand," stated NIST study leader John Gross. "As a result of our findings, NIST is recommending that fabric-covered steel frame structures be evaluated to ensure the adequate performance of the structural framing system under design wind loads." Once the final report is published, NIST will brief and provide technical support on its recommendations to the American Society of Civil Engineers (ASCE) committee currently developing a building standard specifically for tensioned fabric structures. NIST will also brief the appropriate committee of the International Code Council (ICC) on the study's recommendation for use in improving provisions in ICC's model building code.

(www.nist.gov/public_affairs/releases/cowboys_100609.html)

Promote partnership mechanisms with industry and academia through NIST extramural programs

NIST's Technology Innovation Program, Hollings Manufacturing Extension Partnership, and Baldrige National Quality Program provide services and resources directly to researchers, manufacturers, healthcare providers, and other key stakeholders. NIST will strengthen these programs and continue to align them with national needs to increase their impact and effectiveness.

Technology Innovation Program

In December 2009, TIP announced up to $71 million in funding through for 20 new cost-sharing projects that will support innovative, high-risk research in new technologies that address critical national needs. The new projects will include developing unmanned hovering aircraft for bridge inspections, a high-speed sorting system for recycling aerospace metals, and nanomaterials for advanced batteries. The awards will be matched by other funding sources to achieve nearly $150 million in new research over the next two to five years.

"President Obama is leading an effort to drive economic growth and solve national problems by deploying a 21st Century economy," U.S. Commerce Deputy Secretary Dennis Hightower said. "These new projects will develop new technology and material that will play a critical role in modernizing infrastructure and developing the manufacturing sector across the country." More information on the funded projects can be found at http://www.nist.gov/public_affairs/releases/20091215_tip_awards.htm.

NIST is pursuing obtaining full and stable support for TIP, consistent with the FY 2011 President's request for TIP, so that it can meet its promise and impact critical national needs in areas such as energy, the environment, and healthcare where technology breakthroughs can make a significant difference. TIP is evaluating options for potential new critical national needs that might include areas such as energy, green chemistry, complex systems, or personalized medicine.

Hollings Manufacturing Extension Partnership

In FY 2010, $124.7 million was provided for MEP. These funds are helping to expand the resources of the program to provide additional services to help small- and medium-sized manufacturers prevail against unprecedented overseas competition and create and retain more U.S. manufacturing jobs.

The future of U.S. manufacturing requires an efficient production system coupled with business strategies that highlight the unique capabilities of a firm and demonstrate its advantages over competitors. This means manufacturers must master innovative product design, understand the benefits of adopting environmentally sustainable processes, invest in human and physical capital, leverage a range of financing options, realize international trade opportunities, and forecast future customer demands.

Over its 20-year history, the NIST MEP program has helped thousands of companies reinvest in themselves through process improvement and business growth initiatives leading to more sales, new markets, and the adoption of technology to deliver new products and services. MEP will continue to serve as a resource for manufacturing and innovation by expanding and leveraging resources to couple cost reduction strategies with profitable growth through new product development and market expansion.

MEP centers are focused on continuous improvement, business growth, and market diversification.

- Continuous Improvement—Performance Improvement as a Foundation for Business Growth. A culture of continuous improvement is necessary to enhance productivity and free up the capacity that will provide manufacturers a stable foundation to pursue innovation and growth. MEP centers around the country have a strong record of providing information and support that targets plant efficiencies. MEP will continue to implement productivity improvements across all aspects of the enterprise, scaled for smaller companies to readily adopt, and serving as a starting point to leverage the operational improvements into company-transforming strategies.
- Business Growth—Accelerating Manufacturing Transformation Technology Deployment & Acceleration. A key to a long term competitive position for manufacturing in the U.S. is the ability to adopt and commercialize new technologies. MEP's technology acceleration program provides an opportunity to assist companies in taking advantage of new markets for clean energy technology. The National Innovation Marketplace is one tool encouraging greater technology connection and commercialization opportunities.
- Market Diversification. Renewable energy technologies provide manufacturers opportunities in emerging, high-growth, green sectors. MEP centers across the country are conducting emerging industry research and helping companies find the resources to retool in order to position themselves in new supply chains, such as solar panels or wind turbines. Working collaboratively with the U.S. Export Assistance Centers of the International Trade Administration, MEP is also offering access to markets overseas through ExporTech. The ExporTech program conducted by the Commerce U.S. Export Assistance Centers and the NIST MEP program addresses difficulties experienced by companies that struggle overseas without adequate background knowledge of legal, cultural, and financial issues. These training sessions bring together companies with export professionals who help each company develop a personalized Export Action Plan.

Baldrige National Quality Program

NIST's Baldrige National Quality Program (BNQP) has expanded its original focus on business to include other sectors, particularly healthcare, education, and non-profit organizations. In FY 2010, the BNQP is continuing to work closely with organizations from these sectors, as well as manufacturers and service companies, to develop and disseminate proven best practices for management and operation, leading to companies that are more competitive and organizations that deliver better services. It is also taking advantage of 20 years' worth of best practice and quality-improvement data from BNQP to identify strategies and practices that are most likely to strengthen the innovation performance and competitiveness of U.S. industry and other organizations.

Applications for the 2010 Baldrige Award are due in May 2010.[18] Each eligible organization that completes an application package, including paying the appropriate fees, will gain an outside perspective on itself based on 300 to 1000 hours of review by members of the Award's Board of Examiners. The results of each review will be synthesized in a feedback report outlining strengths and opportunities for improvement based on the Award criteria. These feedback reports are often used by organizations in their strategic planning processes to focus on their customers and improve results, as well as to help energize and guide organizational improvement efforts.

As with previous competitions, during this year's competition each Award application will be scored by a team from the Board of Examiners. The higher-scoring organizations will receive site visits. A panel of judges will review the information obtained from the organizations during these site visits and recommend Award recipients. The Secretary of Commerce will make the final selection of Award recipients. Award recipients are required to share information about their exceptional performance practices with other U.S. organizations, but do not need to share proprietary information. The principal mechanisms for sharing information are the annual Quest for Excellence conference and several regional conferences.

Perhaps even more important than the Award competition and information sharing is the self-assessment and learning facilitated by use of the Baldrige criteria. In the last year alone, there have been over 2.2 million downloads of the criteria from the Baldrige web site. For example, using the Baldrige management framework, health care providers are demonstrating improved quality and reduced costs. Many are achieving some of these results through enhanced use of health IT. Four of the recent Baldrige health care recipients are among the 100 most wired hospitals/systems in the U.S.[19] In 2010, the Baldrige Program will once again be revising their criteria to keep them at "the leading edge of validated management practice," driving innovation and competitiveness of U.S. businesses and organizations.

Expand collaboration to leverage NIST capabilities and advance innovation at regional and national levels

NIST will play a significant role in marshaling the collaborative responses required to meet the national and global challenges represented by its investment priority areas: Buildings and Physical Infrastructure, Energy, Environment, Healthcare, Information Technology, and Manufacturing. Success in addressing national priorities through innovation requires integrating the contributions of many different public and private organizations. NIST has a proven track record in initiating and sustaining effective collaboration and coordination. Leveraging its reputation for impartiality and technical expertise, its international standing, and decades of experience as an effective partner, NIST can build on its cooperative relationships with other national laboratories and federal agencies, industry, academia, state and local governments, and international organizations to maximize NIST's impact.

NIST will continue to expand and strengthen its existing partnerships to enable innovation that will address the national priorities singled out in the NIST investment priority areas. NIST will focus significant resources on developing new partnerships. NIST also will expand efforts to increase access and improve the utility of two major centers that support national innovation efforts in materials science, nanotechnology, and other emerging technology areas: the NIST Center for Neutron Research, which provides neutron measurement capabilities to the U.S. research community, and the NIST Center for Nanoscale Science and Technology, which supports nanotechnology development from discovery to production. These centers are described below, along with NIST's collaborative relationship with the Nanoelectronics Research Initiative.

NIST Center for Neutron Research (NCNR)

The NIST Center for Neutron Research (NCNR) focuses on providing neutron measurement capabilities to the U.S. research community. Neutron scattering techniques, in which high intensity beams of neutrons are used as a probe to "see" the structure and dynamics of materials at the nano-scale, are some of the most powerful measurement tools available. NCNR's role is to develop and apply neutron measurement techniques to problems of national importance in many areas of science and engineering.

The NCNR is the Nation's leading neutron research facility, serving more scientists and engineers—over 2000 per year—than all other U.S. facilities combined, and the quality of NCNR research consistently ranks among the best in the world. In FY 2008, NCNR research led to 320 published articles, many of which appeared in the highest-impact scientific journals. The NCNR is widely regarded as the most cost-effective neutron facility in the U.S.

Examples of Existing NIST Collaborations

NIST collaborates extensively with universities in both research and training. Examples include several highly successful joint institutes: JILA (with the University of Colorado), the Joint Quantum Institute (with the University of Maryland), the Hollings Marine Laboratory (with NOAA's National Ocean Service, the Medical University of South Carolina, College of Charleston, and other organizations) and the Center for Advanced Research in Biotechnology (with the University of Maryland).

NIST hosts more than 2500 visiting researchers each year, and it is engaged in more than 60 Cooperative Research and Development Agreements, most with U.S. businesses and industrial organizations.

NIST scientists and engineers participate on nearly 1400 documentary standards committees representing more than 100 standards developing organizations.

Approximately one-fourth of the measurement science work underway in the NIST Laboratories involves direct collaborations with other federal agencies seeking measurement expertise and capabilities in support of their missions.

NIST Center for Nanoscale Science and Technology (CNST)

The NIST Center for Nanoscale Science and Technology (CNST) supports the development of nanotechnology through research on measurement and fabrication methods, standards, and technology, and through operation of a state-of-the-art nanofabrication and nanoscale measurement facility, the NanoFab. The CNST was established in 2007 with the goal of increasing the competitiveness of the U.S. nanotechnology enterprise. This enterprise is supported from discovery to production by the CNST's NanoFab and an agile, multidisciplinary research program. The CNST also serves as a hub linking the nanotechnology community to the comprehensive measurement expertise within all the NIST Laboratories.

The NanoFab is a national shared-use facility, accessible to all on a cost-reimbursable basis. The NanoFab provides researchers from industry, government, and academia rapid access to a comprehensive suite of tools and processes for nanofabrication and nanoscale measurement. This world-class facility is a unique national resource, combining easy access, tool and process development, and training, while providing researchers from across the nation access to NIST expertise in nanoscience and nanotechnology.

The NanoFab features a large dedicated cleanroom, with all the tools operated within a 750 square meter class 100 space, or in adjacent laboratories that have superior air

quality along with vibration, temperature, and humidity control. Over sixty tools are available for electron beam lithography, photolithography, nano-imprint lithography, metal deposition, plasma etching, chemical vapor diffusion, wet chemistry, and silicon micro/nanomachining. The facility is accessible through a straightforward application process designed to get researchers working in the facility in a few weeks.

The NanoFab is interdependent with the CNST Research Program, which develops innovative nanoscale metrology and processing capabilities accessible via collaboration with CNST scientists. Innovative capabilities are available for advancing applications in future electronics, nanofabrication and nanomanufacturing, and energy storage, transport, and conversion. CNST's mission is guided by the understanding that rapid commercial development of nanotechnology—especially the speed with which industry can bring new nanotechnology from discovery to production—depends on the availability and efficacy of applicable metrology tools and processes. Developing these tools and processes will have an immediate and significant impact on the commercial viability of nanotechnologies in a diverse array of fields, such as electronics, computation, information storage, medical diagnostics and therapeutics, and national security and defense.

Nanoelectronics Research Initiative (NRI)

The Semiconductor Research Corporation (SRC) was established to facilitate collaboratively sponsored university research, which is critical to maintain innovation related to complementary-symmetry metal oxide semiconductor (CMOS) and beyond technology. SRC has created the Nanoelectronics Research Initiative (NRI), with the mission of demonstrating novel computing devices capable of replacing the CMOS field-effect transistor (FET) as a logic switch in the 2020 timeframe. These new devices would enable the semiconductor industry to extend the historical cost and performance trends for information technology. It is also likely that the country or company that finds the next-generation technology first will dominate the nanoelectronics era.

In 2006, the first NRI research programs started. The following year, NIST joined NRI, becoming a full partner in all four NRI centers. Dozens of universities in 20 states conduct nanoelectronics research activities funded through these centers, and strong progress has already been made in some key areas.

The U.S. semiconductor industry has been highly supportive of NIST's collaboration with NRI. IBM Senior Vice President and Director of Research John E. Kelly III has stated, "There is tremendous interest in every part of the world to win the nanoelectronics race and reap the economic rewards that will go with it. For America to win, it will take radical collaboration between government, higher education and industry. The best example of this type of collaboration is the important work going on in the Nanoelectronics Research Initiative at more than 30 universities with funding and participation from NIST, IBM and other major semiconductor and research institutions."[20]

Appendix A: Current Programs for Improving Energy Efficiency and Environmental Stewardship

NIST has developed programs for its current major efforts in improving energy efficiency and environmental stewardship. Descriptions of the following programs are provided below:

- Smart Grid Interoperability
- Net-Zero Energy Buildings
- Advanced Alternative Energies
- Greenhouse Gas Measurements and Climate Change
- Sustainable Manufacturing

Smart Grid Interoperability

The Nation is modernizing its electrical power grid in order to increase the reliability and efficiency of the electrical power network, reduce energy costs, and connect distributed, renewable energy sources to the electrical power grid. This revitalized grid, the Smart Grid, will take full advantage of the latest advances in digital sensors and controls, smart power meters and secure communications network. However, incorporating these devices into the Nation's electrical generating, transmission, distribution, and management systems requires interoperability—all of these diverse systems and devices working together. According to the Energy Independence and Security Act (EISA) of 2007, Congress has given NIST the primary responsibility to coordinate the development of a standards framework for ensuring interoperability of Smart Grid devices and systems.

NIST's Smart Grid program encompasses more than coordinating the interoperability standards. By leveraging its expertise in measurement science, modeling, conformance assessment, and standards, NIST will help accelerate the implementation and improve the effectiveness and security of the Smart Grid. Especially in the key areas of power system monitoring, power meters and sensors, electromagnetic interference, communications, conformity assessment programs, and cybersecurity, NIST will play a large role in the success of the development and deployment of the Smart Grid.

The development of standards and related testing and certification procedures for the Smart Grid is a large task that will require at least five years to accomplish. The standards will also require an ongoing effort to support their evolution to incorporate experience gained through early deployment and to incorporate evolving requirements and technology. Nationwide deployment of the Smart Grid based on these standards is expected to take at least 10 to 15 years. The Smart Grid is a highly complex effort combining both power system and information and communications technologies.

NIST's Smart Grid program has already resulted in a draft Release 1.0 Interoperability Framework and Roadmap.

NIST Framework and Roadmap for Smart Grid Interoperability Standards

In September 2009, U.S. Commerce Secretary Gary Locke unveiled an accelerated plan from NIST for developing standards to transform the U.S. power distribution system into a secure, more efficient and environmentally friendly Smart Grid and create clean-energy jobs. The draft plan, titled the *NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 1.0,* identifies about 80 initial standards that will enable the vast number of interconnected devices and systems within the Smart Grid to work with each other.

The plan comprises three phases:

1. Engage stakeholders in a participatory public process to identify applicable standards and requirements, gaps in currently available standards, and priorities for additional standardization activities.
2. Establish a standards panel forum to drive longer-term process.
3. Develop and implement a framework for testing and certification.

Finalizing the standards will ensure that the grid transformation goes smoothly and rapidly—a priority of the Administration. When completed, the Smart Grid will allow consumers to better manage and control their energy use and costs, reduce America's dependence on foreign oil, and create clean-energy jobs.

NIST's draft plan incorporated input from more than 1500 industry, government, and other stakeholders who have participated in the NIST framework development process.

(www.nist.gov/public_affairs/releases/smartgrid_092409.html)

Major outcomes tentatively planned for FY 2010 through 2012 include the following:

- Finalization of the Release 1.0 Interoperability Framework and Roadmap
- Completion of the standards identified in the Release 1.0 Priority Action Plans
- Establishment and ongoing operation of a permanent Smart Grid Interoperability Panel, a public-private partnership to steer the development of interoperable standards
- Development and implementation of a nationwide framework for testing and certification in the highest-priority Smart Grid standards
- Releases 2 and 3 of the Interoperability Framework
- Research results providing the foundation for Release 2 standards in power systems, networking, and cybersecurity
- Development and implementation of a strategy to drive international harmonization

The technical content of NIST's Smart Grid program will focus on developing standards and related testing and certification mechanisms to address the following priorities:

- Energy demand response and consumer energy efficiency to reduce energy consumption and optimize use of grid capacity
- Wide area situational awareness to improve grid reliability and efficiency
- Infrastructure to support wide-scale adoption of electric transportation
- Electric storage to support wide-scale use of variable renewable energy sources
- Evolution of the distribution grid to support distributed renewable energy sources
- Nationwide deployment of an advanced metering infrastructure
- Communications infrastructure for the Smart Grid
- Ensuring cybersecurity of the Smart Grid

Net-Zero Energy Buildings

Buildings represent the largest energy end-use sector for energy (40%) and electricity (73%) and contributor of CO_2 emissions (39%) in the U.S., more than the transportation and industry sectors.[21] It is also the fastest-growing energy sector driving the increasing demand for U.S. electricity infrastructure, with energy consumption in the commercial buildings sector alone rising by 70% from 1980 through 2005. If current trends continue, by 2025 buildings will be the largest consumer of global energy, more than the transportation and industry sectors combined.

The National Science and Technology Council's (NSTC) Committee on Technology report entitled "Federal Research and Development Agenda for Net-Zero Energy, High-Performance Green Buildings"[22] articulates the dual vision of net-zero energy buildings—buildings that produce as much energy as they consume and doubling the service life of building materials, products, and systems to minimize their life-cycle impact. Using currently accessible and cost-effective technologies, building energy consumption can be reduced by approximately one-third. Additional reductions can only be achieved through the introduction of innovative building technologies and materials enabled by new measurement science: quantifying the energy performance of building components and systems once installed within a building; enabling energy use reductions through embedded intelligence in building systems; assessing the performance of emerging green building technologies; enabling the development and use of sustainable building materials; and developing sustainable performance metrics.

The research within NIST's Net-Zero Buildings program fully supports the measurement science needs outlined in the NSTC report for enabling green buildings. The program includes a variety of projects to develop the measurement science required to achieve net-zero energy, high-performance buildings in a timely manner. Several of these projects are described below.

1. **Enable energy-use reductions through in-situ performance measurements.** NIST will develop measurement methods and tools that indicate how energy is consumed by key systems in new and existing buildings. These systems include walls and roofs, ventilation systems, air conditioners and heat pumps, and electrical devices such as computers and appliances. These techniques can be used to identify places where energy is wasted so that repairs can be carried out in a timely manner. Key partners in these efforts will be DOE's national laboratories and university researchers.

2. **Enable building energy use reductions through embedded intelligence in building systems.** Approximately 84% of the life cycle energy use of a building is associated with operating the building rather than the materials and energy used for construction. Building systems almost never achieve their design efficiencies at any time during building operation, and their performance typically degrades over time. Case studies indicate that energy consumption for heating, ventilation, and air conditioning can be reduced 20% just by detecting mechanical faults and ensuring that systems are operating correctly. Other building systems also have significant opportunities for operational efficiency improvements. The key to realizing design potentials is combining new measurement technology and performance metrics with analysis techniques that can be implemented in building automation and control products. The resulting systems can detect and respond to faults and operational errors and inefficiencies.

3. **Provide measurement science for emerging building energy technologies.** Energy and energy efficiency are invisible attributes. Potential users of emerging building energy technologies require actual, as opposed to advertised or rated, performance measures and data before making capital investments. Credible performance measures and data will create market demand for emerging building energy technologies, economies of scale, and reduced cost. To facilitate the development and commercialization of emerging building energy technologies, NIST will develop the measurement science needed to capture laboratory and field performance of emerging building energy technologies that will result in accurate and easy to comprehend performance metrics.

4. **Enable the development and usage of sustainable materials, components, and systems.** Measurement science is needed to identify and develop more sustainable building envelope materials, components, and systems. Increased sustainability will be achieved through enabling building envelope materials, and materials for renewable energy systems used in buildings, to have longer service lives. It will also be achieved via enabling greater incorporation of waste stream materials to replace cement in concrete, and

enabling the use of alternative feedstock (e.g., bio-based) materials for polymers, in order to achieve reduced greenhouse gas emissions in material manufacture and use.

5. **Develop carbon footprint metrics and tools for building sustainability performance evaluation.** The U.S. construction industry needs compelling metrics to support investments in buildings using advanced energy technologies. Proponents of net-zero buildings seek a transformational change in the industry's life-cycle greenhouse gas emissions, or "carbon footprint," but this goal is not supported by existing measurement science. As a result, promising R&D opportunities are not fully exploited by industry due to their uncertain sustainability performance outcomes. Next-generation metrics and tools enabling rigorous carbon footprint assessment over the building service life are needed to link building energy technology innovation to environmental and economic benefits.

Advanced Alternative Energies

Solar energy remains one of the most promising alternative sources of energy as it is readily available, free from geopolitical issues, and does not contribute to the environmental problems associated with carbon emissions. However, adoption of solar energy technologies so far has been limited by the relatively high cost and low efficiency of conventional photovoltaic (PV) solar cells. Various third-generation PV technologies seek to exploit nanostructures and interfaces to dramatically improve performance and overcome these barriers. Other advanced technologies seek to provide low-cost energy generation using organic PVs that are inexpensive to manufacture.

Significant research and development efforts are already underway at other laboratories for advanced PV technologies. However, the development of new supporting measurement science, particularly measurements aimed at understanding and improving advanced devices, is not currently being addressed. In its Advanced Photovoltaics program, NIST will extend its current suite of physical and electrical measurement expertise to develop new measurement instrumentation and techniques for measuring the intrinsic electronic and optoelectronic processes that govern the efficiencies of third-generation PVs. By developing these critical measurement techniques, NIST will supply industry with valuable data about the efficiency, reliability, lifetime, and aging of new PV devices and provide reliable performance metrics that are essential for commercial adoption.

NIST's current efforts in advanced alternative energies are focused on next generation solar, although NIST is exploring other aspects of solar generation, as well as other alternative energy sources. NIST will address next generation solar needs through its Advanced Photovoltaics program. NIST will engage strategically with key stakeholders to identify the full suite of requirements needed by industry and plan future work. Initial projects planned for the program include the following.

1. **Develop new precision measurements of PV electricity conversion that will enable a new generation of solar cells.** The primary limitation to the advancement of new PV technologies is the inability to carefully measure the properties of photogenerated electric current in the proposed new materials and devices. Furthermore, measurement of these quantities with spatial resolutions commensurate with the micrometer and nanometer scales of proposed structures and electrical properties is vital. New nondestructive measurements of the generation and transport of electricity at very small scales will provide an understanding of phenomena that promise leaps in PV performance, and enable technologists to develop and manufacture a new generation of super-efficient solar cells.

2. **Develop measurements of subsurface properties by sample sectioning to support development of advanced PV devices with buried interfaces.** Advanced PV devices rely on sophisticated nanoscale morphology and composition to capture efficiency gains. The physical and chemical processes inside such complex structures, at the interfaces between the interstitial materials and between the PV materials and the contacts define the performance and the aging of the solar cells. The further development of the PV technologies can significantly benefit from new measurements that improve the knowledge of interfacial effects. Cross-sectioning devices and developing methods that can probe these exposed interior regions can improve the understanding of PV performance.

3. **Develop new nondestructive measurements of key subsurface structure and properties to support development of advanced PV devices with buried interfaces.** Being able to measure key parameters of PV structures and devices without modification would provide faster results with less device-dependent error. The ability to probe interior characteristics such as potentials, composition, carrier transport, etc. will improve the diagnosis of problems and the understanding of phenomena. Developing new measurements that can non-destructively locally probe the interior of complex devices will improve the knowledge of important interfacial contribution. When applicable, these new measurements can be validated by known destructive techniques to enhance our development efforts.

Greenhouse Gas Measurements and Climate Change

This NIST program focuses on providing the measurement tools and standards to enable accurate, reliable, and consistent measurements of greenhouse gas (GHG) sources and sinks at various spatial scales, which will be needed for local, national, and international accounting and

mitigation. The program also outlines the development of SI-traceable ground, air, ocean, and space-based climate measurements that are necessary for assessing the success of any efforts to reverse the effects of global warming, including GHG mitigation programs. Finally, the program also focuses on providing chemical and physical reference data to support SI-traceable measurements of the Global Climate Observing System (GCOS) Essential Climate Variables, which are used to monitor the climate system and assess the impact of climate variability.

Projects planned as part of the Greenhouse Gas Measurements and Climate Change program include the following.

1. **Develop and disseminate measurement science and standards to ensure accurate measurements of greenhouse gases from smokestacks.** Effective local, national, and international efforts to reduce GHG emissions through voluntary, regulatory, or market-based approaches require measurement science and standards to establish that emission levels are accurate and comparable, which provides confidence that emission goals are met. Lack of confidence in a regulatory or market-based system reduces compliance and willingness to participate in GHG exchanges. To improve the measurement quality of factory emissions, NIST will expand its successful gas-standards program to include GHG mixtures at typical factory emissions concentration levels. This program was begun as a collaboration with specialty gas manufacturers to support SO_2 emissions measurements for the EPA acid rain program under the Clean Air Act. NIST will also develop capabilities at the NIST Large Fire Laboratory and later at a typical industry smokestack source to validate and calibrate continuous emissions monitoring instruments used for monitoring factory emissions. The test bed will advance concentration and flow-rate measurements required to derive GHG emissions levels.

2. **Develop and validate optical remote measurement tools for the quantitative determination and verification of inventories of GHG sources and sinks.** Methods to accurately quantify the emission and absorption of GHG from large area sources or sinks, such as landfills, forests, estuaries, and agriculture land, are required to ensure accurate and complete GHG inventories and consistency of bottom-up inventory approaches with top-down atmospheric concentration measurements. This is challenged by the need to measure both local atmospheric concentrations of GHG as well as fluxes of GHG from or to the source or sink. Ideally, such measurements would be standoff, i.e., made without placing instruments on the site since the terrain might not be easily or safely navigated. Such standoff systems are also important for validation and verification of claimed emissions levels by factories. A standoff system would ideally allow interrogation of a plume from beyond factory fences.

3. **On a representative large geographical area, assess and improve comparability between bottom-up and top-down inventories based on measurements with uncertainties.** Successful local, state, national, or international GHG monitoring and mitigation programs require the ability to reconcile bottom-up inventories based on accounting for all the GHG sources and sinks with top-down measurements of increase in atmospheric GHG due to total emissions for the spatial region. The lack of agreement between the top-down and bottom-up measurements makes it difficult to establish science-based caps to overall, sector, and geographical area emissions levels. Additionally, such lack of agreement makes it difficult to challenge the accuracy of inventories generated by states or countries since satellite-based top-down measurements do not provide a robust measure of bottom-up levels.

4. **Ensure the highest return in our Nation's investment in satellite remote sensing by establishing the foundation for measurements which are accurate, tied to international standards (i.e., SI), and comparable independent of launch organization, country, or time.** Satellite programs generally have requirements that the pre-launch calibration be tied to international standards based on the SI system of units. Improvements in the accuracy and quality of satellite measurements require advances in pre-launch and on-orbit sensor calibration and characterization. Furthermore, a robust calibration capability will help reduce the impact of a data gap on climate records. NIST will develop the appropriate standards, calibration and characterization methods, and uncertainty analyses tools that serve as the measurement infrastructure for satellite remote sensing. Such an infrastructure benefits not only government satellite programs but also the burgeoning commercial satellite industry and various civilian and government programs dependent on remote sensing measurements and data.

5. **Advance the measurement science, standards, and fundamental data for aerosol particles to improve the prediction of the direct and indirect radiative forcing of atmospheric aerosols and the identification of the anthropogenic and natural sources of atmospheric aerosol particles.** Atmospheric aerosols contribute the largest uncertainty in the change in radiative forcing of the Earth's climate since industrialization. NIST will develop new measurement science to improve knowledge of the chemical, physical, and optical properties of aerosols. Aerosol radiative forcing contributes the greatest uncertainty to our knowledge of the anthropogenic contributions to climate change since industrialization. Fundamental reference data on aerosols will allow researchers to advance their aerosol chemical and radiative models to identify the origin of aerosols found in the atmosphere, and are required to improve the prediction of the chemical, physical, and

optical properties of aerosols in the atmosphere and deposited on the cryosphere.

Sustainable Manufacturing

To provide U.S. manufacturers with a firm basis for sustainability-driven innovations that improve competitiveness, NIST has a Sustainable Manufacturing program that will develop and implement a trusted system of measures and standards to promote U.S. leadership in developing innovative products, competing effectively in global markets and creating high-paying stable jobs while protecting the environment and improving the quality of life for current and future generations. NIST efforts will accelerate innovations in new measurements and measurement protocols, standards, performance metrics, analysis tools, and dissemination mechanisms, leading to new sustainable manufacturing processes, materials, and products for U.S. manufacturers. Industry has emphasized to NIST that much better data is needed and at a much more detailed level to enable significant advancements in decreased energy usage and reduced environmental impacts. This program will identify and target the key manufacturing areas and processes that consume the most energy, generate the largest waste streams, or have the most negative impacts on the environment so that NIST actions can have the biggest impact. In addition, the Sustainable Manufacturing program will identify and address specific sustainable manufacturing processes that are currently limited in their use by industry due to challenges associated with measurements and standards.

As part of the Sustainable Manufacturing programs, NIST has a variety of projects underway. Several of these current projects are described below. Future (FY 2011-2012) research areas could potentially include advances in infrastructural technologies for manufacturing to improve agility; and innovative measurements, test methods, reference materials, and documentary standards.

1. **Develop measurement science and technology for sustainable manufacturing across the entire life cycle of manufactured products and services.** Industry lacks a consistent metrology infrastructure for sustainable manufacturing – an infrastructure that provides traceability to NIST, supports all sectors of manufacturing, and is compatible worldwide through international standards. The following objectives provide a path to achieving this goal:
   a. Develop the measurement methods and standards required by technology-intensive industry sectors to evaluate and employ alternative feedstock materials while maintaining their performance and sustainability in products. These include measurement methods and standards that support the manufacture of materials from alternative feedstocks; that evaluate their performance and reliability; and that assess their durability for long term use and ability to be recycled or reused.
   b. Develop measurement methods, standards, and performance metrics to improve manufacturing process sustainability.
   c. Develop high-accuracy measurement capability for the metrology of complex 3D geometry for critical, energy-efficient manufactured components, including fuel injectors, airframes, wind turbine blades, and ship hulls to improve product performance and reduce the resulting massive energy inefficiencies.

2. **Develop advanced decision support tools and technologies that support the entire life cycle.** Product realization includes all of the activities required to transform raw materials into finished products. Currently, product realization activities, which include design, engineering, production, assembly, and shipping, are carried out in global supply chains. Minimizing their environmental impact means optimizing their performance for energy consumption, hazardous wastes, and transportation

NIST Collaborating to Enable Fabrication of Microelectromechanical Systems

For the past three years, NIST has been partnering with industry, universities, and other organizations to demonstrate the feasibility and accessibility of technologies for fabricating Microelectromechanical Systems (MEMS), tiny mechanical devices built onto semiconductor chips and measured in micrometers (millionths of a meter). These events are in the form of soccer competitions between teams of nanoscale robots—nanobots—and are held in conjunction with RoboCup, an international organization dedicated to using the game of soccer as a testing ground for the robotics technologies of the future.

The soccer nanobots are operated by remote control under an optical microscope. They move in response to changing magnetic fields or electrical signals transmitted across the microchip arena. Although the bots are a few tens of micrometers to a few hundred micrometers long, they are considered "nanoscale" because their masses range from a few nanograms to a few hundred nanograms. They are manufactured from materials such as aluminum, nickel, gold, silicon, and chromium.

The competitions test the nanobots' agility, maneuverability, response to computer control, and ability to move objects—all skills that future industrial nanobots will need for tasks such as microsurgery within the human body or the manufacture of tiny components for microscopic electronic devices. The competitions also drive innovation in this new field of robotics by inspiring young scientists and engineers to become involved.

(http://www.nist.gov/public_affairs/calmed/nanosoccer.html, http://www.nist.gov/public_affairs/techbeat/tb2008_1112.htm)

costs. This requires a robust information-based decision support environment and knowledge-intensive information models that will facilitate the interoperability of decision support tools. NIST is positioned to play a leadership role in developing such an environment by analytical tool development, developing formal product and process models for software interoperability, and evaluating existing models for integrating factory-level information to the enterprise level and ultimately connecting to the smart grid.

3. **Improve U.S. manufacturers' competitiveness through a deployment program to stimulate innovative business practices for sustainable manufacturing.** Knowledge application is occurring faster and more efficiently as companies and other organizations become more interconnected. To be successful, manufacturers must have access to a wide range of resources that will enable them to sell to new customers, compete in new markets, and develop new products, thus creating new, more profitable revenue streams. There is a need to develop, expand, and leverage strong and effective partnerships with government and industry to ensure sustainability is embraced at all levels of the economy – from the largest employers to the smallest suppliers to the workforce itself. In addition, NIST needs to develop a strategy for helping companies to effectively plan and objectively evaluate their progress toward sustainable manufacturing defined through near-term, intermediate, and long-term outcomes, and for ensuring conformance in the sustainable manufacturing area.

Appendix B: Current Programs for Ensuring Consumer Health, Safety, and Security

NIST has developed programs for its current major efforts in ensuring consumer health, safety, and security. Descriptions of the following programs are provided below:

- Health Information Technology
- Biomedical Measurements to Support Disease Diagnosis and Treatment
- Nanomaterial Environmental Health and Safety
- Scalable Cybersecurity for Emerging Technologies and Threats
- Infrastructure Development and Remediation

Health Information Technology (IT)

The U.S. healthcare industry lacks a comprehensive nationwide information infrastructure. Healthcare is a large part of our economy, accounting for $1 out of every $6 spent in the U.S. The U.S. spends more money per capita ($5.7K) per year on healthcare than any other country, but ranks 24th in life expectancy.[23] Adults get, on average, only 55% of the recommended care for many common conditions.[24] Reports suggest that cost, quality, and availability are the main causes of inadequate care. The expanded use of health IT, the comprehensive management of health information and its secure exchange, is a key component of improving this situation.[25]

This program focuses on addressing NIST's responsibilities under ARRA for health IT. The program supports the accelerated development and harmonization of standards for health IT technologies, which helps ensure that medical records will be available anywhere, anytime, only by those authorized to access them. The program also includes creating a health IT technology testing infrastructure to help ensure that the health IT infrastructure standards are implemented consistently. The program also supports the usability of health IT technologies to improve health record workflow and use, as well as performing outreach and continuous process improvement activities to help enable health IT deployment nationwide. The non-ARRA portion of the program is for researching emerging technologies for telemedicine, pervasive healthcare, and personalized medicine to provide remote and home healthcare for aging, underserved, and chronically ill populations.

Projects planned as part of the Health IT program include the following.

1. **Support the development and harmonization of technically robust usable standards for health IT technologies.** Health IT includes deployment of a nationwide network and interoperable electronic health records, through which a patient's medical record will be available anywhere, anytime, but only to those authorized to access it. NIST will enable the development and harmonization of industry-led, consensus-based standards to help ensure that the full set of necessary basic query and retrieval functions, including security and privacy provisions, for clinical information exists. NIST will also advance other selected health IT technology standards as appropriate. Work will be done in collaboration with the American National Standards Institute (ANSI) Healthcare Information Technology Standards Panel (HITSP) and other relevant standards developing organizations, Federal agencies, professional societies, and industry.

2. **Create a health IT technology testing infrastructure.** Once basic infrastructure standards for health IT are put in place, a system to perform conformance testing and certification is necessary to ensure that the standards are implemented consistently and to provide technology developers and buyers with independent measurements to judge system and software performance, thereby accelerating technology deployment. NIST will collaborate with industry to ensure that a testing infrastructure is created.

3. **Support the usability of health IT technologies and continuous process improvement.** A lack of usability in the health IT environment will significantly impede adoption and use of health IT technologies. To address this, NIST will apply usability principles to improve electronic health record workflow and personal health record use. NIST will help enable health IT deployment nationwide and will encourage continuous process improvement and outreach efforts through program support.

4. **Lay the measurement and testing foundation to integrate next-generation healthcare delivery technologies into the health IT standards framework.** There is an ever-growing need to provide remote and home healthcare for aging, underserved (e.g., rural), and chronically ill populations, which can be facilitated by leveraging existing and emerging health IT standards and testing. Telemedicine includes capabilities where wellness checkups and monitoring, diagnoses, and treatment can occur anyplace and anytime. Pervasive healthcare explores the use of emerging technologies such as body sensors, implants, and medical equipment for routine monitoring of chronic conditions. NIST will collaborate with industry to ensure that these technologies can be integrated into the nationwide healthcare infrastructure.

Biomedical Measurements to Support Disease Diagnosis and Treatment

The rising cost of healthcare and increased prevalence of chronic diseases, such as heart disease and diabetes, are having a severe impact on the economic security and quality of life for many in the United States. In 2007, National Healthcare Expenditures (NHE) grew at 6.1% to a total of $2.2 trillion, accounting for 16.2% of U. S. GDP.

At the current rate of increase, NHE will account for 20.3% of GDP by the year 2018.[26] The President's Plan[27] is committed to addressing the major challenges associated with healthcare to improve its delivery and efficacy. The lack of adequate measurement science and standards to ensure accurate and comparable measurements is a major barrier to realizing the potential impacts of new technological innovations that would improve the efficiency, effectiveness, and quality of healthcare. NIST's unique mission, core competencies in measurement science and standards, and history of addressing such needs in other areas provides strong evidence that NIST can help accelerate this innovation.

The NIST Bioscience and Health program targets two major areas of measurement needs: quantitative medical imaging and protein measurement science. Improvements to the measurement and technological infrastructure for these areas will have significant short- and long-term economic impacts and will improve the productivity and quality of research, drug/therapeutic development, and patient care.

Projects planned as part of the Bioscience and Health program include the following.

1. **Develop the underpinning measurement science, reference methods, and certified reference materials needed to increase the accuracy, comparability, and efficacy of measurements used in medical diagnostics.** Laboratory medicine is important for medical decision-making, with over 70% of physicians' decisions based in part on results from one or more of these tests.[28] Yet, of the more than 700 routinely performed laboratory diagnostic tests, internationally-recognized standards are available for only about 70 analytes.[29] New reference methods and standards are critically needed for blood serum protein and nucleic acid markers such as PSA for prostate cancer early detection; BNP in congestive heart failure; viruses; genomic structural variants, messenger RNA, and gene sequences.

   In addition, improved measurement science and technology are needed to more rapidly and effectively enable the advent of the next-generation of diagnostic tests for complex disease signatures based upon proteome, transcriptome, and metabolome analysis with multiplex analytical systems. To address these issues, NIST will develop the measurement science base to underpin the provision of "higher-order" reference measurement procedures, standard reference materials, and measurement quality assurance programs to provide SI-traceability for genetic testing; measurement of single blood protein health status markers; and the advancement of laboratory medicine from single analyte analysis to the use of multiplex analytical tools for proteins, RNA, and metabolites for the discovery and routine analysis of complex disease signatures.

2. **Develop the measurement science and standards to enable greater quantitation of anatomical and biochemical change detection with current and next-generation medical imaging modalities.** It is currently impossible with today's medical imaging measurement systems to fully quantitate changes in the size, shape, texture, and metabolic activity of anatomical lesions from one examination to the next. Standards and measurement quality assurance processes are needed to enable quantitative medical imaging for the modalities most often used in medical diagnostics, including PET-CT, SPECT, Spiral CT, and MRI. There are currently no standards for image generation, transmission, archival storage, and dissemination to researchers that enable their use as references. The calibration of clinical imaging instruments (CT, MRI) is largely un-standardized, which could lead to poor performance. To address these issues, NIST will develop the measurement science needed to provide SI-traceability for evaluation of target structure and composition in vivo and to assure quality of resulting images; work with stakeholders to develop the measurement science, standards, reference materials, and quality assurance processes needed to provide SI-traceability and quantification of target dimensions in vivo; and develop the measurement science and metrology needed to provide SI-traceability for quantification of target metabolism in vivo and the clinical assessment of therapeutic efficacy.

3. **Develop the measurement science and standards to support manufacturing and regulatory approval of biologic drugs.** The cost of protein therapeutics (biologic drugs) is one of the fastest growing components to the overall cost of U.S. health care. These drugs are not synthesized chemically, but rather are made in bioreactors using living cells. They have been shown to be therapeutic and substantially improve patients' health and quality of life. However, they are expensive and generics are not currently available in the U.S. The FDA has been charged with developing a regulatory process to enable an abbreviated development process for follow-on biologic drugs that will be based largely on physico-chemical and biologic measurements. All protein biologic drugs have the propensity to induce an immune reaction in patients who receive them. Currently there is no reliable method to predict either the type or degree of severity of immunogenicity caused by a biologic drug. New methods are also needed to identify and quantify various contaminants that enter biopharmaceuticals during processing and packaging.

   To address these issues, NIST will work with industry stakeholders to develop a metrology program focused on reference physico-chemical and biological methods for characterization of protein biopharmaceuticals' structure, function, and immunogenicity and to identify and quantitate contaminants (viruses, host cell proteins, leachates, and extractables) in biopharmaceuticals. NIST will also work with industry

and academia to develop measurement standards and services to aid biopharmaceutical manufacturers in the understanding of the biological and chemical processes important for designing and optimizing manufacturing processes.

Nanomaterial Environmental Health and Safety (NanoEHS)

In the Nanomaterial Environmental Health and Safety (NanoEHS) program, NIST is establishing the essential measurement science and developing and disseminating critical measurement technology for determining physico-chemical properties and toxicity of nanomaterials and products that incorporate nanomaterials throughout all stages of their life cycles—from nanomaterial production through product fabrication, distribution, storage, use, recycling, and disposal.

As part of its NanoEHS program, NIST is expanding its interactions and coordination with other federal agencies through the NNI Nanotechnology Environmental and Health Implications (NEHI) Working Group. NIST has been a lead organizer in the major NEHI Workshops on defining the most critical research needs in NanoEHS and developing strategies to address these needs. Additionally, NIST is establishing research efforts with individual regulatory agencies and other agencies (e.g., DOE, DOD) focused on addressing their measurement priorities. NIST is also expanding interactions and coordination with the primary U.S. industries developing and manufacturing key nanomaterials for commercial and biomedical applications. Key partnerships with standards developing organizations such as ISO and ASTM and other National Metrology Institutes are an essential part of the NIST program.

Resource constraints will limit the scope and pace of NIST's NanoEHS Program, and make it imperative that NIST focus on a few key nanomaterials and nanomaterial-based products that are anticipated to have the greatest potential impact on the environment and human health. At this time, the key nanomaterials of greatest regulatory concern based on volume production, widespread use in products, and potential hazards are silver, titanium dioxide, and cerium oxide nanoparticles; carbon nanotubes; and clay-based nanocomposites.

Projects planned as part of the NanoEHS program include the following.

1. **Establish the essential measurement science—underlying physical principles that form the basis for novel measurements—to enable science-based lifecycle risk assessment and risk management for key nanomaterials and products that incorporate nanomaterials.** This will include identifying the most critical properties and attributes of key nanomaterials that elicit toxicological responses in ecosystems and humans, and quantifying surface attributes of key nanomaterials in relevant media. Also, NIST will establish the essential measurement science to quantify the extent and rates of transformation processes that control the transport and fate (e.g., the equilibrium state, concentration, and distribution) of key nanomaterials in relevant media.

2. **Develop essential measurement technology—transferable methodologies, reference materials, documentary standards, models, reference data, and transferable instruments—to enable science-based lifecycle risk assessment and risk management for key nanomaterials and products that incorporate nanomaterials.** Objectives supporting this include developing the essential technology for measurements of nanomaterials emissions from manufacturing processes in field environments, as well as developing the essential measurement technologies to quantify the following:
   - Concentrations of key nanomaterials in relevant media, e.g., air, water, soil, sediment, and biological matrices
   - Surface attributes of key nanomaterials in relevant media, including single nanomaterial structures and populations of many nanomaterial structures
   - Releases of key nanomaterials from products in relevant environments during all stages of product life cycles
   - The extent and rates of transformation processes of key nanomaterials in relevant media
   - The toxicity of key nanomaterials in biological matrices
   - The extent and rates of processes that control transport and fate—the equilibrium state, concentration, and distribution—of key nanomaterials in relevant media.

3. **Work with other organizations to establish the essential linkages between physico-chemical properties, exposure, and hazards to enable science-based lifecycle risk assessment and risk management for key nanomaterials and products that incorporate nanomaterials.** To meet this objective, NIST will identify critical measurement needs by instituting key partnerships with the NNI Agencies, industry groups, university-based centers, National Metrology Institutes, standards developing organizations, and other standardization consensus groups. NIST will collaborate and coordinate with key partners to provide the critical physico-chemical and toxicological measurement technologies. NIST will develop web-based outreach and educational tools for NanoEHS measurements as a resource for key partners.

Scalable Cybersecurity for Emerging Technologies and Threats

Cybersecurity has become a particularly important concern for IT. Most IT systems have security configurations that are poorly implemented and maintained, security controls that are prohibitively difficult to use, and security postures that are too complex for most administrators to

understand. This combination allows many threats to successfully compromise systems and delays reactions to these compromises, allowing significant damage to occur. This undermines confidence in vital commercial and public information systems and has a large, direct economic impact—estimates show that Americans are losing billions of dollars each year to cyber crime. Cybersecurity is also vital to national security interests, with increasingly sophisticated and frequent attacks from individuals, organizations, and nation-states that target key IT operations and assets.

NIST has developed a Cybersecurity Program plan that addresses several of its key cybersecurity projects. The essential challenge of cybersecurity is providing appropriate levels of the right security objectives in a cost-effective manner. Many of the security tools and mechanisms available today were designed with yesterday's technologies and threats in mind. Information systems have evolved from physically isolated systems to highly distributed heterogeneous systems interconnected by a variety of communication paths. Many existing security technologies cannot scale to provide a complete solution. In addition, the complexity of IT and the degree to which systems are interconnected have made defense strategies more difficult because attackers need only find one point of penetration for success, while the security practitioner must analyze all possible points of attack and address all potential vulnerabilities in each.

To address these concerns, NIST has a variety of projects underway to advance the art and practice of protecting the Nation's information infrastructure by conducting advanced research needed to defend it against current and future threats. Several of these projects are described below.

1. **Enable key management practices that preserve the confidentiality and integrity of cryptographically-protected information.** Secure adoption of many technologies has been hindered by the lack of technical standards for cryptographic key management, which presents a variety of technical and organizational challenges. Without efficient and usable key management solutions, implementers often transmit and store keys insecurely and neglect to change keys appropriately. These practices jeopardize the security of keys, and thus the security of the information and systems that the keys protect. To address this, NIST, in technical consultation with NSA, DoD, and others, is creating standards for generating, distributing, storing, and destroying cryptographic keys.

2. **Ensure that cryptographic algorithms are capable of protecting information and applications against possible threats from quantum computing.** Quantum computing has the potential to become a major disruptive technology affecting cryptography. If a practical quantum computer can be built, it will be possible to break all the digital signature algorithms and public key-based key establishment schemes that today provide the foundation for electronic commerce and other critical applications. NIST will perform analysis on these forms of cryptography to ensure that there are robust cryptographic algorithms that are not susceptible to future threats from quantum computers.

3. **Promote stronger assurance of online user identity across systems and organizations.** Authenticating a user is verifying a user's claimed identity. This verification is stronger when users are required to provide two or more types of authentication information, such as a password and a biometric, instead of just one. This is known as multifactor authentication (MFA). MFA could be used to achieve stronger assurance of identity for online applications, such as government services and banking, but usability, cost, and interoperability issues have impeded its widespread use. NIST will study factors influencing adoption of MFA and develop a standardized framework and implementation plan for interoperable tokens that contain biometric and/or cryptographic credentials to support logical access control on a multi-platform and multi-operating environment basis.

4. **Improve the usability of security.** Usability is an often overlooked but critical component of security. Computers can be secure but so unusable that users will either bypass the security measures, undermining security, or not perform the work at all. Systems that are usable but not secure become unusable due to compromises. The usability principles of efficiency, effectiveness, and user satisfaction must be incorporated to ensure that it is easy for users to do the right thing and hard to do the wrong thing. NIST will work with industry and academia to improve the usability of security, and thus security itself, through research and outreach.

5. **Accelerate the adoption of security automation technologies and content.** Systems need to be persistently configured to resist malware and other forms of attack. Currently many systems do not implement required security settings, and many applications change system security settings during application installation or configuration. Identifying incorrect settings and remediating them is largely a manual process, error-prone and resource-intensive. To address this, NIST will develop specifications for security automation technologies and create security baselines—sets of standardized security settings—for selected widely used IT products. Organizations can use these security automation technologies and baselines to strengthen their security and reduce costs.

6. **Develop measurement and modeling techniques needed to enable the characterization, prediction, and control of the security of dynamic, large-scale interconnected information systems.** Currently there are no methods for adequately characterizing the fundamental properties of networked information systems that make them either resistant or vulnerable to attack. Cloud, grid, and other interconnected

systems are increasingly being used to reduce cost, but their collective security is not well understood. NIST will conduct research to gain a fundamental understanding of how the characteristics of large-scale interconnected systems affect their resistance to attack and other failures.

7. **Enable secure adoption of emerging virtual technologies by government and industry.** Platform virtualization, cloud computing, social networks, and other emerging virtual technologies are promising, but security challenges threaten their adoption. The most difficult issue to solve is the need for security isolation technologies to protect information on shared hosts and other resources (e.g., storage). There are also other security issues that need to be addressed through new security technologies or innovative application of existing security technologies. NIST will conduct research to determine how these security issues should be mitigated. Addressing these issues will enable widespread secure adoption of virtual technologies, resulting in enormous cost savings and leap-ahead functional advantages.

Infrastructure Development and Remediation

As discussed earlier in this plan, the maintenance of U.S. physical infrastructure is a major issue. However, prioritizing infrastructure investments is not a trivial matter. Quantitative nondestructive evaluation tools exist for inspecting large structures, but such instruments are complex and their output often requires substantial interpretation, making these measurement methods difficult to deploy without clear procedures for their use.[30] Uniform standards do not exist for calibrating and using these instruments, nor is there sufficient understanding of bridge components and their degradation (especially at weak links such as connections, welds, rivets, bolts, etc.) to enable accurate interpretation of sensor data. Without addressing these underlying measurement science issues, the U.S. will continue to rely on existing methods for assessment of structures.

The NIST Physical Infrastructure program is designed to provide measurement science to FHWA and other federal agencies to better assess the status of aging infrastructure and enable cost-effective strategies for its maintenance, repair, rehabilitation, and replacement. Specifically, advances in measurement science are required to:

- Reduce error and uncertainty associated with existing bridge inspection instruments to enable more informative inspection of aging bridges
- Enable more accurate modeling of complex structures by incorporating robust connection performance parameters that address the safety of the overall system, including weak links at welds, rivets, and bolts
- Quantify the effects of extreme conditions (fire, impact, shock loading, corrosion) on the remaining strength of the structure to provide a more accurate de-rating of safety margins due to conditions of use
- Qualify new sensors for advanced inspection, including embedded approaches, to accelerate future implementation of real-time structural health monitoring

As part of the Physical Infrastructure program, NIST has several projects underway. Selected projects are described below.

1. **Reduce error and uncertainty associated with existing bridge inspection instruments.** Inspectors assign condition ratings (0 to 9) to describe the degree of bridge deterioration and the extent to which it is distributed throughout the structure. Visual inspections can be subjective, with a 2001 FHWA study finding significant variability in condition ratings from inspector to inspector.[31] Also, many material defects and concealed elements are incompatible with visual inspection. Nondestructive evaluation (NDE) tools have been developed to assist in bridge monitoring. However, their application in inspections has been limited by the complexity and accessibility of these technologies, as well as a lack of guidance on how to use the methods in the field. Of particular concern is that certain methods can provide false readings due to improper calibration. NIST will enable more widespread use of NDE instrumentation by reducing the error and uncertainty associated with their use, while also simplifying sensor output.

2. **Provide comprehensive testing and modeling of connections and components.** Finite-element modeling is a powerful tool to design a single connection or (through simplifications) an entire structure. Currently, however, it is computationally impossible to model an entire structure down to the level of a rivet or bolt, but it is in these details that the critical failure conditions of the connections lie. Further refining the model by adding fatigue and corrosion of the materials at these critical links is also not currently possible. To address these deficiencies, measurement of how bridge connections degrade and the resulting effect on performance is necessary. These measurements and observations must then be converted into a simple but powerful numerical model to determine the current state of the overall system. Once established, this model will provide the necessary foundation for more accurately determining system safety during operation and will aid in establishing guidelines for sensor specifications and placement strategies for improved bridge inspection. NIST will develop a methodology for finite element modeling of connections that describes material behavior in the elastic and non-linear ranges and can be readily inserted into global structural models to enable accurate, yet computationally affordable, calculation of the global response of a bridge.

3. **Quantify effects of extreme events on performance and remaining system strength.** Structural engineers design for expected service conditions using well-

established, validated design rules backed by decades of experience. However, the performance of in-service structural elements under extreme conditions such as fire, explosion, impact, and natural disasters, especially for aged, degraded (corroded) conditions typical of the U.S. infrastructure, is poorly understood. Accurate estimation of the residual factor of safety for aged structures under normal and extreme conditions is critical to prioritizing the need for repair. To assess the behavior of structural materials under extreme conditions, NIST will design and construct equipment capable of testing the mechanical performance and failure of steel connections under fire conditions; measure the effects of fire on deformation and failure of large and reduced-scale components to more accurately account for structural weakening; and conduct corrosion testing on reduced-scale components. NIST will then incorporate these material properties and measured effects of these extreme conditions into the simplified connection models and verify the modeling assumptions based on reduced-scale testing.

Appendix C: Current Projects for Quantum-Based Measurements

NIST has several projects on quantum-based measurements underway. Selected projects are described below.

1. **Create a new, self-consistent set of international units linked to exactly known values of fundamental constants.** This project will focus on the realization and dissemination of standards for fundamental quantities: time, length, mass, light, temperature, and electrical quantities. NIST will also improve its measurement and realization of fundamental constants that support the move to a quantum-based set of natural units. An example of the potential outcome of this work is to make atomic clocks that are 100 times more accurate than today's best clocks; this would improve navigation accuracy, expand telecommunications bandwidth, increase communications security, and allow extremely precise gravity and magnetic field measurements. The latter could be used for purposes such as improving medical imaging and diagnostic techniques, and detecting tunnels, underground resources, and hidden threats.

2. **Develop general tools to control and manipulate the properties of quantum systems.** Improved control of quantum systems is a key enabling technology that allows us to exploit these systems while preventing deleterious effects of coupling them to their environment. NIST will create new control tools to improve the quality of rudimentary operations and to transform the information in one quantum system to another. NIST will use these tools to perform more complicated simulations of quantum systems and to determine how the tools can help to characterize and control the effects of the environment for quantum systems. This will provide new pathways for interconnecting multiple quantum systems and controlling their interactions.

3. **Investigate new quantum materials capable of creating significantly better and more reproducible solid state quantum systems.** A quantum material is an artificial atom that requires fabrication. Naturally occurring qubits are not well suited for high-speed operation and manufacturing, unlike artificial atoms; however, artificial atoms suffer much more significant degradation than natural qubits because of the complex material environment in which artificial atoms sit. Improved quantum materials would allow us to assess which potential quantum systems may lead to future breakthroughs and understand what essential material characteristics are required in an integrated device. NIST will create improved quantum materials capable of extending the quantum coherence of qubits. NIST will also develop robust quantum control systems for manipulating, transforming, and moving information; this will provide the ability to interconvert quantum information between various types of qubits, thus enabling development of more complicated quantum devices that use qubits for memory, communication, and processing.

4. **Establish measurement standards to characterize dynamic quantum-scale phenomena in integrated quantum systems and devices**. A variety of new quantum materials, including quantum dots, self-assembling DNA molecules, and nanocrystals, are being explored as building blocks of integrated systems and devices for a broad range of applications, such as biological and chemical sensors, chip-scale timing devices and magnetometers, non-conventional solid state energy devices with high energy conversion and storage efficiency, and multi-functional contrast reagents for low-cost medical imaging and therapy. One of the main obstacles in manufacturing robust and reliable, real-world, quantum-engineered products is the lack of fundamental understanding of the effect of the manufacturing process on the critically important quantum-scale functional elements. NIST will develop the tools and expertise needed to measure the dynamic properties of quantum materials while they are processed and assembled into more complex forms. NIST will also seek to validate other existing and emerging dynamic measurement methods and establish standardized tests and protocols for processing quantum materials into integrated devices.

Appendix D: Endnotes

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