
Measurement Science Needs for Advancing Infrastructure Delivery

Industry Sector Baseline Profiles: Bridges, Roads, Power, and Water

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EXECUTIVE SUMMARY

The United States possesses an enormous and aging physical infrastructure, with estimates in the trillions of dollars required for the renewal of its critical components. Renewal and expansion of the existing infrastructure is necessary to maintain quality of life and U.S. competitiveness in the global economy.

Leading industry groups, such as the Construction Industry Institute (CII), Construction Users Roundtable (CURT) and FIATECH, have identified the critical need for fully integrating and automating construction processes. The application of these advanced methods and technologies could enable breakthrough improvements in the delivery, quality, and reliability of the nation's infrastructure.

In 2009, a report released by the National Research Council¹ identified five activities that could lead to breakthrough improvements in construction efficiency relatively soon, within 2-10 years. These include:

1. Widespread deployment and use of interoperable technology applications
2. Improved job-site efficiency through effective interface of people, processes, materials, equipment and information
3. Greater use of prefabrication, preassembly, modularization, and off-site fabrication
4. Innovative widespread use of demonstration installations
5. Effective performance measurements

The National Institute of Standards and Technology (NIST) Building and Fire Research Laboratory (BFRL) commissioned this baseline analysis to build on the foundational findings of the 2009 NRC report, particularly in the area of measurement science² challenges. The objective of the baseline is to increase understanding of the measurement issues related to construction efficiency, identify pathways and stakeholders for future industry collaborations, and identify the challenges and opportunities to improve cost, scheduling, and quality in infrastructure delivery.

The sectors covered in the baseline include **bridges, roads, power generation, and water supply and wastewater systems**. While the focus is on these particular sectors, an overarching goal is to identify cross-cutting issues which NIST can pursue to develop critical pathways towards advancing infrastructure delivery through improved measurement science.

This report provides the following information for each of the four sectors.

- Major stakeholder organizations

¹ National Research Council of the National Academies. "Advancing the Competitiveness and Efficiency of the U.S. Construction Industry," The National Academies Press, 2009. www.nap.edu/catalog/12717.html

² The term *measurement science* includes: (1) development of performance metrics, measurement methods, predictive tools, and protocols as well as reference materials, data, and artifacts; (2) conduct of inter-comparison studies and calibrations; (3) evaluation and/or assessment of technologies, systems, and practices; and (4) development and/or dissemination of technical guidelines and basis for standards, codes, and practices.

- Preliminary measurement science needs and barriers to improved infrastructure delivery
- Government programs
- Key reports and information sources
- Primary industry and academic journals
- Conferences, workshops, and training activities

For all the sectors studied, the results presented are based on a survey of available literature (beyond the NRC Report) and as such are a preliminary view only. They are not intended to be all-inclusive of the measurement challenges in construction productivity in these critical sectors. A subsequent review of the baseline by industry stakeholders will be undertaken to more fully articulate and prioritize the enabling measurement science needed to achieve significant improvements in infrastructure delivery. With this knowledge, NIST will be able to better define the urgent actions needed to address recommendations from the NRC report. It will also aid in defining common metrology problems that cut across multiple sectors, and guide NIST in a critical path of work that will enable solutions with maximum national impacts.

The measurement issues presented here are organized according to a framework of infrastructure delivery that includes five phases: Project Planning and Permitting, Design, Procurement, Construction, and Commissioning and Handover. They are cross-referenced for their relevance to the key issues of cost, scheduling, and quality, and to the five recommended activities of the 2009 NRC Report.

I. INTRODUCTION

The United States possesses an enormous and aging physical infrastructure, which includes the nation's airports, bridges, tunnels, roads, ports, and other fixed portions of transportation systems, power generation and distribution facilities, water and waste facilities, government buildings, and public arenas. With estimates in the trillions of dollars required for the renewal of its critical components, the renewal and expansion of the existing infrastructure is necessary to maintain quality of life and U.S. competitiveness in the global economy.⁴

The construction industry plays a major role in designing, developing, building, and renewing the nation's infrastructure. During the past 40 years, studies have illustrated that construction productivity has declined at an average annual rate of 0.6 percent.³ This trend is in stark contrast to all other non-farm industries (e.g., manufacturing) which have improved labor productivity at an average rate of 1.8 percent per year. Industry studies have identified inefficiencies ranging from 25 percent to 50 percent in current methods for coordinating labor and managing, moving, and installing construction materials.⁴

Other industries have realized productivity advances largely due to the integration of information, automation, and sensing technologies with innovative work processes. Leading industry groups, such as the Construction Industry Institute (CII), Construction Users Roundtable (CURT) and FIATECH, have identified the critical need for fully integrating and automating construction processes. The application of these advanced methods and technologies could enable breakthrough improvements in the delivery, quality, and reliability of the nation's infrastructure.

The challenges to developing and deploying breakthrough improvements in the delivery of physical infrastructure include: the complexity and variability of design and construction (both the work process and the built product), the unstructured environment of a construction site, and the inefficient processes in place for coordinating labor and movement of components. A patchwork of industry associations, government/private research organizations, and consortia are attempting to address innovation in construction project delivery. However, progress is hampered by the reluctance to adopt innovations that will initially add risk and cost.

Some Key Components of the Nation's Infrastructure

Roads, bridges, and rails – ground-based transport of people and goods over thousands of miles

Power – generation, transmission, and delivery of electricity to millions of homes and businesses

Water systems – clean drinking water provided within cities and to rural areas across the country

Dams, levees, and inland waterways – transport over waterways and maintenance of water resources

Aviation – commercial airports for passengers and cargo

³ Teicholz, P., "Labor Productivity Declines in the Construction Industry: Causes and Remedies," AECbytes Viewpoint, Issue 4, April 14, 2004.

⁴ Chapman, R.E., Butry, D.T., "Measuring and Improving the Productivity of the U.S. Construction Industry: Issues, Challenges, and Opportunities," NIST White Paper, May 2008.

A. The NRC 2009 Report on Construction Competitiveness and Efficiency

In 2009, a report released by the National Research Council⁵ identified five activities that could lead to breakthrough improvements in construction efficiency relatively soon, within 2-10 years. These include:

1. Widespread deployment and use of interoperable technology applications
2. Improved job-site efficiency through effective interface of people, processes, materials, equipment and information
3. Greater use of prefabrication, preassembly, modularization, and off-site fabrication
4. Innovative widespread use of demonstration installations
5. Effective performance measurements

These five activities are interrelated and interdependent on a number of levels. As noted in the NRC report, successfully establishing these concepts as standard operating practices will require a strategic, collaborative approach by critical stakeholders, including larger corporations and government agencies that invest hundreds of millions of dollars in infrastructure projects. To achieve widespread changes in construction practices will also require participation by the many contractors, subcontractors, architects, engineers, and others involved in projects throughout all phases of development.

The NRC Report provides a strong foundation and suggests a path forward to advances in construction productivity and competitiveness. The recommendations put forth were arrived at through extensive discussions with a wide range of stakeholders in the construction industry. As such, the NRC Report represents a consensus view of the current challenges and actions needed to improve construction productivity and efficiency.

The Building and Fire Research Laboratory (BFRL) of the National Institute of Standards and Technology (NIST) commissioned this baseline to build on the important findings of the 2009 NRC report. The baseline is based on a survey of currently available literature (beyond the NRC Report) and provides additional information on the underlying measurement issues related to improving construction productivity.

The baseline is a preliminary perspective only and is not intended to be all-inclusive of the measurement needs in this area. Subsequent review of this document by industry stakeholders will be undertaken to fill in the gaps and more fully articulate and prioritize the enabling measurement science needed to achieve significant improvements in infrastructure delivery. With this increased knowledge, NIST will be able to better define the urgent actions needed going forward to address mission-relevant recommendations from the NRC report. The baseline will also aid in defining common metrology problems that cut across multiple sectors, and guide NIST in a critical path of work that will enable solutions with maximum national impacts.

⁵ National Research Council of the National Academies. "Advancing the Competitiveness and Efficiency of the U.S. Construction Industry," The National Academies Press, 2009. www.nap.edu/catalog/12717.html

B. The Role of Measurement Science

The term *measurement science* includes: (1) the development of performance metrics, measurement methods, predictive tools, and protocols as well as reference materials, data, and artifacts; (2) the conduct of inter-comparison studies and calibrations; (3) the evaluation and/or assessment of technologies, systems, and practices; and (4) the development and/or dissemination of technical guidelines and basis for standards, codes, and practices -- in many instances via testbeds, consortia, and/or other partnerships.⁶

Measurement science is directly related to and an important enabler of all five of the recommended activities in the NRC Report. Advancements in measurement science and quality assurance techniques will enable firms to deploy potential improvements, as well as evaluate the cost savings of integration and automation technologies over traditional approaches. Specifically, measurement science is needed to:

- determine construction labor productivity at both discrete and aggregate levels;
- enable real-time monitoring and control of construction processes;
- enable automated access to and integration of diverse information systems;
- and evaluate the performance of promising automation and integration technologies in construction practice.

Components of Measurement Science

- *Reference Data*
- *Reference Materials*
- *Measurement Methods*
- *Methods of Test*
- *Test Beds*
- *Predictive Tools*
- *Performance Metrics*
- *Comparison Studies*
- *Assessment of Technologies*
- *Information Models*
- *Protocols*
- *Technical Guidelines*

Measurement issues occur at all spectrums of the delivery process, from planning to completion (Figure 1). Data on cost, scheduling, and even local site conditions, for example, are needed for project planning and permitting, as well as construction and procurement. Other examples include the characteristics of materials of construction, which are needed to support design and construction, and performance metrics, which enable safety and cost-effectiveness throughout the construction process.

Figure 1. Stages of Infrastructure Delivery



⁶ Chapman, R.E., Butry, D.T., "Measuring and Improving the Productivity of the U.S. Construction Industry: Issues, Challenges, and Opportunities," NIST White Paper, May 2008.

The BFRL plans to work with industry and the research community to overcome barriers and assist in delivering the needed measurement science. Providing new or enhanced measurement capabilities will enable industry to move forward with greater productivity through:

- reduction of infrastructure project delivery times and construction costs;
- increased capabilities to identify and implement productivity-improving practices and technologies;
- reduced uncertainty, unpredictability, and risk in construction processes; and
- new construction processes and capabilities.

C. Study Scope and Objectives

As noted earlier, the intent of this baseline is to build on the important findings of the 2009 NRC report with respect to the measurement challenges related to increasing construction productivity. The main objectives of the study are to:

- Develop a comprehensive picture of industry stakeholders and relevant resources for information and networking;
- Identify measurement science needs, including new opportunities as well as those that have already been identified and even researched; and
- Aid in identifying cross-cutting measurement issues to maximize the impact of metrology improvements on construction productivity across sectors.

To determine the focus of this baseline, BFRL reviewed assessments of the Nation's infrastructure¹ and identified four important sectors for further study to articulate the measurement science needed to achieve breakthrough improvements in infrastructure delivery: **roads, bridges, power generation, and water supply and wastewater systems**. Improvements in these sectors could also provide spill-over benefits to other construction sectors. Further, identifying common barriers and opportunities across these sectors will enable NIST to apply their efforts in ways that will have the greatest impact across the construction industry.

The sectors selected for this study are some of the most critical to our infrastructure. The nation has about 1 million miles of water mains, 600,000 bridges, 4 million miles of public roadways,⁷ and 3,100 electric utilities generating electricity carried over 157,000 miles of high voltage transmission lines.⁸

Numerous studies by both the public and private sectors have repeatedly noted that as a nation, we have failed to properly maintain, develop, and invest in the continued health and growth of this infrastructure. The highly publicized 2009 Report Card for America's Infrastructure, produced by the American Society of Civil Engineers (<http://www.infrastructurereportcard.org/>), awarded "Cs" and "Ds" to eleven components of the U.S. infrastructure. The sectors selected for this study all received a "D" score, with the

⁷ NIST, *Advancing Sensing Technologies and Advanced Repair Materials for the Infrastructure*; 2009.

⁸ ASCE 2009 Report Card for America's Infrastructure. <http://www.infrastructurereportcard.org/>

exception of bridges, which received a “C”. The ASCE Report Card notes that a five year investment of \$2.2 trillion will be required to upgrade the nation’s infrastructure to acceptable levels.

D. Methodology

To initiate the study, a comprehensive list of literature relevant to each sector was compiled, including government reports, roadmaps, and strategic plans; trade association and industry consortium evaluations; academic papers; and the research portfolios of national laboratories and institutes. Internet websites were tapped for information on major public and private organizations.

The literature was reviewed to provide information on the primary stakeholders, relevant resources, and measurement needs. Stakeholders include government agencies, departments, and offices engaged in infrastructure issues, as well as relevant trade associations, industry groups, standard development organizations, and regulatory associations. A summary description is provided for each entity and program of interest. Relevant resources include major conferences, databases, and journals, with direct links provided for each.

Infrastructure delivery is a highly capital-intensive process which often spans large geographical areas, multiple jurisdictions, and numerous contractors. To aid in identifying and presenting measurement needs, an organizing structure was used that is based on typical industry practices. These include the five separate phases of infrastructure delivery shown in Figure 1 and below. Each of these phases has its own set of measurement issues and barriers.

- Project planning, scheduling, and permitting
- Design
- Procurement and procurement scheduling
- Construction scheduling, productivity, and techniques
- Commissioning and Handover (to the owning/operating organization, including handover to operations and maintenance)

The overall scope of the methodology is shown in Figure 2. The source literature was reviewed for measurement needs within these phases. For each sector, the results are presented in a matrix format which cross-references the five phases and three key categories: 1) cost, 2) scheduling, and 3) quality and functionality. For each measurement need, information is provided on the measurement challenges and/or needs, and the potential approaches and outcomes. In addition, the source document for each measurement challenge is referenced.

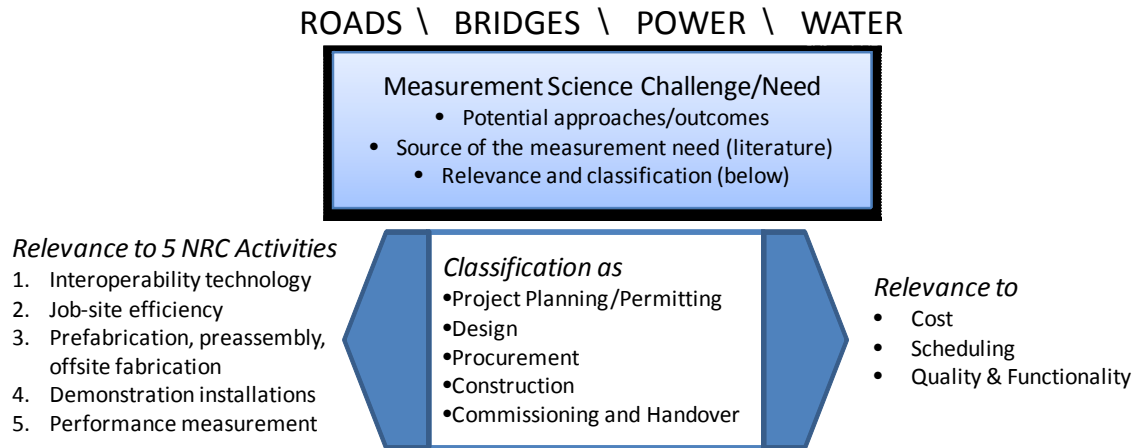


Figure 2. Scope of the Baseline Methodology

To allow for analysis and identification of synergies with the 2009 NRC Report, each measurement challenge is associated with the five recommended NRC activities, as appropriate. This permits identification of measurement challenges that relate to the NRC Report, as well as those that exist outside the scope of that report.

It should be noted that the source documents used for this review are in most cases not focused on measurement science, i.e., they are focused on technology challenges or barriers or broader perspectives. As a result, information is lacking in many cases on the finer details of the measurement need, why it exists, and/or the potential solutions. In addition, there are areas where no measurement challenges have been identified in the literature within some of the categories. This does not mean that measurement needs do not exist; rather that they are not documented in the literature in a publically available report or journal.

Despite these limitations, the presented results provide a good initial perspective of the measurement challenges related to increasing construction productivity in the four selected sectors. Further review of and input to this baseline from stakeholders in the construction sector will be needed to further articulate the full scope of measurement challenges that exist. This will be accomplished by providing the initial baseline summaries to focus groups consisting of industry experts for review and validation of the preliminary findings of each sectoral report. Following this, the findings and comments of the focus groups will be compiled and used to form the foundation for a workshop to be held in May of 2010. The purpose of this will be to identify additional measurement science needs as well as to further expand upon infrastructure technology and process opportunities and barriers.

II. BASELINE PROFILE - BRIDGES

The ASCE Report Card assigns a “C” to the nation’s bridge infrastructure, the highest grade it assigns any national infrastructure component. It also notes that while bridges are generally designed to be structurally sound for 50 years – the average age of the nation’s bridges is 43 years. According to the U.S. Department of Transportation, as of December 2008, 12.1% of the nation’s bridges were categorized as structurally deficient and 14.8% were categorized as functionally obsolete. Maintaining the current overall level of bridge conditions (keeping the backlog of deficient bridges steady) would require a combined public and private investment of \$650 billion over 50 years, for an average annual investment level of \$13 billion.⁹ There is the opportunity for improved design, construction, and maintenance technologies to both reduce the cost of O&M, and increase the speed, as well as the quality and longevity of renovation and new bridge construction.

The following sections present a list of resources relevant to the construction processes of bridges, as well as potential applications, opportunities, and challenges for measurement science.

A. Key Stakeholders

Many stakeholders are involved in addressing the variety of bridge infrastructure issues. Listed here are a few of the sector’s prominent players, with a larger list including summary descriptions of the entities located in Section E below.

- American Association of State Highway and Transportation Officials (AASHTO)
- Bridge Engineering Association
- Federal Highway Administration (FHWA)
- International Association for Bridge and Structural Engineering (IABSE)
- International Association for Bridge Maintenance and Safety (IABMAS)
- National Bridge Research Organization (NaBRO)

There are also stakeholders such as standards development organizations, engineering firms, and trade groups that have interests and expertise in many different aspects of infrastructure. Some prominent cross-cutting organizations are noted here. A further listing of stakeholders with summary descriptions can be found in Appendix A.

- American Society of Civil Engineers (ASCE)
- ASTM International
- Construction Industry Institute (CII)
- Construction Users Roundtable (CURT)
- FIATECH

⁹ ASCE Infrastructure Report Card—Bridges;
http://www.infrastructurereportcard.org/sites/default/files/RC2009_bridges.pdf

B. Technology and Process Opportunities and Barriers

The survey of available literature has presented an assortment of technology and process opportunities and barriers for the advancement of bridge infrastructure delivery. Listed here are several recurring themes which have been extracted from the primary compilation of measurement science needs and considerations listed in the table in Section C.

- Opportunities for greater accessibility to information and the integration of data to improve project planning speed and efficiency
- Increased use of accelerated construction methods such as prefabrication, preassembly, modularization, and off-site construction to support the minimization of field fabrication efforts and enhance on-site construction efficiency
- Development of measurement technologies and analysis methods such as predictive models, smart sensors, and embedded systems to support bridge management and maintenance through the monitoring of bridge structure

C. Measurement Science Needs and Considerations

Table II-1. Bridge Infrastructure Measurement Baseline				
Delivery Improvement	Measurement Science Challenge/Need	Potential Approaches/Outcomes	Resources and Source Documents	Relevant NRC Activity*
Project Planning and Permitting				
Cost				
Scheduling	Data and information to support new permitting and relocation processes and accommodate the needs and rights of utilities and railroads that share roadway rights-of-way to keep projects on schedule and budget	New, streamlined scheduling, permitting, and relocating processes that allow for the timely and efficient progression of renewal projects for agencies, utilities, and railroads; develop recommendations for the institutional and procedural changes necessary for implementation of those processes.	Implementing the Results of the Second Strategic Highway Research Program: Saving Lives, Reducing Congestion, Improving Quality of Life – Special Report 296	1
Quality and Functionality	Facilitation of an innovative and equitable contracting environment through performance-based specifications	Performance-based specifications that afford the contractor greater construction control while managing agency risk, as well as on re-examining the allocation of risk inherent in the special nature of accelerated construction.	Implementing the Results of the Second Strategic Highway Research Program: Saving Lives, Reducing Congestion, Improving Quality of Life – Special Report 296	5

Table II-1. Bridge Infrastructure Measurement Baseline				
Delivery Improvement	Measurement Science Challenge/Need	Potential Approaches/Outcomes	Resources and Source Documents	Relevant NRC Activity*
	Measurement infrastructure to support development of a long-term highway infrastructure performance program that includes databases, tools, test methods, procedures, and technologies to combine bridge and pavement information	Collection of meaningful data to support integrated asset management systems and processes that consider the full life cycle of highway infrastructure from planning through design, construction, and preservation.	Highways of the Future – A Strategic Plan for Highway Infrastructure Research and Development	1
Design				
Cost				
Scheduling				
Quality and Functionality	Innovative Load Testing Systems for bridge foundations (i.e., Statnamic rapid load test, the Osterberg load cell, and several dynamic load test systems)	More reliable design information to allow for foundation optimization. Allows for economic and faster load testing; several methods need documentation for standardized test procedures and data interpretation.	Geotechnical Research Program	4
	Adequate resistance factors for Load Resistance and Factor Design (LRFD)	Availability of resistance factors will make for an orderly transition to LRFD methods.	Geotechnical Research Program	4
	Micropile technology characterization	Requires investigation of both vertical (compression and tension) and lateral resistance (structurally and geotechnically) of micropile systems.	Geotechnical Research Program	4
	Integration of measurements and data to support Automated Geotechnical Information and Design Aid System	Integration of all of the FHWA research-quality databases and recently developed design improvements into a comprehensive design aid system to allow bridge engineers to quickly and economically obtain information and evaluate design alternatives from a centrally located computer source.	Geotechnical Research Program	1

Table II-1. Bridge Infrastructure Measurement Baseline				
Delivery Improvement	Measurement Science Challenge/Need	Potential Approaches/Outcomes	Resources and Source Documents	Relevant NRC Activity*
	Characterization of geosynthetic reinforcement application and design criteria	Data to answer questions related to mobilization of the resistance in the composite mass structure when using geosynthetic materials combined with modular blocks and granular soil materials as foundation support for bridges and excavation support for roadways. Also provide resolution to other design issues such as vertical spacing distances between the geosynthetic reinforcing sheets and the connection methods between the reinforcing elements and the facing blocks.	Geotechnical Research Program	4
	Parametric studies of the behavior of Mechanically Stabilized Earth Walls (MSEWs)	Conduct further studies that implement experimental data from laboratory and large-scale tests to quantify the effects of connection strength, reinforcement stiffness, and soil properties such as soil stiffness and dilatancy on the behavior of MSEWs.	Effects of Geosynthetic Reinforcement Spacing on the Behavior of Mechanically Stabilized Earth Walls	4
	Data and tools to support integrated and automated design and construction systems	Integrated system for design, construction, and life cycle management for steel and concrete bridges, including superstructure and substructure.	Integrated Bridge Project Delivery and Life Cycle Management	1
	Synthesis study of performance and quality of precast structural elements for bridge construction	Document the use of prefabricated components and systems that minimize traffic disruption in the work zone while maintaining construction quality.	Prefabricated Bridge Elements and Systems Research	4
	Characterization of the behavior of stud pockets connecting precast slab and steel girder assemblies	Supports systems such as the Texas DOT system for casting full-depth concrete slabs on steel girders on the ground prior to lifting them into their final position. System reduces on-site construction time, minimizes traffic disruption, and increases safety in construction zones.	Prefabricated Bridge Elements and Systems Research	4
	Data and measurements to enable new techniques and technologies that are compatible with existing and potential new bridge systems	Innovations require some modifications of standard design approaches and new bridge designs that are more compatible with existing innovative construction techniques and technologies.	Implementing the Results of the Second Strategic Highway Research Program: Saving Lives, Reducing Congestion, Improving Quality of Life – Special Report 296	1
Procurement				
Cost				
Scheduling				

Table II-1. Bridge Infrastructure Measurement Baseline				
Delivery Improvement	Measurement Science Challenge/Need	Potential Approaches/Outcomes	Resources and Source Documents	Relevant NRC Activity*
Quality and Functionality				
Construction				
Cost	Standard practice for measuring task-level and project-level productivity	Improved metrics will increase the rate of investment in productivity-enhancing technologies, including information, communication, and automation and integration technologies, conveying benefits in the form of lower costs of building services and products.	Metrics and Tools for Measuring Construction Productivity: Technical and Empirical Considerations	5
Scheduling	Data and tools to enable faster in-situ construction methods	Supports use of innovative technologies to replace traditional methods, and adaptation of roadway and bridge designs to optimize use of new technologies. Enhances completion of preliminary engineering tasks, such as the timely relocation of public utilities, before construction begins; and the development of techniques and guidelines better suited to renewal construction, such as performance specifications and rapid non-destructive testing.	Implementing the Results of the Second Strategic Highway Research Program: Saving Lives, Reducing Congestion, Improving Quality of Life – Special Report 296	2
Quality and Functionality	Methods/data to resolve QC/QA problems with auger-cast piling, auger-cast, or continuous flight auger (CFA) piles	CFA piles with automated computer control for monitoring installation and automated QC; also bored cased secant pile (CSP) techniques with automated computer control.	Innovative Technology for Accelerated Construction of Bridge and Embankment Foundations in Europe	2
	Instrumentation on compaction equipment to measure dynamic modulus in real time	Improved compaction uniformity and effective compaction effort; 100% QC coverage for performance-based approaches to specifications.	Innovative Technology for Accelerated Construction of Bridge and Embankment Foundations in Europe	2
	Real-time automated installation control and documentation	Systems to monitor, measure, control, and document critical aspects of technology, thereby allowing rapid construction without compromising quality.	Innovative Technology for Accelerated Construction of Bridge and Embankment Foundations in Europe	2

Table II-1. Bridge Infrastructure Measurement Baseline				
Delivery Improvement	Measurement Science Challenge/Need	Potential Approaches/Outcomes	Resources and Source Documents	Relevant NRC Activity*
	QC/QA program parameters modeled after the ISO 9000 series process	Provide more consistency in design and construction quality.	Innovative Technology for Accelerated Construction of Bridge and Embankment Foundations in Europe	2
	Soil-mix design criteria and construction quality control procedures	Significant potential to reduce costs and time delays if rational guidance for strength, deformation, and durability concerns can be developed.	Geotechnical Research Program	2
	Optimization of top-down construction techniques (i.e., soil nailing, ground anchor tiebacks, slurry walls)	Further refinements to optimize techniques include increased knowledge of the load transfer mechanism between the reinforcing elements and various soil types or ground treatments; and study of corrosion and durability aspects.	Geotechnical Research Program	4
	Measurements to support minimization of field fabrication efforts	Prefabrication, modular construction, and innovative installation strategies for bridges and pavements; rapid construction systems such as modular pavements and prefabricated bridges or bridge elements to help reduce traffic disruption by permitting elements of pavements, bridges, and other roadway infrastructure to be built off-site and then installed in assembly-line fashion; off-site construction permits more intensive quality control, thus improving the level of performance and longevity of the highway infrastructure.	Implementing the Results of the Second Strategic Highway Research Program: Saving Lives, Reducing Congestion, Improving Quality of Life – Special Report 296	3
	Data and tools to support innovative, high speed inspection and monitoring processes that facilitate faster construction	Faster construction inspection and monitoring of performance.	Implementing the Results of the Second Strategic Highway Research Program: Saving Lives, Reducing Congestion, Improving Quality of Life – Special Report 296	2
	Accelerated construction, rehabilitation, and reconstruction methodologies	Support for: prefabricated structures, including bridge substructures and superstructures; geotechnical construction; advanced fabrication, construction, and erection techniques and equipment. All of these involve a substantial investment by contractors. If there is no incentive for the contractor to invest, competitive pressures will result in	Highways of the Future – A Strategic Plan for Highway Infrastructure Research and Development	3

Table II-1. Bridge Infrastructure Measurement Baseline				
Delivery Improvement	Measurement Science Challenge/Need	Potential Approaches/Outcomes	Resources and Source Documents	Relevant NRC Activity*
		business as usual.		
	Bridge and pavement construction standards	Ability to hold contractors responsible for meeting structural and functional thresholds over the long term (more than 15 years).	Highways of the Future – A Strategic Plan for Highway Infrastructure Research and Development	2
	Database of project-level productivity measures for capital facilities; while sources exist for task-level productivity data, no such sources exist for project-level productivity measures	Database consisting of both raw and index-based metrics, ideally incorporating the capability to analyze how the use of industry best practices and automation and integration technologies affect project-level productivity.	Metrics and Tools for Measuring Construction Productivity: Technical and Empirical Considerations	5
Commission and Handover (including O&M)				
Cost	Advanced infrastructure performance prediction and design models for both service-level and extreme events	Facilitates effective inspection, maintenance, and repair.	Highways of the Future – A Strategic Plan for Highway Infrastructure Research and Development	1
Scheduling	Improved bridge and pavement monitoring sensors and systems (e.g., smart sensors, embedded sensors and systems)	Permits both periodic and continuous performance evaluation and accurate condition assessment.	Highways of the Future – A Strategic Plan for Highway Infrastructure Research and Development	1
	Development, testing and validation of cost-effective, field-deployable sensing systems that are capable of providing continuous data	Enables effective prioritization of repair and retrofit schedules.	NIST Civil Infrastructure White Paper 2009	1
Quality and Functionality	High-speed, high-resolution, non-destructive technologies	Allows for non-destructive inspection, evaluation, and performance monitoring.	Highways of the Future – A Strategic Plan for Highway Infrastructure Research and Development	1

Table II-1. Bridge Infrastructure Measurement Baseline				
Delivery Improvement	Measurement Science Challenge/Need	Potential Approaches/Outcomes	Resources and Source Documents	Relevant NRC Activity*
	Data and tools to enable improved systems, preservation techniques, analysis methods, and technologies	Prevention of material degradation, corrosion, cracking, fatigue, and other serviceability problems.	Highways of the Future – A Strategic Plan for Highway Infrastructure Research and Development	1
	Ability to measure and monitor the dynamic response characteristics of a bridge substructure	Determination of bridge foundation conditions may be applied to quantify losses in foundation stiffness caused by earthquakes, scour, and impact events. Identification of bridge foundation type may be employed to estimate bridge stability and vulnerability under dead and live load ratings.	Dynamic Bridge Substructure Evaluation and Monitoring	1
	Sensing and measurement technologies to support bridge management; non-quantitative, subjective, highly variable, and nonspecific nature of current data make it inadequate for comprehensive long-term decision support.	Quantitative data for bridge management will provide a greater level of accuracy, reliability, and utility of data necessary for asset management. Enhanced safety and maintenance can result from improved incident detection and assessment.	The Role of Sensing and Measurement in Achieving FHWA's Strategic vision for Highway Infrastructure	1
<p>Table Notes</p> <p>*Five recommended activities from the 2009 NRC Report:</p> <ol style="list-style-type: none"> 1. Widespread deployment and use of interoperable technology applications 2. Improved job-site efficiency through effective interface of people, processes, materials, equipment and information 3. Greater use of prefabrication, preassembly, modularization, and off-site fabrication 4. Innovative widespread use of demonstration installations 5. Effective performance measurement 				

D. Government Entities & Programs

U.S. Department of Transportation (U.S. DOT)

- Federal Highway Administration (FHWA)
Geotechnical Engineering & Geotechnical Research Program
<http://www.fhwa.dot.gov/engineering/geotech/index.cfm>
<http://www.tfrc.gov/structur/gtr/geohome.htm>

The scope of their research includes analytical studies, laboratory testing, and field monitoring of construction sites in order to develop, refine, and validate new or improved designs. It includes research into a wide range of materials properties, instrumentation techniques, monitoring methods, analytical techniques, performance assessment, and design principles.

Innovative Bridge Research and Construction Program (IBRC)
<http://www.fhwa.dot.gov/bridge/ibrc/>

IBRC is an initiative by the FHWA to provide direction and funding to help state, county and local bridge owners incorporate innovative materials and materials technologies in their bridge projects. The intent of the program is to reduce congestion associated with bridge construction and maintenance projects, to increase productivity by lowering the life-cycle costs of bridges, to keep Americans and America's commerce moving, and to enhance safety.

Innovative Bridge Research and Deployment Program (IBRD)

<http://www.fhwa.dot.gov/bridge/ibrd/index.cfm>

IBRD promotes, demonstrates, evaluates, and documents the application of innovative designs, materials, and construction methods in the construction, repair, and rehabilitation of bridges and other highway structures.

National Bridge Inspection Standards (NBIS)

<http://www.fhwa.dot.gov/bridge/nbis.htm>

The NBIS sets the national standards for the proper safety inspection and evaluation of all highway bridges.

Prefabricated Bridge Elements and Systems

<http://www.fhwa.dot.gov/bridge/prefab/index.cfm>

Prefabricated bridge elements and systems may be manufactured on-site or off-site, under controlled conditions, and brought to the job location ready to install. Traffic and environmental impacts are reduced, constructibility is increased, and safety is improved because work is moved out of the right-of-way to a remote site, minimizing the need for lane closures, detours, and use of narrow lanes. Prefabrication of bridge elements and systems can be accomplished in a controlled environment without concern for job-site limitations, which increases quality and can lower costs.

Prefabricated bridge elements especially tend to reduce costs where use of sophisticated techniques would be needed for cast-in-place, such as in long water crossings or higher structures, like multi-level interchanges.

Turner-Fairbank Highway Research Center (TFHRC)

<http://www.tfhrc.gov/>

TFHRC provides FHWA and the world highway community with the most advanced research and development related to new highway technologies. The research focuses on providing solutions to complex technical problems through the development of more economical, environmentally sensitive designs; more efficient, quality controlled constructions practices; and more durable materials.

■ Research and Innovative Technology Administration (RITA)

<http://www.rita.dot.gov/>

RITA coordinates the U.S. DOT's research programs and is charged with advancing the deployment of cross-cutting technologies to improve our Nation's transportation system. As directed by Congress in its founding legislation, RITA leads DOT in: coordinating, facilitating and reviewing the Department's research and development programs and activities; advancing innovative technologies, including intelligent transportation systems; performing comprehensive transportation statistics research,

analysis and reporting; and providing education and training in transportation and transportation-related fields.

Bureau of Transportation Statistics

<http://www.bts.gov/>

The Bureau provides data and statistics on all modes of transportation and transportation infrastructure including airlines, roads, rail, and household travel patterns.

Intelligent Transportation Systems (ITS)

<http://www.its.dot.gov/index.htm>

Intelligent transportation systems (ITS) improve transportation safety and mobility and enhance American productivity through the integration of advanced communications technologies into the transportation infrastructure and in vehicles. ITS encompass a broad range of wireless and wire line communications-based information and electronics technologies.

University Transportation Centers

http://utc.dot.gov/utc_safetea-lu.html

Internationally recognized centers of excellence, fully integrated within institutions of higher learning, that serve as a vital source of leaders who are prepared to meet the nation's need for safe, efficient and environmentally sound movement of people and goods.

Volpe National Transportation Systems Center

<http://www.volpe.dot.gov/index.html>

Volpe has responded to most of the major transportation challenges of the last quarter century, including national security, world energy crises, and related evaluations of alternative fuels; and the need to modernize air traffic control systems and to develop sophisticated logistics and communications systems to support national initiatives overseas.

- Federal Transit Administration (FTA)

<http://www.fta.dot.gov/>

The FTA provides stewardship of combined formula and discretionary programs totaling more than \$10B to support a variety of locally planned, constructed, and operated public transportation systems throughout the United States.

E. Standards Organizations, Trade Associations, & Stakeholders

The following is a list of nationally relevant organizations involved in the deployment of bridge infrastructure.

- American Association of State Highway and Transportation Officials (AASHTO)

<http://www.transportation.org/>

AASHTO is a nonprofit, nonpartisan association representing highway and transportation departments in the 50 states, the District of Columbia, and Puerto Rico. It represents all five transportation modes: air, highways, public transportation,

rail, and water. Its primary goal is to foster the development, operation, and maintenance of an integrated national transportation system.

- American Concrete Institute (ACI)

<http://www.concrete.org/general/home.asp>

The ACI is a nonprofit technical and educational society organized in 1904 and is one of the world's leading authorities on concrete technology. ACI is a forum for the discussion of all matters related to concrete and the development of solutions to problems. ACI publishes reliable information on concrete and its applications, conducts educational seminars, provides a standard certification program for the industry, provides local forums for discussion through the Chapter program, and encourages student involvement in the concrete field.

- American Concrete Pavement Association (ACPA)

<http://www.pavement.com/>

ACPA's National office is behind every chapter and every member addressing the broad range of issues facing the industry today; ACPA National provides members with professional services through: National Technical Initiatives, National Market Development Initiatives, and National Government Relations Advocacy, as well as Local Initiatives and Support.

- American Council of Engineering Companies (ACEC)

<http://www.acec.org/>

The ACEC is the voice of America's engineering industry. Council members – numbering more than 5,500 firms throughout the country – are engaged in a wide range of engineering works that propel the nation's economy, and enhance and safeguard America's quality of life. ACEC is a large federation of 51 state and regional councils representing the great breadth of America's engineering industry. ACEC member firms employ more than hundreds of thousands of engineers, architects, land surveyors, scientists, and other specialists, responsible for more than \$200 billion of private and public works annually. Member firms range in size from a single registered professional engineer to corporations employing thousands of professionals.

- American Institute of Steel Construction (AISC)

<http://www.aisc.org/>

The AISC is a not-for-profit technical institute and trade association established in 1921 to serve the structural steel design community and construction industry in the United States. AISC's mission is to make structural steel the material of choice by being the leader in structural-steel-related technical and market-building activities, including: specification and code development, research, education, technical assistance, quality certification, standardization, and market development. AISC has a long tradition of service to the steel construction industry providing timely and reliable information.

- American Road & Transportation Builders Association (ARTBA)

<http://www.artba.org/>

ARTBA is a federation whose primary goal is to aggressively grow and protect transportation infrastructure investment to meet the public and business demand for safe and efficient travel. In support of this mission, ARTBA also provides programs

and services designed to give its 5,000+ public and private sector members a global competitive edge.

- American Segmental Bridge Institute (ASBI)

<http://www.asbi-assoc.org/>

ASBI provide a forum where owners, designers, constructors, and suppliers can meet to further refine current design, construction and construction management procedures, and evolve new techniques that will advance the quality and use of concrete segmental bridges. ASBI is a unique organization in that all components of the bridge construction industry are included as members.

- American Society of Civil Engineers (ASCE)

<http://www.asce.org/>

Founded in 1852, the American Society of Civil Engineers (ASCE) represents more than 147,000 members of the civil engineering profession worldwide, and is America's oldest national engineering society. ASCE's vision is to position engineers as global leaders building a better quality of life.

- American Society of Testing and Materials (ASTM International)

<http://www.astm.org/index.shtml>

ASTM International is one of the largest voluntary standards development organizations in the world—a trusted source for technical standards for materials, products, systems, and services. Known for their high technical quality and market relevancy, ASTM International standards have an important role in the information infrastructure that guides design, manufacturing and trade in the global economy.

- Asphalt Emulsion Manufacturers Association (AEMA)

<http://www.aema.org/>

AEMA is a proactive organization dedicated to the advancement of the asphalt emulsion industry, constantly focusing on system preservation and the construction of the world's infrastructure. Since 1973, the Association has served as a forum for discussion, a clearinghouse of information, and a platform of action for the asphalt emulsion industry. Through its meetings, seminars, website, and publications, AEMA has helped to bring state-of-the-art asphalt emulsion technology to all parts of the world.

- Asphalt Institute

<http://www.asphaltinstitute.org/>

The Asphalt Institute's mission is to promote the use, benefits, and quality performance of petroleum asphalt, through environmental, marketing, research, engineering and technical development, and through the resolution of issues affecting the industry. The Asphalt Institute will achieve its mission through a commitment to the highest standards of ethical and professional conduct and the development of its people, technical expertise, and relationships.

- Association of Equipment Manufacturers (AEM)

<http://www.aem.org/>

AEM membership is made up of more than 800 companies and represents 200+ product lines. AEM's role is to provide trade association services on a global basis for companies that manufacture equipment worldwide in the following industries: Agriculture, Construction, Forestry, Mining and Utility. AEM provides a wide variety

of services that help members compete effectively in the global marketplace. Our core services include: Global Public Policy, Market Information, Technical and Safety, and Trade Shows; along with additional services which include: Global Business Development, Education and Workforce Development.

- Association for Bridge Construction & Design (ABCD; various regional chapters)
<http://abcdpittsburgh.org/>
ABCD aims to: educate bridge designers, constructors, federal, state, and local officials, as well as the general public in the vital role of safe bridges in our society; improve and encourage the science of bridge design, construction and reconstruction by providing a forum for members to exchange and develop new ideas and techniques; provide technical information and assistance to various public and private authorities for bridge programs; and educate and encourage public and private authorities in new and improved techniques for testing and reconstruction.
- Bridge Engineering Association
<http://www.bridgeengineer.org/>
The Bridge Engineering Association is a not-for-profit organization whose mission is to promote the state-of-the-art in bridge engineering technology through the publications of the latest in bridge engineering technology and the organization of conferences, seminars and forums on various themes of interest to the bridge engineering community.
- Concrete Reinforcing Steel Institute (CRSI)
<http://www.crsi.org/>
CRSI serves architects, engineers, contractors and other construction professionals through membership opportunities, design manuals, technical publications, educational seminars and more. CRSI also has a nationwide Region Manager network for local marketing, technical and membership support.
- Construction Industry Institute (CII)
<https://www.construction-institute.org/scriptcontent/index.cfm>
The Construction Industry Institute, based at The University of Texas at Austin, is a consortium of more than 100 leading owner, engineering-contractor, and supplier firms from both the public and private arenas. These organizations have joined together to enhance the business effectiveness and sustainability of the capital facility life cycle through CII research, related initiatives, and industry alliances. A learning organization with a wealth of knowledge and information, CII is unique in the engineering and construction industry.
- Construction Users Roundtable (CURT)
<http://www.curt.org/>
An autonomous, not-for-profit organization, CURT strives to produce meaningful changes within the construction industry-promoting overall cost effectiveness; improving the way construction is planned, managed, justified and executed. Additionally, CURT works toward changing and improving what owners allow, require, and accept responsibility for on their domestic and global construction projects.
- FIATECH
<http://fiatech.org>

FIATECH is a consortium of industries and companies – owners from the industrial, power, and retail markets that, of necessity, build large assets such as refineries, power plants, large commercial buildings, or manufacturing facilities. In addition, it includes the leading providers of engineering, design, and construction services. FIATECH not only provides a communication hub for members to quickly learn of new approaches, methods, and materials; it also does things. Project teams are formed to identify and accelerate the adoption of technologies and systems; demonstration projects are conducted to validate and perfect new approaches or methods; and teams are formed to aid and facilitate the deployment of those breakthrough initiatives that have been validated. In essence, it is each member's highly robust R&D organization.

- **Innovative Pavement Research Foundation (IPRF)**
<http://www.iprf.org/>
Provide a unified means of building resources, developing strategies, and implementing programs to address concrete pavement research, technology advancement and transfer, and public education on the inherent economic efficiencies, safety, and quality-of-life advantages of portland cement concrete pavements for highways, streets, roads, and airports. IPRF is engaged in research focused on five goals associated with concrete pavement research, technology, and innovation, including: develop current best practices, reduce initial costs, reduce user delays, develop cost-competitive options, and achieve design expectations.
- **International Association for Bridge and Structural Engineering (IABSE)**
<http://www.iabse.org/>
IABSE is a scientific/technical association with 3,900 members in 100 countries, counting 48 National Groups worldwide. IABSE deals with all aspects of structural engineering: the science and art of planning, design, construction, operation, monitoring and inspection, maintenance, rehabilitation and preservation, demolition and dismantling of structures, taking into consideration technical, economic, environmental, aesthetic and social aspects. The term 'Structures' includes bridges, buildings and all types of civil engineering structures, composed of any structural material.
- **International Association for Bridge Maintenance and Safety (IABMAS)**
<http://iabmas.atlss.lehigh.edu/index.htm>
The International Association for Bridge Maintenance and Safety (IABMAS) encompasses all aspects of bridge maintenance, safety, and management. Specifically, it deals with: bridge repair and rehabilitation issues; bridge management systems; needs of bridge owners, financial planning, whole life costing and investment for the future; bridge related safety and risk issues; economic and other implications.
- **International Bridge, Tunnel and Turnpike Association (IBTTA)**
<http://ibtta.org/>
IBTTA is the worldwide alliance of toll operators and associated industries that provides a forum for sharing knowledge and ideas to promote and enhance toll-financed transportation services.
- **International Council for Research and Innovation in Building and Construction (CIB)**
<http://www.cibworld.nl/site/home/index.html>

CIB was established in 1953 as an Association whose objectives were to stimulate and facilitate international cooperation and information exchange between governmental research institutes in the building and construction sector, with an emphasis on those institutes engaged in technical fields of research. CIB has since developed into a world wide network of over 5000 experts from about 500 member organizations with a research, university, industry or government background, who collectively are active in all aspects of research and innovation for building and construction.

- International Grooving & Grinding Association (IGGA)

<http://www.igga.net/>

IGGA is a non profit Trade Association founded in 1972 by a group of dedicated industry professionals committed to the development of the diamond grinding and grooving process for surfaces constructed with Portland cement concrete and asphalt. In 1995, the IGGA joined in affiliation with the American Concrete Pavement Association (ACPA) to represent its newly formed Concrete Pavement Restoration Division. The IGGA / ACPA CPR Division now serves as the technical resource and industry representative in the marketing of optimized pavement surfaces, concrete pavement restoration and pavement preservation around the world.

- International Union of Operating Engineers (IUOE)

<http://www.iuoe.org/>

The IUOE is a progressive, diversified trade union that primarily represents operating engineers, who work as heavy equipment operators, mechanics, and surveyors in the construction industry, and stationary engineers, who work in operations and maintenance in building and industrial complexes, and in the service industries.

- Intelligent Transportation Society of America

<http://www.itsa.org/>

The Intelligent Transportation Society of America is the leading advocate for technologies that improve the safety, security and efficiency of the nation's surface transportation system. Our members include private corporations, public agencies, and academic institutions involved in the research, development and design of Intelligent Transportation Systems technologies that enhance safety, increase mobility and sustain the environment.

- National Bridge Research Organization (NaBRO)

<http://www.nabro.unl.edu/index.asp>

In fostering cooperation between academia, industry and government agencies NaBRO will be a liaison in developing and implementing new technologies related to bridge design and construction.

- National Center for Asphalt Technology (NCAT)

<http://www.ncat.us/>

The NCAT at Auburn University has been instrumental in bringing improvements in asphalt pavements to practice across the country for more than two decades. NCAT was created to ensure this industry's ability to provide pavements that are durable, environmentally friendly, quiet, safe and economical. NCAT works with state highway agencies, the Federal Highway Administration, and the highway construction industry to develop and evaluate new products, design technologies and construction methods which quickly lead to pavement improvements. Its research

center and test track make it one of the world's leading institutions for asphalt pavement research and an important source of information for those tasked with maintaining our nation's infrastructure.

- National Concrete Pavement Technology Center

<http://www.cptechcenter.org/>

The National Concrete Pavement Technology Center (National CP Tech Center) at Iowa State University is a national hub for concrete pavement research and technology transfer. The Center was founded in 2000 and currently has four industry sponsors: the American Concrete Pavement Association (ACPA), the Concrete Steel Reinforcing Institute (CRSI), the Iowa Department of Transportation, and the Iowa Concrete Paving Association (ICPA). The Center has been instrumental in developing and helping to advance the nation's strategic plan for concrete pavement research, The CP Road Map.

- National Ready Mixed Concrete Association

<http://www.nrmca.org/>

The National Ready Mixed Concrete Association is the leading industry advocate. Our mission is to provide exceptional value for our members by responsibly representing and serving the entire ready mixed concrete industry through leadership, promotion, education and partnering to ensure ready mixed concrete is the building material of choice. We work in conjunction through a partnership agreement with state associations on issues such as promotion and regulatory concerns and extend what they can do to a national level. Our commitment to our members is second to none and we strive for constant communication on the latest information, products, services and programs to help our members expand their markets, improve their operations and be their voice in Washington.

- National Steel Bridge Alliance (NSBA)

<http://www.aisc.org/contentNSBA.aspx?id=20090&linkidentifier=id&itemid=20090>

The NSBA, a division of the American Institute of Steel Construction (AISC), is dedicated to advancing the state-of-the-art of steel bridge design and construction.

- Portland Cement Association (PCA)

<http://www.cement.org/>

The Portland Cement Association represents cement companies in the United States and Canada. It conducts market development, engineering, research, education, and public affairs programs.

- Post-Tensioning Institute (PTI)

<http://www.post-tensioning.org/>

The Post-Tensioning Institute is recognized as the worldwide authority on post-tensioning. PTI is dedicated to expanding post-tensioning applications through marketing, education, research, teamwork, and code development while advancing the quality, safety, efficiency, profitability, and use of post-tensioning systems.

- Precast/Prestressed Concrete Institute (PCI)

<http://www.pci.org/>

The Precast/Prestressed Concrete Institute (PCI) is the foremost developer of standards and methods for designing, fabricating, and constructing precast concrete structures. As the technical institute of the precast concrete structures industry, PCI maintains the “body of knowledge” necessary for the safety, quality, cost effectiveness,

and continuous improvement of precast concrete structures. PCI also operates the world's leading certification program for firms and individuals in the precast concrete structures industry, and conducts a wide variety of educational seminars, technical conferences, conventions, exhibitions, and awards programs.

F. Reports and Publications

Studies

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American Association of State Highway and Transportation Officials (AASHTO) Transportation Security Task Force. National Needs Assessment for Ensuring Transportation Infrastructure Security. October 2002.

<http://www.transportation.org/sites/security/docs/NatlNeedsAssess.pdf>

American Society of Civil Engineers. 2009 Report Card for America's Infrastructure.

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Monitoring. December 2005 <http://www.springerlink.com/content/g24755632v575g18/>

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Federal Highway Administration. A Laboratory and Field Study of Composite Piles for Bridge Substructures, May 2006. <http://www.tfsrc.gov/structur/pubs/04043/index.htm>

Federal Highway Administration. Dynamic Bridge Substructure Evaluation and Monitoring, September 2005.

<http://www.fhwa.dot.gov/engineering/geotech/pubs/03089/index.cfm>

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Federal Highway Administration. Innovative Technology for Accelerated Construction of Bridge and Embankment Foundations in Europe, 2002.

<http://www.fhwa.dot.gov/engineering/geotech/index.cfm>

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Federal Highway Administration. Step Frequency Ground Penetrating Radar Applications to Highway Infrastructure Measurement and System Integration Feasibility with Complementary Sensors. January 2006.

http://www.gprinstitute.org/workshops/TRB06/Michael%20Scott_Starodub_Step%20Frequency%20Ground%20Penetrating%20Radar%20Applications%20to%20Highway%20Infrastructure%20Measurement.pdf

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National Academies Press. Advancing the Competitiveness and Productivity of the U.S. Construction Industry. 2009. http://www.nap.edu/catalog.php?record_id=12717

National Academies Press. Implementing the Results of the Second Strategic Highway Research Program: Saving Lives, Reducing Congestion, Improving Quality of Life – Special Report 296, 2009. http://books.nap.edu/catalog.php?record_id=12591

National Academies Press. The Federal Investment in Highway Research, 2006-2009: Strengths and Weaknesses – Special Report 295, 2008. http://books.nap.edu/catalog.php?record_id=12536

National Institute of Standards and Technology. Civil Infrastructure – Advancing Sensing Technologies and Advanced Repair Materials for the Infrastructure: Water Systems, Dams, Levees, Bridges, Roads, and Highways, 2009. http://www.nist.gov/tip/comp_09/white_papers/ci_wp_031909.pdf

National Institute of Standards and Technology. Metrics and Tools for Measuring Construction Productivity: Technical and Empirical Considerations, 2009. <http://www.bfml.nist.gov/oae/publications/nistsp/NISTSP1101.pdf>

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Technical Guidance and Manuals

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Strategic Plans and Roadmaps

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National Surface Transportation Infrastructure Financing Commission. Paying Our Way: A New Framework for Transportation Finance. February 2009. http://financecommission.dot.gov/Documents/NSTIF_Commission_Final_Report_Exec_Summary_Feb09.pdf

Additional Information Databases and Resources

Federal Highway Administration. Geotechnical Engineering General Publications. http://www.fhwa.dot.gov/engineering/geotech/library_listing.cfm

Federal Highway Administration. Geotechnical Research Program Publications. <http://www.tfrc.gov/structur/gtr/publication.htm>

Federal Highway Administration. National Bridge Inventory Database. <http://www.fhwa.dot.gov/BRIDGE/britab.cfm>

Federal Highway Administration. Prefabricated Bridge Elements and Systems. <http://www.fhwa.dot.gov/bridge/prefab/pubs.cfm>

Federal Highway Administration Technology Portals:

- Fiber Reinforced Polymer (FRP) Composite Bridge Technology
<http://www.fhwa.dot.gov/bridge/frp/>
- High Performance Concrete
<http://knowledge.fhwa.dot.gov/cops/hpcx.nsf/home>
- High Performance Steel
<http://www.fhwa.dot.gov/bridge/hps.htm>

- High Strength Bolts
<http://www.fhwa.dot.gov/bridge/bolts.htm>
- Load and Resistance Factor Design
<http://www.fhwa.dot.gov/bridge/lrfd/index.htm>
- Segmental Concrete Bridge Technology
<http://www.fhwa.dot.gov/bridge/segmental/index.htm>

G. Journals

- Bridge Design and Engineering
<http://www.bridgeweb.com/>
- Bridges Magazine
<http://www.gobridges.com/>
- Bridge Views Newsletter
http://www.cement.org/bridges/br_newsletter.asp
- Journal of Bridge Engineering
<http://scitation.aip.org/beo/>
- Journal of Computing in Civil Engineering
<http://scitation.aip.org/cpo>
- Journal of Construction Engineering and Management
<http://cedb.asce.org/cgi/WWWdisplay.cgi?0880010>
- Journal of Infrastructure Systems
<http://pubs.asce.org/journals/infrastructure/default.htm>
- Journal of Intelligent Material Systems and Structures
<http://jim.sagepub.com/>
- Journal of Transportation Engineering
<http://pubs.asce.org/journals/transportation/default.htm>
- Journal of Transportation Systems Engineering and Information Technology
http://www.elsevier.com/wps/find/journaldescription.cws_home/712490/description#description
- Journal of Urban Planning and Development
<http://pubs.asce.org/journals/urban/default.htm>
- Public Works Management & Policy
<http://pwm.sagepub.com/>
- Rebuilding America's Infrastructure
<http://www.rebuildingamericainfrastructure.com/tag-bridges-1.html>
- Roads & Bridges
<http://www.roadsbridges.com/index.cfm>
- Structural Engineering International
<http://www.iabse.org/journalsei/index.php>
- Structural Health Monitoring

- <http://shm.sagepub.com/>
- Transportation Journal
<http://www.astl.org/i4a/pages/index.cfm?pageid=3288>
 - Transportation Research
http://www.elsevier.com/wps/find/journaldescription.cws_home/600119/description#description
 - Transportation Research Record (Journal of the Transportation Research Board)
<http://trb.metapress.com/home/main.mpx>
 - Tunnelling and Underground Space Technology
http://www.elsevier.com/wps/find/journaldescription.cws_home/799/description#description

H. Conferences, Workshops, & Training

- New York Bridge Conference
<http://www.bridgeengineer.org/2009/2009welcome.htm>
Topics of Interest: Bridge safety; NDE inspection; bridge design; long span bridges; dynamic performance evaluation; bridge cost; bridge research; accelerated fabrication and construction; LFRD; ASD; bridge deck evaluation; baseline structural modeling; dynamic and seismic analysis; movable bridges; bridge performance; load testing; instrumentation; advanced materials.
Recent Events: New York, NY – August 17-18, 2009
- World Steel Bridge Symposium and Workshops
<http://www.aisc.org/contentNSBA.aspx?id=20090&linkidentifier=id&itemid=20090>
Topics of Interest: AISC certification; accelerated construction; prefabricated bridge elements and systems; cost effectiveness; erection and analysis; practical design.
Recent Events: San Antonio, TX – November 17-20, 2009
- FHWA Bridge Engineering Conference
<http://www.2010bridge.com/>
Topics of Interest: Pre-fabricated bridge elements and systems; fabrication and construction; innovative bridge materials and products; non-destructive bridge evaluation methodology and techniques; inspection/maintenance; steel, concrete, timber, and FRP composite bridges; accelerated bridge construction; design for 100-year service life; case studies; seismic bridge engineering; foundation/geotechnical; substructure.
Recent Events: Orlando, FL – April 8-9, 2010
- International Bridge Conference
<http://www.eswp.com/bridge/>
Topics of Interest: Accelerated bridge construction; bridge management/monitoring/evaluation; bridge rehabilitation; construction; context sensitive design; long span bridges.
Upcoming Events: Pittsburgh, PA – June 6-9, 2010
- International Conference on Bridge Maintenance, Safety and Management
<http://iabmas.atlss.lehigh.edu/index.htm>

Topics of Interest: Bridge repair and rehabilitation issues; bridge management systems; needs of bridge owners, financial planning, whole life costing and investment for the future; bridge related safety and risk issues; economic and other implications.

Upcoming Events: Philadelphia, PA – July 11-15, 2010

- International Association for Bridge and Structural Engineering Symposium

<http://www.iabse.org/conferences/venice2010/index.php>

Topics of Interest: Basis of design; infrastructure hazard and safety concepts; management and planning of operation and maintenance; infrastructure design as a meeting point for architecture; engineering, ethics and social responsibility.

Upcoming Events: Venice, Italy – September 22-24, 2010

- International Bridge Engineering Conference

<http://guest.cvent.com/EVENTS/Info/Summary.aspx?e=4c1cac9a-c7af-4808-8557-cdda0b87362d>

Topics of Interest: Accelerated bridge construction; bridge case studies; bridge Decks; bridge management and preservation; codes and specifications (LRFD); concrete bridges; culverts; foundations/geotechnical; innovative materials/laboratory testing; inspection/monitoring; LRFR/field testing; multi-hazard (e.g., seismic, blast, impact, surge); NDE/NDT; scour/hydrology and hydraulics; steel bridges.

Upcoming Events: San Antonio, TX – December 1-3, 2010

- National Highway Institute Geotechnical Courses

<http://www.fhwa.dot.gov/engineering/geotech/training.cfm>

Topics of Interest: LRFD; design; construction; monitoring; foundations; instrumentation; inspection; qualification.

- Transportation Curriculum Coordination Council Geotechnical Certification Technical Committee

<http://www.fhwa.dot.gov/engineering/geotech/training.cfm>

Topics of Interest: Inspection tutorials and qualifications.

III. BASELINE PROFILE - ROADS

The nation's roads were awarded a "D" grade by the ASCE. The report card also notes that the amount of vehicle miles traveled (VMT) in congestion has increased, while the number of VMT on high quality roads have declined. In addition, the quality of the nation's roads and highways are the worst primarily in urban areas where they receive the most wear and tear. At the same time, the demands and stresses being put on a compromised system are increasing rapidly.¹⁰

The following sections present a list of resources relevant to the construction processes of roads, as well as potential applications, opportunities, and challenges for measurement science.

A. Key Stakeholders

Many stakeholders are involved in addressing the variety of road infrastructure issues. Listed here are a few of the sector's prominent players, with a larger list including summary descriptions of the entities located in Section E below.

- American Association of State Highway and Transportation Officials (AASHTO)
- American Road and Transportation Builders Association (ARTBA)
- Federal Highway Administration (FHWA)
- Innovative Pavement Research Foundation (IPRF)
- National Center for Asphalt Technology (NCAT)

There are also stakeholders such as standards development organizations, engineering firms, and trade groups that have interests and expertise in many different aspects of infrastructure. Some prominent cross-cutting organizations are noted here. A further listing of stakeholders with summary descriptions can be found in Appendix A.

- American Society of Civil Engineers (ASCE)
- ASTM International
- Construction Industry Institute (CII)
- Construction Users Roundtable (CURT)
- FIATECH

B. Technology and Process Opportunities and Barriers

The survey of available literature has presented an assortment of technology and process opportunities and barriers for the advancement of road infrastructure delivery. Listed here

¹⁰ ASCE Infrastructure Report Card—Roads;
http://www.infrastructurereportcard.org/sites/default/files/RC2009_roads.pdf

are several recurring themes which have been extracted from the primary compilation of measurement science needs and considerations listed in the table in Section C.

- Opportunities for greater accessibility to information and the integration of data to improve project planning speed and efficiency
- Increased use of performance metrics and tools such as real-time automated installation control to support innovative, high-speed inspection and monitoring processes that facilitate faster in-situ construction
- Development of measurement technologies and analysis methods such as predictive models, smart sensors, and embedded systems to support road management and maintenance through the monitoring of road conditions

C. Measurement Science Needs and Considerations

Table III-1. Road Infrastructure Measurement Baseline				
Delivery Improvement	Measurement Science Challenge/Need	Potential Approaches/Outcomes	Resources and Source Documents	Relevant NRC Activity*
Project Planning and Permitting				
Cost				
Scheduling	Data and information to support new permitting and relocation processes and accommodate the needs and rights of utilities and railroads that share roadway rights-of-way to keep projects on schedule and budget	New, streamlined permitting and relocating processes that allow for the timely and efficient progression of renewal projects for agencies, utilities, and railroads; develop recommendations for the institutional and procedural changes necessary for implementation of those processes.	Implementing the Results of the Second Strategic Highway Research Program: Saving Lives, Reducing Congestion, Improving Quality of Life – Special Report 296	1
Quality and Functionality	Facilitation of an innovative and equitable contracting environment through performance-based specifications	Performance-based specifications that afford the contractor greater construction control while managing agency risk, as well as on re-examining the allocation of risk inherent in the special nature of accelerated construction.	Implementing the Results of the Second Strategic Highway Research Program: Saving Lives, Reducing Congestion, Improving Quality of Life – Special Report 296	5
	Measurement infrastructure to support development of a long-term highway infrastructure performance program that includes databases, tools, test methods, procedures, and technologies to combine bridge and pavement information	Collection of meaningful data to support integrated asset management systems and processes that consider the full life cycle of highway infrastructure from planning through design, construction, and preservation.	Highways of the Future – A Strategic Plan for Highway Infrastructure Research and Development	1

Table III-1. Road Infrastructure Measurement Baseline				
Delivery Improvement	Measurement Science Challenge/Need	Potential Approaches/Outcomes	Resources and Source Documents	Relevant NRC Activity*
Design				
Cost	Development of technologies to enable expanded use of recycled or waste materials in highway construction	Can reduce the costs of new construction while providing equal or improved performance	Highways of the Future – A Strategic Plan for Highway Infrastructure Research and Development	4
Scheduling				
Quality and Functionality	Assessment of high-performance, long-life, advanced materials that increase resiliency and reduce maintenance and reconstruction needs	Improved materials can increase the performance of road surfaces and reduce overall lifecycle costs.	Highways of the Future – A Strategic Plan for Highway Infrastructure Research and Development	4
	Characterization of geosynthetic reinforcement application and design criteria	Data to answer questions related to mobilization of the resistance in the composite mass structure when using geosynthetic materials combined with modular blocks and granular soil materials as excavation support for roadways and foundation support for bridges.	Geotechnical Research Program	4
	Service-level infrastructure design and material standards	Enables more innovation than current prescriptive infrastructure design and material standards	Highways of the Future – A Strategic Plan for Highway Infrastructure Research and Development	5
	Infrastructure designs and details that facilitate effective inspection, maintenance, and repair	Designs can allow faster and cheaper repairs to be made.	Highways of the Future – A Strategic Plan for Highway Infrastructure Research and Development	1
Procurement				
Cost				
Scheduling				
Quality and Functionality				
Construction				
Cost	Standard practice for measuring task-level and project-level productivity	Improved metrics will increase the rate of investment in productivity-enhancing technologies, including information, communication, and automation and	Metrics and Tools for Measuring Construction Productivity: Technical	5

Table III-1. Road Infrastructure Measurement Baseline				
Delivery Improvement	Measurement Science Challenge/Need	Potential Approaches/Outcomes	Resources and Source Documents	Relevant NRC Activity*
		integration technologies, conveying benefits in the form of lower costs of building services and products.	and Empirical Considerations	
Scheduling	Data and tools to enable faster in-situ construction methods	Supports use of innovative technologies to replace traditional methods, and adaptation of roadway and bridge designs to optimize use of new technologies. Enhances completion of preliminary engineering tasks, such as the timely relocation of public utilities, before construction begins; and the development of techniques and guidelines better suited to renewal construction, such as performance specifications and rapid non-destructive testing.	Implementing the Results of the Second Strategic Highway Research Program: Saving Lives, Reducing Congestion, Improving Quality of Life – Special Report 296	2
	Evaluation of shorter construction times, accelerated build/repair schedules, and greater consideration of road closures	Opens up opportunities for developing new assessment tools for these strategies.	Implementing the Results of the Second Strategic Highway Research Program: Saving Lives, Reducing Congestion, Improving Quality of Life – Special Report 296	2
	Techniques and guidelines better suited to renewal construction	Development of a consistent, systematic approach to performing highway renewal that is rapid, causes minimal disruption, and produces long-lived facilities.	Implementing the Results of the Second Strategic Highway Research Program: Saving Lives, Reducing Congestion, Improving Quality of Life – Special Report 296	2
	Data and tools to support innovative, high speed inspection and monitoring processes that facilitate faster construction	Faster construction inspection and monitoring of performance.	Implementing the Results of the Second Strategic Highway Research Program: Saving Lives, Reducing Congestion, Improving Quality of Life – Special Report 296	2
Quality and Functionality	Real-time automated installation control and documentation	Systems to monitor, measure, control, and document critical aspects of technology, thereby allowing rapid construction without compromising quality.	Innovative Technology for Accelerated Construction of Bridge and Embankment Foundations in Europe	2

Table III-1. Road Infrastructure Measurement Baseline				
Delivery Improvement	Measurement Science Challenge/Need	Potential Approaches/Outcomes	Resources and Source Documents	Relevant NRC Activity*
	QC/QA program parameters modeled after the ISO 9000 series process	Provide more consistency in design and construction quality.	Innovative Technology for Accelerated Construction of Bridge and Embankment Foundations in Europe	2
	Soil-mix design criteria and construction quality control procedures	Significant potential to reduce costs and time delays if rational guidance for strength, deformation, and durability concerns can be developed.	Innovative Technology for Accelerated Construction of Bridge and Embankment Foundations in Europe	2
	Optimization of top-down construction techniques (i.e., soil nailing, ground anchor tiebacks, slurry walls)	Further refinements to optimize techniques include increased knowledge of the load transfer mechanism between the reinforcing elements and various soil types or ground treatments; and study of corrosion and durability aspects.	Geotechnical Research Program	4
	Design, calibration, and testing of “smart” construction equipment using automated, GPS-enabled systems, GIS maps, and on-site sensors to build roads	Increased construction project productivity and preferred quality of the end product.	The Efficiency of a 3D Blade Control System in the Construction of Structure Layers by Road Grader-Automated Design-Build of Road Construction in Finland	4
	Measurements to support minimization of field fabrication efforts	Prefabrication, modular construction, and innovative installation strategies for pavements and bridges; rapid construction systems such as modular pavements and prefabricated bridges to help reduce traffic disruption by permitting elements of pavements, bridges, and other roadway infrastructure to be built off-site and then installed in assembly-line fashion; off-site construction permits more intensive quality control, thus improving the level of performance and longevity of the highway infrastructure.	Implementing the Results of the Second Strategic Highway Research Program: Saving Lives, Reducing Congestion, Improving Quality of Life – Special Report 296	3
	Construction inspection and monitoring performance metrics	Innovative, high-speed inspection and monitoring processes that can ensure that the desired quality and performance are obtained.	TRIP, Rough Roads Report, May 2009	5
	Standardization of States and FHWA’s use of International Roughness Index (IRI) and Present Serviceability Rating (PSR)	Improved road condition rating and assessment.	National Center for Asphalt Technology	2

Table III-1. Road Infrastructure Measurement Baseline				
Delivery Improvement	Measurement Science Challenge/Need	Potential Approaches/Outcomes	Resources and Source Documents	Relevant NRC Activity*
	to rate road conditions			
	Specification/standardization of guidelines for the selection of tack coat materials and application rates to ensure effective bonding between layers of hot mix asphalt	Enhanced construction and performance of roadway surfacing.	National Center for Asphalt Technology	2
	Pavement and bridge construction standards	Ability to hold contractors responsible for meeting structural and functional thresholds over the long term (more than 15 years).	Highways of the Future – A Strategic Plan for Highway Infrastructure Research and Development	2
	Database of project-level productivity measures for capital facilities; while sources exist for task-level productivity data, no such sources exist for project-level productivity measures	Database consisting of both raw and index-based metrics, ideally incorporating the capability to analyze how the use of industry best practices and automation and integration technologies affect project-level productivity.	Metrics and Tools for Measuring Construction Productivity: Technical and Empirical Considerations	5
Commission and Handover (including O&M)				
Cost	Data and tools to support maintenance systems that adopt appropriate maintenance techniques for varying asset types	Design, development, and validation of 'smart' maintenance systems.	Implementing the Results of the Second Strategic Highway Research Program: Saving Lives, Reducing Congestion, Improving Quality of Life – Special Report 296	1
	Data and tools to support modeling systems that enable the asset owner to configure the system to operate as efficiently as possible	More efficient and cost-effective operation and maintenance of infrastructure systems.	Implementing the Results of the Second Strategic Highway Research Program: Saving Lives, Reducing Congestion, Improving Quality of Life – Special Report 296	1
	Advanced infrastructure performance prediction and design models for both service-level and extreme events	Facilitates effective inspection, maintenance, and repair.	Highways of the Future – A Strategic Plan for Highway Infrastructure Research and Development	1

Table III-1. Road Infrastructure Measurement Baseline				
Delivery Improvement	Measurement Science Challenge/Need	Potential Approaches/Outcomes	Resources and Source Documents	Relevant NRC Activity*
Scheduling	Improved pavement and bridge monitoring sensors and systems (e.g., smart sensors, embedded sensors and systems)	Permits both periodic and continuous performance evaluation and accurate condition assessment.	Highways of the Future – A Strategic Plan for Highway Infrastructure Research and Development	1
	Development, testing and validation of cost-effective, field-deployable sensing systems that are capable of providing continuous data	Enables effective prioritization of repair and retrofit schedules.	NIST Civil Infrastructure White Paper 2009	1
Quality and Functionality	Data and tools to enable improved systems, preservation techniques, analysis methods, and technologies	Prevention of material degradation, corrosion, cracking, fatigue, and other serviceability problems.	Highways of the Future – A Strategic Plan for Highway Infrastructure Research and Development	1
	High-speed, high-resolution, non-destructive technologies	Allows for non-destructive inspection, evaluation, and performance monitoring.	Highways of the Future – A Strategic Plan for Highway Infrastructure Research and Development	1
<p>Table Notes</p> <p>*Five recommended activities from the 2009 NRC Report:</p> <ol style="list-style-type: none"> 1. Widespread deployment and use of interoperable technology applications 2. Improved job-site efficiency through effective interface of people, processes, materials, equipment and information 3. Greater use of prefabrication, preassembly, modularization, and off-site fabrication 4. Innovative widespread use of demonstration installations 5. Effective performance measurement 				

D. Government Entities & Programs

U.S. Department of Transportation (U.S. DOT)

- Federal Highway Administration (FHWA)
Geotechnical Engineering & Geotechnical Research Program
<http://www.fhwa.dot.gov/engineering/geotech/index.cfm>
<http://www.tfhrc.gov/structur/gtr/geohome.htm>

The scope of their research includes analytical studies, laboratory testing, and field monitoring of construction sites in order to develop, refine, and validate new or improved designs. It includes research into a wide range of materials properties, instrumentation techniques, monitoring methods, analytical techniques, performance assessment, and design principles.

Turner-Fairbank Highway Research Center (TFHRC)
<http://www.tfhrc.gov/>

TFHRC provides FHWA and the world highway community with the most advanced research and development related to new highway technologies. The research focuses on providing solutions to complex technical problems through the development of more economical, environmentally sensitive designs; more efficient, quality controlled constructions practices; and more durable materials.

- Research and Innovative Technology Administration (RITA)

<http://www.rita.dot.gov/>

RITA coordinates the U.S. DOT's research programs and is charged with advancing the deployment of cross-cutting technologies to improve our Nation's transportation system. As directed by Congress in its founding legislation, RITA leads DOT in: coordinating, facilitating and reviewing the Department's research and development programs and activities; advancing innovative technologies, including intelligent transportation systems; performing comprehensive transportation statistics research, analysis and reporting; and providing education and training in transportation and transportation-related fields.

Bureau of Transportation Statistics

<http://www.bts.gov/>

The Bureau provides data and statistics on all modes of transportation and transportation infrastructure including airlines, roads, rail, and household travel patterns.

Intelligent Transportation Systems (ITS)

<http://www.its.dot.gov/index.htm>

Intelligent transportation systems (ITS) improve transportation safety and mobility and enhance American productivity through the integration of advanced communications technologies into the transportation infrastructure and in vehicles. ITS encompass a broad range of wireless and wire line communications-based information and electronics technologies.

University Transportation Centers

http://utc.dot.gov/utc_safetea-lu.html

Internationally recognized centers of excellence, fully integrated within institutions of higher learning, that serve as a vital source of leaders who are prepared to meet the nation's need for safe, efficient and environmentally sound movement of people and goods.

Volpe National Transportation Systems Center

<http://www.volpe.dot.gov/index.html>

Volpe has responded to most of the major transportation challenges of the last quarter century, including national security, world energy crises, and related evaluations of alternative fuels; and the need to modernize air traffic control systems and to develop sophisticated logistics and communications systems to support national initiatives overseas.

- Federal Transit Administration (FTA)

<http://www.fta.dot.gov/>

The FTA provides stewardship of combined formula and discretionary programs totaling more than \$10B to support a variety of locally planned, constructed, and operated public transportation systems throughout the United States.

- National Cooperative Highway Research Program
<http://www.trb.org/NCHRP/Public/NCHRP.aspx>
Administered by the Transportation Research Board (TRB) and sponsored by the member departments (i.e., individual state departments of transportation) of the American Association of State Highway and Transportation Officials (AASHTO), in cooperation with the Federal Highway Administration (FHWA), the National Cooperative Highway Research Program (NCHRP) was created in 1962 as a means to conduct research in acute problem areas that affect highway planning, design, construction, operation, and maintenance nationwide.
- National Transit Database (FTA)
<http://www.ntdprogram.gov/ntdprogram/>
The National Transit Database (NTD) is the Federal Transit Administration's (FTA) national database of statistics for the transit industry. The NTD is comprised of data reported by more than 600 transit agencies across the US, which is then analyzed and compiled into reports published by FTA and made available to the public on the NTD Program website. The database includes all modes of public transportation utilized on local and regional routes throughout the country, including private and public buses, heavy and light rail, ferryboats and vanpool service, as well as services for senior citizens and persons with disabilities, and taxi services operated under contract to a public transportation agency.
- Transportation Research Information Services (TRIS)
<http://www.trb.org/InformationServices/Public/TRISOnline.aspx>
TRIS Online is a joint project between the Bureau of Transportation Statistics (BTS) and the Transportation Research Board. In January 1999, BTS and TRB signed a memorandum of understanding to make available the Transportation Research Information Services (TRIS) Database through the National Transportation Library. TRB continues to produce and maintain the TRIS Database with funding by sponsors of TRB, primarily the State departments of transportation and selected federal transportation agencies. BTS makes TRIS available on the NTL's Web site as TRIS Online.

E. Standards Organizations, Trade Associations, & Stakeholders

The following is a list of nationally relevant organizations involved in the deployment of road infrastructure.

- American Association of State Highway and Transportation Officials (AASHTO)
<http://www.transportation.org/>
AASHTO is a nonprofit, nonpartisan association representing highway and transportation departments in the 50 states, the District of Columbia, and Puerto Rico. It represents all five transportation modes: air, highways, public transportation,

rail, and water. Its primary goal is to foster the development, operation, and maintenance of an integrated national transportation system.

- American Concrete Institute (ACI)

<http://www.concrete.org/general/home.asp>

The ACI is a nonprofit technical and educational society organized in 1904 and is one of the world's leading authorities on concrete technology. ACI is a forum for the discussion of all matters related to concrete and the development of solutions to problems. ACI publishes reliable information on concrete and its applications, conducts educational seminars, provides a standard certification program for the industry, provides local forums for discussion through the Chapter program, and encourages student involvement in the concrete field.

- American Concrete Pavement Association (ACPA)

<http://www.pavement.com/>

ACPA's National office is behind every chapter and every member addressing the broad range of issues facing the industry today; ACPA National provides members with professional services through: National Technical Initiatives, National Market Development Initiatives, and National Government Relations Advocacy, as well as Local Initiatives and Support.

- American Council of Engineering Companies (ACEC)

<http://www.acec.org/>

The ACEC is the voice of America's engineering industry. Council members – numbering more than 5,500 firms throughout the country – are engaged in a wide range of engineering works that propel the nation's economy, and enhance and safeguard America's quality of life. ACEC is a large federation of 51 state and regional councils representing the great breadth of America's engineering industry. ACEC member firms employ more than hundreds of thousands of engineers, architects, land surveyors, scientists, and other specialists, responsible for more than \$200 billion of private and public works annually. Member firms range in size from a single registered professional engineer to corporations employing thousands of professionals.

- American Road & Transportation Builders Association (ARTBA)

<http://www.artba.org/>

ARTBA is a federation whose primary goal is to aggressively grow and protect transportation infrastructure investment to meet the public and business demand for safe and efficient travel. In support of this mission, ARTBA also provides programs and services designed to give its 5,000+ public and private sector members a global competitive edge.

- American Society of Civil Engineers (ASCE)

<http://www.asce.org/>

Founded in 1852, the American Society of Civil Engineers (ASCE) represents more than 147,000 members of the civil engineering profession worldwide, and is America's oldest national engineering society. ASCE's vision is to position engineers as global leaders building a better quality of life.

- American Society of Testing and Materials (ASTM International)

<http://www.astm.org/index.shtml>

ASTM International is one of the largest voluntary standards development organizations in the world—a trusted source for technical standards for materials, products, systems, and services. Known for their high technical quality and market relevancy, ASTM International standards have an important role in the information infrastructure that guides design, manufacturing and trade in the global economy.

- ASTM International Committee D04 of Road and Paving Materials

<http://www.astm.org/COMMIT/COMMITTEE/D04.htm>

Committee D04 develops standards in many areas that contribute to the science of road building and help ensure quality road paving and construction materials: bituminous mixtures, asphalt, aggregates, preformed and formed in-place sealants, bridges and structures, highway traffic materials.

- Asphalt Emulsion Manufacturers Association (AEMA)

<http://www.aema.org/>

AEMA is a proactive organization dedicated to the advancement of the asphalt emulsion industry, constantly focusing on system preservation and the construction of the world's infrastructure. Since 1973, the Association has served as a forum for discussion, a clearinghouse of information, and a platform of action for the asphalt emulsion industry. Through its meetings, seminars, website, and publications, AEMA has helped to bring state-of-the-art asphalt emulsion technology to all parts of the world.

- Asphalt Institute

<http://www.asphaltinstitute.org/>

The Asphalt Institute's mission is to promote the use, benefits, and quality performance of petroleum asphalt, through environmental, marketing, research, engineering and technical development, and through the resolution of issues affecting the industry. The Asphalt Institute will achieve its mission through a commitment to the highest standards of ethical and professional conduct and the development of its people, technical expertise, and relationships.

- Association of Equipment Manufacturers (AEM)

<http://www.aem.org/>

AEM membership is made up of more than 800 companies and represents 200+ product lines. AEM's role is to provide trade association services on a global basis for companies that manufacture equipment worldwide in the following industries: Agriculture, Construction, Forestry, Mining and Utility. AEM provides a wide variety of services that help members compete effectively in the global marketplace. Our core services include: Global Public Policy, Market Information, Technical and Safety, and Trade Shows; along with additional services which include: Global Business Development, Education and Workforce Development.

- Construction Industry Institute (CII)

<https://www.construction-institute.org/scriptcontent/index.cfm>

The Construction Industry Institute, based at The University of Texas at Austin, is a consortium of more than 100 leading owner, engineering-contractor, and supplier firms from both the public and private arenas. These organizations have joined together to enhance the business effectiveness and sustainability of the capital facility life cycle through CII research, related initiatives, and industry alliances. A learning

organization with a wealth of knowledge and information, CII is unique in the engineering and construction industry.

- Construction Users Roundtable (CURT)

<http://www.curt.org/>

An autonomous, not-for-profit organization, CURT strives to produce meaningful changes within the construction industry—promoting overall cost effectiveness; improving the way construction is planned, managed, justified and executed. Additionally, CURT works toward changing and improving what owners allow, require, and accept responsibility for on their domestic and global construction projects.

- FIATECH

<http://fiatech.org>

FIATECH is a consortium of industries and companies – owners from the industrial, power, and retail markets that, of necessity, build large assets such as refineries, power plants, large commercial buildings, or manufacturing facilities. In addition, it includes the leading providers of engineering, design, and construction services. FIATECH not only provides a communication hub for members to quickly learn of new approaches, methods, and materials; it also does things. Project teams are formed to identify and accelerate the adoption of technologies and systems; demonstration projects are conducted to validate and perfect new approaches or methods; and teams are formed to aid and facilitate the deployment of those breakthrough initiatives that have been validated. In essence, it is each member's highly robust R&D organization.

- Innovative Pavement Research Foundation (IPRF)

<http://www.iprf.org/>

Provide a unified means of building resources, developing strategies, and implementing programs to address concrete pavement research, technology advancement and transfer, and public education on the inherent economic efficiencies, safety, and quality-of-life advantages of portland cement concrete pavements for highways, streets, roads, and airports. IPRF is engaged in researched focused on five goals associated with concrete pavement research, technology, and innovation, including: develop current best practices, reduce initial costs, reduce user delays, develop cost-competitive options, and achieve design expectations.

- Intelligent Transportation Society of America

<http://www.itsa.org/>

The Intelligent Transportation Society of America is the leading advocate for technologies that improve the safety, security and efficiency of the nation's surface transportation system. Our members include private corporations, public agencies, and academic institutions involved in the research, development and design of Intelligent Transportation Systems technologies that enhance safety, increase mobility and sustain the environment.

- International Bridge, Tunnel and Turnpike Association (IBTTA)

<http://ibtta.org/>

IBTTA is the worldwide alliance of toll operators and associated industries that provides a forum for sharing knowledge and ideas to promote and enhance toll-financed transportation services.

- International Council for Research and Innovation in Building and Construction (CIB)

<http://www.cibworld.nl/site/home/index.html>

CIB was established in 1953 as an Association whose objectives were to stimulate and facilitate international cooperation and information exchange between governmental research institutes in the building and construction sector, with an emphasis on those institutes engaged in technical fields of research. CIB has since developed into a world wide network of over 5000 experts from about 500 member organizations with a research, university, industry or government background, who collectively are active in all aspects of research and innovation for building and construction.

- International Grooving & Grinding Association (IGGA)

<http://www.igga.net/>

IGGA is a non profit Trade Association founded in 1972 by a group of dedicated industry professionals committed to the development of the diamond grinding and grooving process for surfaces constructed with Portland cement concrete and asphalt. In 1995, the IGGA joined in affiliation with the American Concrete Pavement Association (ACPA) to represent its newly formed Concrete Pavement Restoration Division. The IGGA / ACPA CPR Division now serves as the technical resource and industry representative in the marketing of optimized pavement surfaces, concrete pavement restoration and pavement preservation around the world.

- International Union of Operating Engineers (IUOE)

<http://www.iuoe.org/>

The IUOE is a progressive, diversified trade union that primarily represents operating engineers, who work as heavy equipment operators, mechanics, and surveyors in the construction industry, and stationary engineers, who work in operations and maintenance in building and industrial complexes, and in the service industries.

- National Center for Asphalt Technology (NCAT)

<http://www.ncat.us/>

The NCAT at Auburn University has been instrumental in bringing improvements in asphalt pavements to practice across the country for more than two decades. NCAT was created to ensure this industry's ability to provide pavements that are durable, environmentally friendly, quiet, safe and economical. NCAT works with state highway agencies, the Federal Highway Administration, and the highway construction industry to develop and evaluate new products, design technologies and construction methods which quickly lead to pavement improvements. Its research center and test track make it one of the world's leading institutions for asphalt pavement research and an important source of information for those tasked with maintaining our nation's infrastructure.

- National Concrete Pavement Technology Center

<http://www.cptechcenter.org/>

The National Concrete Pavement Technology Center (National CP Tech Center) at Iowa State University is a national hub for concrete pavement research and technology transfer. The Center was founded in 2000 and currently has four industry sponsors: the American Concrete Pavement Association (ACPA), the Concrete Steel Reinforcing Institute (CRSI), the Iowa Department of Transportation, and the Iowa Concrete Paving Association (ICPA). The Center has been instrumental in developing

and helping to advance the nation's strategic plan for concrete pavement research, The CP Road Map.

- National Ready Mixed Concrete Association

<http://www.nrmca.org/>

The National Ready Mixed Concrete Association is the leading industry advocate. Our mission is to provide exceptional value for our members by responsibly representing and serving the entire ready mixed concrete industry through leadership, promotion, education and partnering to ensure ready mixed concrete is the building material of choice. We work in conjunction through a partnership agreement with state associations on issues such as promotion and regulatory concerns and extend what they can do to a national level. Our commitment to our members is second to none and we strive for constant communication on the latest information, products, services and programs to help our members expand their markets, improve their operations and be their voice in Washington.

F. Reports and Publications

Studies

American Association of State Highway and Transportation Officials (AASHTO) Transportation Security Task Force. National Needs Assessment for Ensuring Transportation Infrastructure Security. October 2002.

<http://www.transportation.org/sites/security/docs/NatlNeedsAssess.pdf>

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Chase, Steven B. "The Role of Sensing and Measurement in Achieving FHWA's Strategic Vision for Highway Infrastructure" in Sensing Issues in Civil Structural Health Monitoring. December 2005. <http://www.springerlink.com/content/g24755632v575g18/>

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Federal Highway Administration. 2006 Status of the Nation's Highways, Bridges, and Transit: Conditions & Performance. <http://www.fhwa.dot.gov/policy/2006cpr/index.htm>

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- Journal of Urban Planning and Development
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- Transportation Research
http://www.elsevier.com/wps/find/journaldescription.cws_home/600119/description#description
- Transportation Research Record (Journal of the Transportation Research Board)
<http://trb.metapress.com/home/main.mpx>
- Tunnelling and Underground Space Technology
http://www.elsevier.com/wps/find/journaldescription.cws_home/799/description#description

H. Conferences, Workshops, & Training

- 2010 AASHTO Annual Meeting, October 29-November 2, 2009; Beau Rivage Resort and Casino, Biloxi, MS <http://www.transportation.org/meetings/224.aspx>
- 2009 AASHTO Annual Meeting, October 22-26, 2009; Palm Desert, CA
- National Highway Institute Geotechnical Courses
<http://www.fhwa.dot.gov/engineering/geotech/training.cfm>
Topics of Interest: LFRD; design; construction; monitoring; foundations; instrumentation; inspection; qualification.
- Transportation Curriculum Coordination Council Geotechnical Certification Technical Committee
<http://www.fhwa.dot.gov/engineering/geotech/training.cfm>
Topics of Interest: Inspection tutorials and qualifications.

IV. BASELINE PROFILE - POWER

The nation's electric power infrastructure consists of generation capacity, as well as transmission and distribution lines, substations, and other installations. The ASCE Report Card gave a "D+" to the nation's energy infrastructure and estimated a \$29.5 billion shortfall in investments in energy infrastructure over the next five years.¹¹ Especially in the areas of transmission, distribution, and generation assets, there are opportunities for technology to improve delivery.

The following sections present a list of resources relevant to the construction processes for electric power generation, as well as potential applications, opportunities, and challenges for measurement science.

A. Key Stakeholders

Many stakeholders are involved in addressing the variety of power infrastructure issues. Listed here are a few of the sector's prominent players, with a larger list including summary descriptions of the entities located in Section E below.

- National Association of Regulatory Utility Commissioners (NARUC)
- North American Electricity Regulatory Corporation (NERC)
- Electric Power Research Institute (EPRI)
- Edison Electric Institute (EEI)
- Institute of Electrical and Electronics Engineers (IEEE)

There are also stakeholders such as standards development organizations, engineering firms, and trade groups that have interests and expertise in many different aspects of infrastructure. Some prominent cross-cutting organizations are noted here. A further listing of stakeholders with summary descriptions can be found in Appendix A.

- American Society of Civil Engineers (ASCE)
- ASTM International
- Construction Industry Institute (CII)
- Construction Users Roundtable (CURT)
- FIATECH

B. Technology and Process Opportunities and Barriers

The survey of available literature has presented an assortment of technology and process opportunities and barriers for the advancement of power infrastructure delivery. Listed

¹¹ ASCE Infrastructure Report Card—Energy;
http://www.infrastructurereportcard.org/sites/default/files/RC2009_energy.pdf

here are several recurring themes which have been extracted from the primary compilation of measurement science needs and considerations listed in the table in Section C.

- Opportunities to more efficiently plan and schedule repairs and upgrades to existing transmissions infrastructure, as well as for the construction of new transmission lines
- Increased use of radio frequency ID tags for improving the efficiency of power plant construction scheduling
- Development of modeling tools (such as integrated resource planning) for siting power generation facilities and transmission corridors based on projected increases in demand and on resource availability

C. Measurement Science Needs and Considerations

Table IV-1. Power Infrastructure Measurement Baseline				
Delivery Improvement	Measurement Science Challenge/Need	Potential Approaches/Outcomes	Resources and Source Documents	Relevant NRC Activity*
Project Planning and Permitting				
Cost				
Scheduling	Data to support “one-stop” certification and siting for generation and multi-state transmission projects	Enable streamlined planning processes, especially for generation and interstate transmission projects; reduction of costs; support for consolidated review and approval.	CAP, Wired for Progress; 2009	2
	Validation and refinement of Probabilistic Risk Assessment (PRA) models to prioritize and schedule construction and repair of critical transmission infrastructure	Increased reliance on modeling will allow limited funds to be targeted toward the most important sections of the infrastructure.	EPRI 2010 Grid Planning Portfolio	1
	Tools to effectively include incremental and major line and systems upgrades into planning, including prioritization to achieve optimum system improvement	Integration of long term, multi-year investment plans to improve planning and scheduling of upgrades.	EPRI 2010 Grid Planning Portfolio	1
Quality and Functionality	Data and methods to support interconnection-wide planning efforts for generation plant siting and permitting	Optimizes reliability, efficiency, and economics as opposed to fragmented state, utility, and regional approach; would substantially reduce the cost and time associated with planning and permitting.	CAP, Wired for Progress; 2009	2
	Development and validation of novel methodologies for determining dynamically changing load classes and compositions using smart meters	Improved modeling and data preparation capabilities for system planners.	EPRI 2010 Grid Planning Portfolio	1

Table IV-1. Power Infrastructure Measurement Baseline				
Delivery Improvement	Measurement Science Challenge/Need	Potential Approaches/Outcomes	Resources and Source Documents	Relevant NRC Activity*
	Development and validation of transmission system model management techniques and tools	Facilitates conventional model building and management practices of system planning	EPRI 2010 Grid Planning Portfolio	1
Design				
Cost	Validation of the Foundation and Design (FAD) module to optimize foundation design based on soil conditions and other design parameters	Will improve the range of the software and its applicability to different soil types and locations.	EPRI 2010 Grid Planning Portfolio	1
	Documentation of successful applications (costs, other parameters) of synchro-phasor devices in order to realize their full value in improving electric power system reliability and efficiency	Quantifying the costs and benefits of phasor systems will allow improved decision-making for infrastructure and grid planners.	EPRI 2010 Grid Planning Portfolio	5
Scheduling	Modification of NRC procedures concerning the design, review and approval of digital plant control systems for GEM III+ units	Will allow the design and review process to coincide with the actual project schedule	DOE NP2010 Nuclear Power Plant Construction Infrastructure Assessment	5
Quality and Functionality	Performance measurements to support validation of the TLW software package for effective design of transmissions lines, and integration with other designs and modules	Results from design software need to be measured against the performance of actual construction performance.	EPRI 2010 Grid Planning Portfolio	5
	High-frequency vibration screening tests should be conducted to identify any HF sensitivities or abnormalities in the components; existing equipment qualification test data should be reviewed	Will improve the resilience of nuclear plants to seismic activity	Seismic Screening of Components Sensitive to High-Frequency Vibratory Motions	5
Procurement				
Cost				
Scheduling	Assessment of manufacturing capabilities and lead times for suppliers of critical nuclear power plant components such as forged steel pressure vessel rings and high-nickel piping	Will enable more accurate scheduling of build times and help prevent cost overruns	Application of Advanced Construction Technologies to New Nuclear Power Plants	2
Quality and Functionality				
Construction				
Cost				

Table IV-1. Power Infrastructure Measurement Baseline				
Delivery Improvement	Measurement Science Challenge/Need	Potential Approaches/Outcomes	Resources and Source Documents	Relevant NRC Activity*
Scheduling	Measuring productivity gains possible from the use of RFID tags for construction components	Integration of RFID/GIS-enabled construction process will reduce costs and construction times.	CI, Leveraging Technology to Improve Construction Productivity; 2008	5
	Perform environmental qualification of cold-shrink splices for cables and use national laboratory test facilities to study the effect of aging on cable splices	Possible that NRC may revise standard practices which currently restrict the use of splices	Application of Advanced Construction Technologies to New Nuclear Power Plants	5
Quality and Functionality	Changes in inspection processes that accommodate the fabrication and construction of large components away from the plant site; assessment of the impact of 10CFR 50 Appendix B QA requirements of feasibility	Promotion of prefabrication, preassembly, and modularization	Application of Advanced Construction Technologies to New Nuclear Power Plants	3
	Development of common formats for information sharing (with NRC, regulators, and others)	Assessment of NIST FIATECH project for applicability and usefulness, as well as application to NRC's CIPIMS project	Application of Advanced Construction Technologies to New Nuclear Power Plants	1
	Modification of existing inspection techniques to accommodate steel-plate reinforced concrete structures (revision of ACI-349.3R)	Will enable alternative to structural concrete reinforced with steel bars	Application of Advanced Construction Technologies to New Nuclear Power Plants	5
Commission and Handover (including O&M)				
Cost	Development and validation of overhead transmission line inspection and assessment methods and guidelines	Improved inspection techniques will increase frequency and accuracy, and lower cost.	EPRI 2010 Overhead Transmission Portfolio	2
Scheduling	Information to accurately perform meaningful inspections of distribution system	Enhanced distribution system operation and controls.	EPRI 2010 Grid Planning Portfolio	2
	Techniques to install, inspect, and assess the remaining life of compression connectors	Optimization of installation techniques and improved inspection methods.	EPRI 2010 Overhead Transmission Portfolio	2
Quality and Functionality	Metrics for evaluation of increased deployment and use of remote controls and sensors to monitor and optimize current and future capacity and performance of transmission infrastructure	Improved system design, optimization, and performance.	EPRI 2010 Overhead Transmission Portfolio	5

Table IV-1. Power Infrastructure Measurement Baseline				
Delivery Improvement	Measurement Science Challenge/Need	Potential Approaches/Outcomes	Resources and Source Documents	Relevant NRC Activity*
	Cross-arm inspection and population management methods	Increased transmission line safety and reduction of sustained unplanned outages.	EPRI 2010 Overhead Transmission Portfolio	5
	Field tool to evaluate transmission line grounds	Ability to accurately measure structures that are grounded in multiple locations for improved lightning performance and transmission line safety.	EPRI 2010 Overhead Transmission Portfolio	5
<p>Table Notes</p> <p>*Five recommended activities from the 2009 NRC Report:</p> <ol style="list-style-type: none"> 1. Widespread deployment and use of interoperable technology applications 2. Improved job-site efficiency through effective interface of people, processes, materials, equipment and information 3. Greater use of prefabrication, preassembly, modularization, and off-site fabrication 4. Innovative widespread use of demonstration installations 5. Effective performance measurement 				

D. Government Entities & Programs

- Department of Energy, Office of Electricity Delivery and Energy Reliability

<http://www.oe.energy.gov/>

The mission of the Office of Electricity Delivery and Energy Reliability is to lead national efforts to modernize the electric grid; enhance security and reliability of the energy infrastructure; and facilitate recovery from disruptions to energy supply.

- Department of Energy, Office of Fossil Energy

<http://www.fe.doe.gov/>

Ensuring that we can continue to rely on clean, affordable energy from our traditional fuel resources is the primary mission of DOE's Office of Fossil Energy. Fossil fuels supply 85% of the nation's energy, and we are working on such priority projects as pollution-free coal plants, more productive oil and gas fields, and the continuing readiness of federal emergency oil stockpiles.

- Department of Energy, Office of Nuclear Energy

<http://www.ne.doe.gov/default.html>

The primary mission of the Office of Nuclear Energy is to advance nuclear power as a resource capable of making major contributions in meeting the nation's energy supply, environmental, and energy security needs by resolving technical, cost, safety, security and regulatory issues through research, development, and demonstration.

- Federal Energy Regulatory Commission (FERC)

<http://www.ferc.gov/>

FERC is an independent agency that regulates the interstate transmission of electricity, natural gas, and oil. FERC also reviews proposals to build liquefied natural gas (LNG) terminals and interstate natural gas pipelines as well as licensing

hydropower projects. Its mission is to assist consumers in obtaining reliable, efficient and sustainable energy services at a reasonable cost through appropriate regulatory and market means.

- Nuclear Regulatory Commission (NRC)

<http://www.nrc.gov/>

The U.S. Nuclear Regulatory Commission (NRC) was created as an independent agency by Congress in 1974 to enable the nation to safely use radioactive materials for beneficial civilian purposes while ensuring that people and the environment are protected. The NRC regulates commercial nuclear power plants and other uses of nuclear materials, such as in nuclear medicine, through licensing, inspection and enforcement of its requirements.

E. Standards Organizations, Trade Associations, & Stakeholders

The following is a list of nationally relevant organizations involved in the deployment of energy and electricity infrastructure.

- American Council of Engineering Companies (ACEC) <http://www.acec.org/>
 - The ACEC is the voice of America's engineering industry. Council members – numbering more than 5,500 firms throughout the country – are engaged in a wide range of engineering works that propel the nation's economy, and enhance and safeguard America's quality of life. ACEC is a large federation of 51 state and regional councils representing the great breadth of America's engineering industry. ACEC member firms employ more than hundreds of thousands of engineers, architects, land surveyors, scientists, and other specialists, responsible for more than \$200 billion of private and public works annually. Member firms range in size from a single registered professional engineer to corporations employing thousands of professionals.
- American Public Power Association (APPA) www.appanet.org
 - The American Public Power Association (APPA) is the service organization for the nation's more than 2,000 community-owned electric utilities that serve more than 45 million Americans. Its purpose is to advance the public policy interests of its members and their consumers, and provide member services to ensure adequate, reliable electricity at a reasonable price with the proper protection of the environment.
- American Society of Civil Engineers (ASCE) <http://www.asce.org/>
 - Founded in 1852, the American Society of Civil Engineers (ASCE) represents more than 147,000 members of the civil engineering profession worldwide, and is America's oldest national engineering society. ASCE's vision is to position engineers as global leaders building a better quality of life.
- American Society of Mechanical Engineers (ASME International) <http://www.asme.org/>

- Founded in 1880 as the American Society of Mechanical Engineers, ASME is a not-for-profit professional organization that enables collaboration, knowledge sharing and skill development across all engineering disciplines, while promoting the vital role of the engineer in society. ASME codes and standards, publications, conferences, continuing education and professional development programs provide a foundation for advancing technical knowledge and a safer world.
- Energy Conservation Group <http://divisions.asme.org/ecg/>
 The purpose of the Energy Conversion Group is to promote the art and science of mechanical engineering in the power generation and energy conversion fields through the technical divisions that constitute the Group. These objectives are achieved through the Energy Conversion Board encouraging, promoting and coordinating the various division activities, liaison with other groups, national organizations, regions and sections of the Society, and by representing the interests of the divisions on the Council of Engineering of the Society. The member Divisions are: Internal Combustion Engine, Nuclear Engineering, Power, Solar Energy and Advanced Energy Systems.
- Pressure Technology Group <http://divisions.asme.org/ptg/>
 The Pressure Technology Group represents the Pressure Vessels and Piping (PVP) and Non-Destructive Evaluation (NDE) Engineering Divisions. Activities of the PT group are intended to provide a knowledge center for the international pressure technology community, serving manufacturing, operations, inspection and research in the various pressure industries. Activities of the divisions include the annual Pressure Vessels and Piping Conference, the International Pipeline Conference as well as the NDE Topical Conference. Additionally, members of the PT divisions participate in the ASME Codes and Standards committees and in various international pressure technology conferences. In addition, the group publishes the *Journal of Pressure Vessels Technology* as well as numerous conference proceedings. This Group's mentors regional events and provides expertise important to products in the global marketplace.
- American Society of Testing and Materials (ASTM International) <http://www.astm.org/index.shtml>
 - ASTM International is one of the largest voluntary standards development organizations in the world-a trusted source for technical standards for materials, products, systems, and services. Known for their high technical quality and market relevancy, ASTM International standards have an important role in the information infrastructure that guides design, manufacturing and trade in the global economy.
- American Supply Association (ASA) <http://www.asa.net/>
 - ASA is a not-for-profit national organization serving wholesale distributors and their suppliers in the plumbing, heating, cooling and industrial and mechanical pipe, valves and fittings industries. ASA provides a forum for trading partners from around the country to discuss critical issues facing

them, and offers a menu of products and services uniquely geared to their needs.

- Association of Equipment Manufacturers (AEM) <http://www.aem.org/>
 - AEM membership is made up of more than 800 companies and represents 200+ product lines. AEM's role is to provide trade association services on a global basis for companies that manufacture equipment worldwide in the following industries: Agriculture, Construction, Forestry, Mining and Utility. AEM provides a wide variety of services that help members compete effectively in the global marketplace. Our core services include: Global Public Policy, Market Information, Technical and Safety, and Trade Shows; along with additional services which include: Global Business Development, Education and Workforce Development.
- Construction Industry Institute (CII) <https://www.construction-institute.org/scriptcontent/index.cfm>
 - The Construction Industry Institute, based at The University of Texas at Austin, is a consortium of more than 100 leading owner, engineering-contractor, and supplier firms from both the public and private arenas. These organizations have joined together to enhance the business effectiveness and sustainability of the capital facility life cycle through CII research, related initiatives, and industry alliances. A learning organization with a wealth of knowledge and information, CII is unique in the engineering and construction industry.
- Construction Users Roundtable (CURT) <http://www.curt.org/>
 - An autonomous, not-for-profit organization, CURT strives to produce meaningful changes within the construction industry-promoting overall cost effectiveness; improving the way construction is planned, managed, justified and executed. Additionally, CURT works toward changing and improving what owners allow, require, and accept responsibility for on their domestic and global construction projects.
- Edison Electric Institute (EEI) <http://www.eei.org/Pages/default.aspx>
 - The Edison Electric Institute is the association of U.S. Shareholder-Owned Electric Companies. Its members serve 95 percent of the ultimate customers in the shareholder-owned segment of the industry, and represent approximately 70 percent of the U.S. electric power industry. EEI provides public policy leadership, critical industry data, market opportunities, strategic business intelligence, one-of-a-kind conferences and forums, and top-notch products and services.
- Electric Power Research Institute (EPRI) <http://my.epri.com/portal/server.pt>
 - The Electric Power Research Institute, Inc. (EPRI) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, health, safety and the environment. EPRI also provides

technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies.

- Electric Power Supply Association (EPSA) <http://www.epsa.org/forms/documents/DocumentFormPublic/>
 - EPSA is the national trade association representing competitive power suppliers, including generators and marketers. Effort by EPSA members have resulted in: more efficient generating technologies that have driven down the cost of producing electricity; cost-effective environmental solutions that have resulted in significantly cleaner air and water; innovations in power plant management and maintenance that have lowered operating costs without compromising reliability; cost-saving transactions among power marketers that move electricity to where it is most needed; and new comprehensive risk management strategies that result in more competitively priced power.
- FIATECH <http://fiatech.org>
 - FIATECH is a consortium of industries and companies – owners from the industrial, power, and retail markets that, of necessity, build large assets such as refineries, power plants, large commercial buildings, or manufacturing facilities. In addition, it includes the leading providers of engineering, design, and construction services. FIATECH not only provides a communication hub for members to quickly learn of new approaches, methods, and materials; it also does things. Project teams are formed to identify and accelerate the adoption of technologies and systems; demonstration projects are conducted to validate and perfect new approaches or methods; and teams are formed to aid and facilitate the deployment of those break-through initiatives that have been validated. In essence, it is each member's highly robust R&D organization.
- Hydraulic Institute (HI) <http://www.pumps.org/>
 - The Hydraulic Institute is the largest association of pump industry manufacturers in North America, serving member companies and pump users by providing product standards and a forum for the exchange of industry information. HI has established itself as the leading spokesperson for the North American pump industry, offering a wide variety of programs and services such as: standards development, networking opportunities, access to specific statistical data and economic reports, electronic services, educational materials, breaking industry news, participation in industry initiatives, and more.
- Institute of Electrical and Electronics Engineers (IEEE) <http://ieee.org/portal/site>
 - IEEE is the world's largest professional association advancing innovation and technological excellence for the benefit of humanity. IEEE and its members inspire a global community to innovate for a better tomorrow through its highly cited publications, conferences, technology standards, and professional and educational activities. IEEE is the trusted "voice" for engineering, computing and technology information around the globe.

- International Council for Research and Innovation in Building and Construction (CIB) <http://www.cibworld.nl/site/home/index.html>
 - CIB was established in 1953 as an Association whose objectives were to stimulate and facilitate international cooperation and information exchange between governmental research institutes in the building and construction sector, with an emphasis on those institutes engaged in technical fields of research. CIB has since developed into a worldwide network of over 5000 experts from about 500 member organizations with a research, university, industry or government background, who collectively are active in all aspects of research and innovation for building and construction.
- International Union of Operating Engineers (IUOE) <http://www.iuoe.org/>
 - The IUOE is a progressive, diversified trade union that primarily represents operating engineers, who work as heavy equipment operators, mechanics, and surveyors in the construction industry, and stationary engineers, who work in operations and maintenance in building and industrial complexes, and in the service industries.
- National Association of Clean Air Agencies <http://www.4cleanair.org/>
 - The National Association of Clean Air Agencies (NACAA) represents air pollution control agencies in 53 states and territories and over 165 major metropolitan areas across the United States. State and local air pollution control officials formed NACAA (formerly STAPPA/ALAPCO) over 30 years ago to improve their effectiveness as managers of air quality programs. The associations serve to encourage the exchange of information among air pollution control officials, to enhance communication
- National Association of Regulatory Utility Commissioners (NARUC) <http://naruc.org/>
 - NARUC is an association representing the State public service commissioners who regulate essential utility services, such as electricity, gas, telecommunications, water, and transportation, throughout the country. As regulators, our members are charged with protecting the public and ensuring that rates charged by regulated utilities are fair, just, and reasonable.
- National Association of State Energy Officials (NASEO) <http://naseo.org/>
 - The National Association of State Energy Officials (NASEO) is the only national non-profit organization whose membership includes the governor-designated energy officials from each state and territory. NASEO was formed by the states and through an agreement with the National Governors Association in 1986. The organization was created to improve the effectiveness and quality of state energy programs and policies, provide policy input and analysis, share successes among the states, and to be a repository of information on issues of particular concern to the states and their citizens. NASEO is an instrumentality of the states and derives basic funding from the states and the federal government.
- National Council on Electricity Policy <http://www.ncouncil.org/>
 - The National Council on Electricity Policy (National Council) is a unique venture between State and Federal Electricity Officials. The mission of the

National Council is to enable better coordination between federal and state entities responsible for electricity policy and programs. Our members understand that improved intrastate, regional and federal coordination can result in more informed policy decisions. To accomplish our mission we implement four types of activities: project-based activities, policy calls, annual planning meeting, and outreach.

- National Electrical Manufacturers Association <http://www.nema.org/>
 - NEMA is the trade association of choice for the electrical manufacturing industry. NEMA promotes the competitiveness of the U.S. electrical product industry through the development of standards, advocacy in federal and state legislatures and executive agencies, and the collection and analysis of economic data.
- North American Electric Reliability Corporation (NERC) <http://www.nerc.com/>
 - Our mission is to ensure the reliability of the bulk power system in North America. To achieve that, we develop and enforce reliability standards; assess reliability annually via 10-year and seasonal forecasts; monitor the bulk power system; and educate, train, and certify industry personnel. NERC is a self-regulatory organization, subject to oversight by the U.S. Federal Energy Regulatory Commission and governmental authorities in Canada.
- Plastics Pipe Institute (PPI) <http://plasticpipe.org/index.html>
 - The Plastics Pipe Institute Inc. (PPI) is the major trade association representing all segments of the plastics piping industry, promoting contemporary use of plastics piping for water and gas distribution, sewer and wastewater, oil and gas production, industrial and mining uses, power and communications, duct and irrigation. Comprised of approximately 300 members and associates, PPI serves as a channel for information sharing, issues resolution, idea exploration, and successful implementation guidance.
- The Regulatory Assistance Project <http://www.raonline.org/>
 - The Regulatory Assistance Project (RAP) is a non-profit organization, formed in 1992 by experienced utility regulators, that provides research, analysis, and educational assistance to public officials on electric utility regulation.
- Tube & Pipe Association, International (TPA) <http://www.fmanet.org/members/tpa-membership.cfm>
 - TPA is the technology affiliate of the Fabricators & Manufacturers Association, Intl., and provides the tools and resources companies need to improve operations. TPA informs and educates tube and pipe producing and fabricating professionals through conferences, expositions, magazines, technical research library, networking opportunities, and more.
- Valve Manufacturers Association of America (VMA) <http://www.vma.org/>
 - VMA represents the interests of nearly 100 North American manufacturers of valves and actuators. The organization provides a host of services such as meetings to exchange views on issues impacting on industry, networking

opportunities, statistical reports, workshops and seminars, and access to marketing communications.

F. Reports and Publications

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http://my.epri.com/portal/server.pt?space=CommunityPage&cached=true&parentname=ObjMgr&parentid=2&control=SetCommunity&CommunityID=404&RaiseDocID=00000000001015111&RaiseDocType=Abstract_id

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<http://www.electricitystorage.org/site/technologies/>

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<http://www.eia.doe.gov/oss/TransmissionDataNeeds-DH.pdf>

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<http://www.awea.org/GreenPowerSuperhighways.pdf>

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http://www.americanprogress.org/issues/2009/02/wired_for_progress.html

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G. Journals

- IET Generation, Transmission, & Distribution
<http://ieeexplore.ieee.org/xpl/RecentIssue.jsp?punumber=4082359>
- International Journal of Emerging Electric Power Systems
<http://www.bepress.com/ijeeps/>
- Journal of Computing in Civil Engineering
<http://scitation.aip.org/cpo>
- Journal of Construction Engineering and Management
<http://cedb.asce.org/cgi/WWWdisplay.cgi?0880010>
- Journal of Pressure Vessel Technology
http://catalog.asme.org/Journals/PrintOnlineProduct/JOURNAL_PRESSURE_VESSEL.cfm
- The Electricity Journal
http://www.elsevier.com/wps/find/journaldescription.cws_home/600875/description#description
- Transmission & Distribution World <http://tdworld.com/>

H. Conferences, Workshops, & Training

2010 IEEE Power & Energy Society Conference and Exposition; April 19-22, 2010, New Orleans, LA. <http://www.ieeet-d.org/>

Electrical Transmission and Substation Structures Conference; November 8-12, 2009, Fort Worth, TX. <http://content.asce.org/conferences/ets2009/welcome.html>

Structural Engineering Institute of the American Society of Civil Engineers
<http://content.seinstitute.org/>

V. BASELINE PROFILE - WATER

The water infrastructure of the U.S. consists of its reservoirs, dams, treatment plants, water mains, sewer lines, and wastewater facilities. The ASCE Report Card gave the U.S. drinking water and wastewater infrastructure a “D-“ and predicted investment shortfalls of \$108.6 billion over the next five years. In addition the Report Card awarded a “D” to the nation’s dam infrastructure and predicted a \$7.45 billion shortfall.¹²

The following presents a list of resources relevant to the construction processes of water infrastructure, as well as potential applications, opportunities, and challenges for measurement science.

A. Key Stakeholders

Many stakeholders are involved in addressing the variety of water infrastructure issues. Listed here are a few of the sector’s prominent players, with a larger list including summary descriptions of the entities located in Section E below.

- Association of Metropolitan Water Agencies (AMWA)
- National Association of Regulatory Utility Commissioners (NARUC)
- American Water Works Association (AWWA)
- American Public Works Association (APWA)

There are also stakeholders such as standards development organizations, engineering firms, and trade groups that have interests and expertise in many different aspects of infrastructure. Some prominent cross-cutting organizations are noted here. A further listing of stakeholders with summary descriptions can be found in Appendix A.

- American Society of Civil Engineers (ASCE)
- ASTM International
- Construction Industry Institute (CII)
- Construction Users Roundtable (CURT)
- FIATECH

B. Technology and Process Opportunities and Barriers

The survey of available literature has presented an assortment of technology and process opportunities and barriers for the advancement of water infrastructure delivery. Listed here are several recurring themes which have been extracted from the primary compilation of measurement science needs and considerations listed in the table in Section C.

¹² ASCE Infrastructure Report Card—Drinking Water; Wastewater; Dams:
http://www.infrastructurereportcard.org/sites/default/files/RC2009_drinkwater.pdf,
http://www.infrastructurereportcard.org/sites/default/files/RC2009_waste_water.pdf,
http://www.infrastructurereportcard.org/sites/default/files/RC2009_dams.pdf

- Opportunities for increased use of climate change models in predicting the impacts of changes in precipitation and snow melt patterns to more effectively plan infrastructure projects
- Increased use of cost-benefit analysis of system upgrades as well as full-cost pricing systems to enable effective investment and maintenance
- Development of remote sensing technologies and devices for improved in-situ monitoring of existing pipes and infrastructure

C. Measurement Science Needs and Considerations

Table V-1. Water Infrastructure Measurement Baseline				
Delivery Improvement	Measurement Science Challenge/Need	Potential Approaches/Outcomes	Resources and Source Documents	Relevant NRC Activity*
Project Planning and Permitting				
Cost	Metrics for full cost pricing of water infrastructure delivery	Allows utilities to recover actual costs and invest in long-term maintenance strategies	Condition Assessment of Wastewater Collection Systems	5
	Measurements and methods to more economically and reliably modernize outdated water storage and delivery infrastructure	Greater ability to budget and plan modernization projects.	Confronting the Nation's Water Problems: The Role of Research	5
Scheduling				
Quality and Functionality	Integration of climate change models, including snowpack and groundwater resources, into strategic and capital planning	Improved and integrated models through more accurate assessments of existing water resources.	Water Infrastructure Sustainability and Adaptation to Climate Change	1
	Improved modeling and in-depth evaluation of quantitative assessment tools which predict the pathways between climate change and infrastructure impacts	Greater ability to recognize and implement changes to infrastructure planning.	Water Infrastructure Sustainability and Adaptation to Climate Change	1
	Characterize, assess and recognize constraints brought about by the size, age, and complexity of existing water infrastructures	Ability to enumerate the opportunities for innovation.	Improving the Nation's Water Security: Opportunities for Research	5
	Identify, develop, and apply valid non-stationary probabilistic climate change models that link to regional and local hydrology	Ability to project multi-decadal hydrologic behavior, thus probing changes impacting water resources and infrastructure planning.	Toward a Sustainable and Secure Water Future: A Leadership Role for the U.S.	1

Table V-1. Water Infrastructure Measurement Baseline				
Delivery Improvement	Measurement Science Challenge/Need	Potential Approaches/Outcomes	Resources and Source Documents	Relevant NRC Activity*
			Geological Survey	
Design				
Cost	Economic analysis to quantify the cost and benefits of innovative designs for water systems	Ability to determine facets regarding security, water quality, and sustainability.	Improving the Nation's Water Security: Opportunities for Research	5
Scheduling				
Quality and Functionality	Validation and testing of the Army Corps ReSim model; development of a risk-based approach instead of traditional rule curve for designing reservoirs	Requires a shift from traditional planning methods, but may be better suited to increased uncertainty in future resources.	Water Infrastructure Sustainability and Adaptation to Climate Change	5
	Validate the feasibility of dual water systems to address water quality concerns in aging infrastructure while meeting demand for non-potable uses	Determines acceptability and management demands of decentralized wastewater treatment facilities and the net benefits to water security.	Improving the Nation's Water Security: Opportunities for Research	5
	Assess the accessibility of reclaimed water for progressively more intense levels of non-potable use (e.g., irrigation, toilet flushing, laundering)	Determines acceptability and management demands of alternative water sources for greater water security.	Improving the Nation's Water Security: Opportunities for Research	5
	Validate the feasibility of distributed treatment via point-of-use/point-of-entry devices installed at the scale of individual buildings or small neighborhoods	Assesses reliability and takes into account the unique characteristics of a locale.	Improving the Nation's Water Security: Opportunities for Research	5
Procurement				
Cost				
Scheduling				
Quality and Functionality				
Construction				
Cost				
Scheduling				
Quality and Functionality	Systematic review of water projects after construction by the Army Corps of Engineers	Ability to better understand how demands upon water projects have changed over time, strengths and weaknesses of planning methods, and how project operations have (or have not) changed to meet changing	Analytical Methods and Approaches for Water Resources Project	2

Table V-1. Water Infrastructure Measurement Baseline				
Delivery Improvement	Measurement Science Challenge/Need	Potential Approaches/Outcomes	Resources and Source Documents	Relevant NRC Activity*
		conditions.	Planning	
Commission and Handover (including O&M)				
Cost	Definition of costs and benefits of pipe inspection and rehabilitation as part of a utility's condition assessment program	Requires characterizing and standardizing cost and benefit assessment across utility infrastructure and possibly watersheds.	Condition Assessment of Wastewater Collection Systems	5
	Methods of determining the impact of deteriorating collection systems on municipal budgets	Requires determining the level of deterioration and how inspection, repair, and replacement costs impact long-term budgeting decisions.	Condition Assessment of Wastewater Collection Systems	5
Scheduling	Validation of formal risk assessment methods to prioritize resources for maintenance and rehabilitation activities	Requires implementing various risk assessment methods and evaluating results across different management/utility regimes.	Condition Assessment of Wastewater Collection Systems	5
	Development, testing, and validation of cost-effective, field-deployable sensing systems that are capable of providing continuous data	Enables effective prioritization of repair and retrofit schedules.	NIST Civil Infrastructure White Paper 2009	4
Quality and Functionality	Metrics for performance and cost of innovative and advanced infrastructure monitoring technologies, and their applicability to wastewater collection sewers	Requires measuring the performance of different monitoring technologies and comparing them to one another, as well as assessing the costs and applicability.	Condition Assessment of Wastewater Collection Systems	1
	Identify and evaluate innovative CCTV technologies used by some more advanced utilities	Zoom cameras, digital inspection, push cameras, and advances in crawler technology will enhance the quality of defect identification and pipe condition assessment.	Condition Assessment of Wastewater Collection Systems	4
	Protocols, metrics, and site selection criteria for field demonstration of selected innovative condition-assessment technologies and decisions-support systems	Enables testing and comparison of different technology options.	Condition Assessment of Wastewater Collection Systems	5
	Standardization of data to enable comparisons between historical data and new pipe inspection technologies, including those with proprietary data structures	Enables benchmarking based on historical data, as well as comparison of different systems and utility infrastructure.	Condition Assessment of Wastewater Collection Systems	1
	Application of the Pipeline Assessment Certification Program (PACP) coding system	Standardization of assessment methodology enables relative assessment of infrastructure and can assist in prioritizing investment in repairs and upgrades.	Condition Assessment of Wastewater Collection Systems	1

Table V-1. Water Infrastructure Measurement Baseline				
Delivery Improvement	Measurement Science Challenge/Need	Potential Approaches/Outcomes	Resources and Source Documents	Relevant NRC Activity*
	Development of standard technical guidelines, uniform data requirements, and indicators for condition assessment of sewers and non-sewer assets	Standardization enables relative assessment of infrastructure and can assist in prioritizing investment in repairs and upgrades.	Condition Assessment of Wastewater Collection Systems	1
	Validation of EPA's Strategic Asset Management program	Requires gathering extensive amounts of information of the condition of infrastructure as well as having a firm grasp of life-cycle costs.	Water Infrastructure Sustainability and Adaptation to Climate Change	5
	Tools to forecast, design, and manage water resources and infrastructure that are sensitive to environmental changes	Estimates of future climate change project greater environmental variability that will likely catalyze changes in the frequency and magnitude of floods and droughts. Changes in the hydrologic cycle will also have economic effects. These tools will better prepare for the outcomes of these effects.	Toward a Sustainable and Secure Water Future: A Leadership Role for the U.S. Geological Survey	5
<p>Table Notes</p> <p>*Five recommended activities from the 2009 NRC Report:</p> <ol style="list-style-type: none"> 1. Widespread deployment and use of interoperable technology applications 2. Improved job-site efficiency through effective interface of people, processes, materials, equipment and information 3. Greater use of prefabrication, preassembly, modularization, and off-site fabrication 4. Innovative widespread use of demonstration installations 5. Effective performance measurement 				

D. Government Entities & Programs

- Army Corps of Engineers Institute for Water Resources
<http://www.iwr.usace.army.mil/>
 This Corp division provides the U.S. Army Corps of Engineers with forward-looking insights and analyses on emerging water resources issues.
- Army Corps of Engineers, Water Supply Management
<http://www.vtn.iwr.usace.army.mil/>
 As one of the nation's largest water supply agencies, the U.S. Army Corps of Engineers plays a major role in ensuring that Americans have enough water to meet their needs. The Corps has 134 multiple purpose projects that contain storage for water supply in 26 states and Puerto Rico.
- Environmental Protection Agency (EPA), Office of Research and Development, Water Quality Research Program
<http://www.epa.gov/ord/npd/waterqualityresearch-intro.htm>
 The mission of the Water Quality Research Program is to protect human health and the environment in support of the Clean Water Act by providing the methods, approaches, and tools needed to assess, restore, and protect aquatic systems and

provide measurable improvement in water quality. The program's three main areas of research involve water quality protection, watershed management, and source control management.

- U.S. Geological Survey, <http://water.usgs.gov/>
As the primary Federal science agency for water-resource information, the U.S. Geological Survey (USGS) monitors the quantity and quality of water in the Nation's rivers and aquifers, assesses the sources and fate of contaminants in aquatic systems, develops tools to improve the application of hydrologic information, and ensures that its information and tools are available to all potential users.
- U.S.G.S. Cooperative Water Program <http://water.usgs.gov/coop/>
For more than 100 years, the Cooperative Program has been a highly successful cost-sharing partnership between the USGS and water-resource agencies at the State, local, and tribal levels.

E. Standards Organizations, Trade Associations, & Stakeholders

The following is a list of nationally relevant organizations involved in the deployment of both drinking water and wastewater infrastructure.

- American Concrete Institute (ACI) <http://www.concrete.org/general/home.asp>
 - The American Concrete Institute (ACI) is a nonprofit technical and educational society organized in 1904 and is one of the world's leading authorities on concrete technology. ACI is a forum for the discussion of all matters related to concrete and the development of solutions to problems. ACI publishes reliable information on concrete and its applications, conducts educational seminars, provides a standard certification program for the industry, provides local forums for discussion through the Chapter program, and encourages student involvement in the concrete field. Committee members involved with these activities meet at bi-annual conventions.
- American Concrete Pipe Association (ACPA) http://www.concrete-pipe.org/index.php?cp_Session=c9f847c0b1a0ed7072169b57529655f0
 - The American Concrete Pipe Association (ACPA) is a nonprofit organization, composed primarily of manufacturers of concrete pipe and related conveyance products located throughout the United States, Canada and in over 40 foreign countries. ACPA membership also includes manufacturers of equipment and/or providers of products and services related to the concrete pipe industry. ACPA provides members with research, technical and marketing support to promote and advance the use of concrete pipe for drainage and pollution control applications.
- American Concrete Pressure Pipe Association (ACPPA) <http://www.acppa.org/>
 - The American Concrete Pressure Pipe Association (ACPPA) is a nonprofit trade association representing manufacturers of concrete pressure pipe on the North American Continent. ACPPA sponsors research projects and conducts educational programs to promote and advance the use of concrete pressure pipe in water and wastewater applications.

- American Council of Engineering Companies (ACEC) <http://www.acec.org/>
 - The ACEC is the voice of America's engineering industry. Council members – numbering more than 5,500 firms throughout the country – are engaged in a wide range of engineering works that propel the nation's economy, and enhance and safeguard America's quality of life. ACEC is a large federation of 51 state and regional councils representing the great breadth of America's engineering industry. ACEC member firms employ more than hundreds of thousands of engineers, architects, land surveyors, scientists, and other specialists, responsible for more than \$200 billion of private and public works annually. Member firms range in size from a single registered professional engineer to corporations employing thousands of professionals.
- American Public Works Association <http://www.apwa.net/>
 - The American Public Works Association is an international educational and professional association of public agencies, private sector companies, and individuals dedicated to providing high quality public works goods and services. APWA provides a forum in which public works professionals can exchange ideas, improve professional competency, increase the performance of their agencies and companies, and bring important public works-related topics to public attention in local, state and federal arenas. The association is a highly participatory organization, with hundreds of opportunities for leadership and service, and a network of several dozen national committees in every area of public works.
- American Society of Civil Engineers (ASCE) <http://www.asce.org/>
 - Founded in 1852, the American Society of Civil Engineers (ASCE) represents more than 147,000 members of the civil engineering profession worldwide, and is America's oldest national engineering society. ASCE's vision is to position engineers as global leaders building a better quality of life.
- American Society of Testing and Materials (ASTM International) <http://www.astm.org/index.shtml>
 - ASTM International is one of the largest voluntary standards development organizations in the world—a trusted source for technical standards for materials, products, systems, and services. Known for their high technical quality and market relevancy, ASTM International standards have an important role in the information infrastructure that guides design, manufacturing and trade in the global economy.
- American Supply Association (ASA) <http://www.asa.net/>
 - ASA is a not-for-profit national organization serving wholesale distributors and their suppliers in the plumbing, heating, cooling and industrial and mechanical pipe, valves and fittings industries. ASA provides a forum for trading partners from around the country to discuss critical issues facing them, and offers a menu of products and services uniquely geared to their needs.
- American Water Works Association (AWWA) <http://www.awwa.org/>

- AWWA is the authoritative resource on safe water, providing knowledge, information and advocacy to improve the quality and supply of water in North America and beyond. AWWA advances public health, safety and welfare by uniting the efforts of the full spectrum of the water community.
- Association of Equipment Manufacturers (AEM) <http://www.aem.org/>
 - AEM membership is made up of more than 800 companies and represents 200+ product lines. AEM's role is to provide trade association services on a global basis for companies that manufacture equipment worldwide in the following industries: Agriculture, Construction, Forestry, Mining and Utility. AEM provides a wide variety of services that help members compete effectively in the global marketplace. Our core services include: Global Public Policy, Market Information, Technical and Safety, and Trade Shows; along with additional services which include: Global Business Development, Education and Workforce Development.
- Association of Metropolitan Water Agencies <http://www.amwa.net/cs/home>
 - The Association of Metropolitan Water Agencies (AMWA) is an organization of the largest publicly owned drinking water systems in the United States. AMWA is the nation's only policy-making organization solely for metropolitan drinking water suppliers. The Association represents the interests of these water systems by working with Congress and the federal agencies to ensure safe and cost-effective federal drinking water laws and regulations that protect public health.
- Association of State and Interstate Water Pollution Control Administrators <http://www.asiwpc.org/>
 - The Association of State and Interstate Water Pollution Control Administrators (ASIWPCA) is a national, nonpartisan professional organization. ASIWPCA members are the State, Interstate and Territorial officials who are responsible for the implementation of surface water protection programs throughout the nation. In addition to serving as a liaison among these officials, ASIWPCA facilitates their communication with the Federal government and promotes public education. Long before the enactment of the Clean Water Act, State and Interstate professionals were working to protect and improve water quality. They continue to lead the way in creating and realizing a vision for clean water in America.
- Clean Water Construction Coalition <http://www.cleanwaterconstructioncoalition.org/>
 - The Clean Water Construction Coalition is a national organization of construction associations whose purpose is to promote federal legislation that improves water and wastewater infrastructure on a national level. The Clean Water Construction Coalition is currently comprised of 28 dedicated state associations representing 11,000 member firms and is provided additional support by 11 organizational partners.
- Construction Industry Institute (CII) <https://www.construction-institute.org/scriptcontent/index.cfm>

- The Construction Industry Institute, based at The University of Texas at Austin, is a consortium of more than 100 leading owner, engineering-contractor, and supplier firms from both the public and private arenas. These organizations have joined together to enhance the business effectiveness and sustainability of the capital facility life cycle through CII research, related initiatives, and industry alliances. A learning organization with a wealth of knowledge and information, CII is unique in the engineering and construction industry.
- Construction Users Roundtable (CURT) <http://www.curt.org/>
 - An autonomous, not-for-profit organization, CURT strives to produce meaningful changes within the construction industry-promoting overall cost effectiveness; improving the way construction is planned, managed, justified and executed. Additionally, CURT works toward changing and improving what owners allow, require, and accept responsibility for on their domestic and global construction projects.
- FIATECH <http://fiatech.org>
 - FIATECH is a consortium of industries and companies – owners from the industrial, power, and retail markets that, of necessity, build large assets such as refineries, power plants, large commercial buildings, or manufacturing facilities. In addition, it includes the leading providers of engineering, design, and construction services. FIATECH not only provides a communication hub for members to quickly learn of new approaches, methods, and materials; it also does things. Project teams are formed to identify and accelerate the adoption of technologies and systems; demonstration projects are conducted to validate and perfect new approaches or methods; and teams are formed to aid and facilitate the deployment of those break-through initiatives that have been validated. In essence, it is each member’s highly robust R&D organization.
- Hydraulic Institute (HI) <http://www.pumps.org/>
 - The Hydraulic Institute is the largest association of pump industry manufacturers in North America, serving member companies and pump users by providing product standards and a forum for the exchange of industry information. HI has established itself as the leading spokesperson for the North American pump industry, offering a wide variety of programs and services such as: standards development, networking opportunities, access to specific statistical data and economic reports, electronic services, educational materials, breaking industry news, participation in industry initiatives, and more.
- International Council for Research and Innovation in Building and Construction (CIB) <http://www.cibworld.nl/site/home/index.html>
 - CIB was established in 1953 as an Association whose objectives were to stimulate and facilitate international cooperation and information exchange between governmental research institutes in the building and construction sector, with an emphasis on those institutes engaged in technical fields of research. CIB has since developed into a worldwide network of over 5000

experts from about 500 member organizations with a research, university, industry or government background, who collectively are active in all aspects of research and innovation for building and construction.

- International Union of Operating Engineers (IUOE) <http://www.iuoe.org/>
 - The IUOE is a progressive, diversified trade union that primarily represents operating engineers, who work as heavy equipment operators, mechanics, and surveyors in the construction industry, and stationary engineers, who work in operations and maintenance in building and industrial complexes, and in the service industries.
- National Association of Clean Water Agencies http://www.nacwa.org/index.php?option=com_content&view=frontpage&Itemid=1
 - The emergence of NACWA as a nationally-recognized leader in environmental policy and a sought-after technical resource on water quality and ecosystem protection issues has paralleled the maturation of the nation's most successful environmental law - the Clean Water Act. NACWA was established in 1970 by a group of individuals representing 22 large municipal sewerage agencies. They came together to secure federal funding for municipal wastewater treatment and discuss emerging national interest in improving the quality of the nation's waters.
- National Association of Pipe Fabricators (NAPF) <http://www.napf.com/>
 - NAPF serves the ductile iron pipe industry, promoting quality products and materials specified for water and wastewater treatment plants. NAPF has developed and produced a Standards Catalogue that not only covers the existing ANSI/AWWA Standards, but includes additional valuable information not currently available to the industry. The organization continues to assist in updating existing standards to more appropriately reflect changes within the industry.
- National Association of Regulatory Utility Commissioners (NARUC) <http://naruc.org/>
 - NARUC is an association representing the State public service commissioners who regulate essential utility services, such as electricity, gas, telecommunications, water, and transportation, throughout the country. As regulators, our members are charged with protecting the public and ensuring that rates charged by regulated utilities are fair, just, and reasonable.
- National Association of Water Companies (NAWC) <http://www.nawc.org/>
 - The National Association of Water Companies (NAWC) represents all aspects of the private water service industry. The range of our members' business includes ownership of regulated drinking water and wastewater utilities and the many forms of public-private partnerships and management contract arrangements.
- National Society of Professional Engineers (NSPE) <http://www.nspe.org/index.html>
 - NSPE, in partnership with the State Societies, is the organization of licensed Professional Engineers (PEs) and Engineer Interns (EIs). Through education, licensure advocacy, leadership training, multi-disciplinary networking, and

outreach, NSPE enhances the image of its members and their ability to ethically and professionally practice engineering.

- Plastics Pipe Institute (PPI) <http://plasticpipe.org/index.html>
 - The Plastics Pipe Institute Inc. (PPI) is the major trade association representing all segments of the plastics piping industry, promoting contemporary use of plastics piping for water and gas distribution, sewer and wastewater, oil and gas production, industrial and mining uses, power and communications, duct and irrigation. Comprised of approximately 300 members and associates, PPI serves as a channel for information sharing, issues resolution, idea exploration, and successful implementation guidance.
- Tube & Pipe Association, International (TPA) <http://www.fmanet.org/members/tpa-membership.cfm>
 - TPA is the technology affiliate of the Fabricators & Manufacturers Association, Intl., and provides the tools and resources companies need to improve operations. TPA informs and educates tube and pipe producing and fabricating professionals through conferences, expositions, magazines, technical research library, networking opportunities, and more.
- Valve Manufacturers Association of America (VMA) <http://www.vma.org/>
 - VMA represents the interests of nearly 100 North American manufacturers of valves and actuators. The organization provides a host of services such as meetings to exchange views on issues impacting on industry, networking opportunities, statistical reports, workshops and seminars, and access to marketing communications.
- Water & Wastewater Equipment Manufacturers Association (WWEMA) <http://www.wwema.org/>
 - The Water and Wastewater Equipment Manufacturers Association (WWEMA) is a non-profit trade organization founded in 1908 to represent the interests of companies that manufacture products sold to the potable water and wastewater treatment industries. Its mission is to inform, educate and provide leadership on issues which affect the worldwide water and wastewater equipment industry.
- Water Environment Federation (WEF) <http://www.wef.org/>
 - The Water Environment Federation is a not-for-profit technical and educational organization with 35,000 individual members and 75 affiliated Member Associations representing water quality professionals around the world. WEF and its Member Associations proudly work to achieve our mission of preserving and enhancing the global water environment. WEF and its global network of Member Associations help provide water quality professionals with the latest in water quality education, training, and business opportunities. WEF's diverse membership includes scientists, engineers, regulators, academics, plant managers and operators, and other professionals working in the United States and around the world. As a membership organization, WEF uses the collective knowledge of its membership to further a shared goal of improving water quality.

- Water Infrastructure Network (WIN) <http://www.win-water.org/index.shtml>
 - The Water Infrastructure Network (WIN) is a broad-based coalition of local elected officials, drinking water and wastewater service providers, state environmental and health administrators, engineers and environmentalists dedicated to preserving and protecting the health, environmental and economic gains that America's drinking water and wastewater infrastructure provides.
- Water Infrastructure Security Enhancements (WISE) Project <http://www.asce.org/static/1/wise.cfm>
 - The American Society of Civil Engineers (ASCE), American Water Works Association (AWWA), and Water Environment Federation (WEF) teamed up in 2003 to produce guidance documents for physical security of water and wastewater utilities under the Water Infrastructure Security Enhancements (WISE) project. The project was funded by the United States Environmental Protection Agency (USEPA).
- Water Research Foundation <http://www.waterresearchfoundation.org/>
 - The Water Research Foundation is a member-supported, international, nonprofit organization that sponsors research to enable water utilities, public health agencies, and other professionals to provide safe and affordable drinking water to consumers. The Foundation's four main goals focus on infrastructure, management and customer relations, water quality, and water resources and environmental sustainability. Specific research projects focus on treatment, distribution, resources, monitoring and analysis, management, and health effects.
- Water Utility Climate Alliance (WUCA) <http://www.wucaonline.org/html/>
 - The Water Utility Climate Alliance (WUCA) was formed to provide leadership and collaboration on climate change issues affecting the country's water agencies. Comprised of eight of the nation's largest water providers, WUCA members supply drinking water for more than 36 million people throughout the United States. Members include Denver Water, the Metropolitan Water District of Southern California, New York City Department of Environmental Protection, Portland Water Bureau and San Diego County Water Authority, San Francisco Public Utilities Commission, Seattle Public Utilities and Southern Nevada Water Authority.
- Western Coalition of Arid States <http://www.westcas.com/index.html>
 - A grassroots organization, WESTCAS is dedicated to encouraging the development of water programs and regulations which assure adequate supplies of high quality water for those living in the arid regions while protecting the environment. WESTCAS has current members in the following states: Arizona, California, Colorado, Idaho, New Mexico, Nevada, Oregon, and Texas.

F. Reports and Publications

Studies

American Society of Civil Engineers. 2009 Report Card for America's Infrastructure: Drinking Water <http://www.infrastructurereportcard.org/fact-sheet/drinking-water>

Congressional Research Service—Report for Congress. Water Infrastructure Needs and Investment: Review and Analysis of Key Issues. Updated November 2008. <http://www.fas.org/sgp/crs/homesecc/RL31116.pdf>

National Academy of Science. Drinking Water Distribution Systems: Assessing and Reducing Risks. 2006 http://www.nap.edu/catalog.php?record_id=11728

National Institute of Standards and Technology. Civil Infrastructure – Advancing Sensing Technologies and Advanced Repair Materials for the Infrastructure: Water Systems, Dams, Levees, Bridges, Roads, and Highways, 2009. http://www.nist.gov/tip/comp_09/white_papers/ci_wp_031909.pdf

National Research Council, Committee on Advancing the Competitiveness and Productivity of the U.S. Construction Industry. Advancing the Competitiveness and Productivity of the U.S. Construction Industry. 2009. http://www.nap.edu/catalog.php?record_id=12717

National Research Council, Committee on Assessment of Water Resources Research. Confronting the Nation's Water Problems: The Role of Research, 2004. http://www.nap.edu/catalog.php?record_id=11031

National Research Council, Committee on Water Resources Activities. Toward a Sustainable and Secure Water Future: A Leadership Role for the U.S. Geological Survey, 2009. http://www.nap.edu/catalog.php?record_id=12672

National Research Council, Committee on Water System Security Research. Improving the Nation's Water Security: Opportunities for Research, 2007. http://www.nap.edu/catalog.php?record_id=11872

National Research Council, Panel on Methods and Techniques of Project Analysis, Committee to Assess the U.S. Army Corps of Engineers Methods of Analysis and Peer Review for Water Resources Project Planning. Analytical Methods and Approaches for Water Resources Project Planning, 2004. http://www.nap.edu/catalog.php?record_id=10973

U.S. Environmental Protection Agency. Aging Water Infrastructure Research Program: State of the Technology for the Condition Assessment and Rehabilitation of Wastewater Collection Systems. May 2009. <http://www.epa.gov/nrmrl/pubs/600r09049/600r09049.pdf>

U.S. Environmental Protection Agency. National Risk Management Laboratory. Aging Water Infrastructure Research Program. September 2007. <http://www.epa.gov/nrmrl/pubs/600f07015/600f07015.pdf>

U.S. Environmental Protection Agency. Summary of the Water Infrastructure Forum. January 2003

http://www.epa.gov/waterinfrastructure/pdfs/summary_si_waterinfrastructureforum-2003.pdf

U.S. Environmental Protection Agency. Sustaining our Nation's Water Infrastructure August 2006.

http://www.epa.gov/waterinfrastructure/pdfs/brochure_si_sustainingournationswaters.pdf

U.S. Environmental Protection Agency. The Clean Water and Drinking Water Infrastructure Gap Analysis. September 2002.

http://www.epa.gov/waterinfrastructure/pdfs/report_si_infrastructuregap.pdf

Water Infrastructure Network. Water Infrastructure Now: Recommendations for Clean and Safe Water in the 21st Century. <http://www.win-water.org/reports/winow.pdf>

Strategic Plans and Roadmaps

U.S. Environmental Protection Agency. Office of Research and Development, Office of Water. Proceedings of the First National Expert and Stakeholder Workshop on Water Infrastructure Sustainability and Adaptation to Climate Change. April 2009.

<http://www.epa.gov/nrmrl/wswrd/wqm/wrap/pdf/workshop/600r09010.pdf>

Additional Information Databases and Resources

EPANET - EPANET is software that models water distribution piping systems. It performs extended-period simulations of the hydraulic and water quality behavior within pressurized pipe networks. EPANET was developed to help water utilities maintain and improve the quality of water delivered to consumers through distribution systems. It can be used to design sampling programs, study disinfectant loss and by-product formation, conduct system vulnerability and consumer exposure assessments, and to improve a system's hydraulic performance.

Storm Water Management Model (SWMM) - SWMM is a dynamic rainfall-runoff simulation model used for single-event or long-term (continuous) simulation of runoff quantity and quality from urban areas. SWMM tracks the quantity and quality of runoff, flow rate, flow depth, and quality of water in each pipe and channel during a simulation period. It can be used for designing urban and highway drainage systems, for Federal Emergency Management Agency (FEMA) floodplain mapping, and for studying sewer inflow and infiltration.

Water Quality Models - Tools for simulating the movement of precipitation and pollutants from the ground surface through pipe and channel networks, storage treatment units and finally to receiving waters.

G. Journals

- Computer-Aided Civil and Infrastructure Engineering
<http://www.wiley.com/bw/aims.asp?ref=1093-9687&site=1>

- Journal of Computing in Civil Engineering
<http://scitation.aip.org/cpo>
- Journal of Construction Engineering and Management
<http://cedb.asce.org/cgi/WWWdisplay.cgi?0880010>
- Journal of Environmental Engineering
<http://pubs.asce.org/journals/environmental/default.htm>
- Journal of Hydraulic Engineering
<http://pubs.asce.org/journals/hydraulic/default.htm>
- Journal of Hydrologic Engineering
<http://pubs.asce.org/journals/hydrologic/default.htm>
- Journal of Irrigation and Drainage Engineering
<http://www.wiley.com/bw/aims.asp?ref=1093-9687&site=1>
- Journal of Water Resources Planning and Management
<http://pubs.asce.org/journals/waterresouces/default.htm>

H. Conferences, Workshops, & Training

2010 Design-Build for Water/Wastewater Conference, April 19-21, 2010. Gaylord Texan Resort & Convention Center, Grapevine (Dallas), TX <http://www.designbuildwaterww.com/>

2009 Water Quality Technology Conference and Exposition, November 15-19, 2009, Seattle, WA
<http://www.awwa.org/Conferences/wqtc.cfm?ItemNumber=32120&navItemNumber=3545&showLogin=N>

American Concrete Institute 2009 Fall Convention, November 8-12, 2009. Marriott New Orleans, New Orleans, LA
http://www.concrete.org/EVENTS/EV_CONVENTIONS.HTM

Water/Energy Sustainability Symposium at the 2009 GWPC Annual Forum, September 13-16, 2009. Hilton Salt Lake City Center, Salt Lake City, UT
<http://www.gwpc.org/meetings/forum/forum.htm>

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<http://www.infrastructurereportcard.org/>

NRC 2009. National Research Council of the National Academies. "Advancing the Competitiveness and Efficiency of the U.S. Construction Industry," The National Academies Press, 2009. www.nap.edu/catalog/12717.html

NIST 2009. Advancing Sensing Technologies and Advanced Repair Materials for the Infrastructure; 2009.

NIST 2008. Chapman, R.E., Butry, D.T., "Measuring and Improving the Productivity of the U.S. Construction Industry: Issues, Challenges, and Opportunities," NIST White Paper, May 2008.

Teicholz, P., "Labor Productivity Declines in the Construction Industry: Causes and Remedies," AECbytes Viewpoint, Issue 4, April 14, 2004.

APPENDIX A - ADDITIONAL STAKEHOLDERS

- American Bearing Manufacturers Association (ABMA)
<http://www.abma-dc.org/>
ABMA is a non-profit trade association consisting of manufacturers of anti-friction bearings and major components thereof who manufacture in the United States. The Association serves the membership and industry through conferences, education seminars, bearing statistical programs, special projects and standards development, both national and international.
- American Composites Manufacturers Association (ACMA)
<http://www.acmanet.org/>
ACMA represents 850 of approximately 3000 composites manufacturers and suppliers to the industry, making a range of products for the transportation, power, and water industries. It provides a forum for the composites industry to develop and enhance shared opportunities and address common challenges, with priority goals that include: recognizing sources of education and information for the industry; proactively and positively affecting regulatory and legislative outcomes; and promoting the development and expansion of markets for composite products.
- Associated General Contractors of America (AGC)
<http://www.agc.org/>
AGC is the leading association for the construction industry, representing more than 33,000 leading firms in the industry - including general contractors, specialty contractors and service providers and suppliers. Operating in partnership with its nationwide network of Chapters, AGC provides a full range of services satisfying the needs and concerns of its members, thereby improving the quality of construction and protecting the public interest.
- Casting Industry Suppliers Association (CISA)
<http://www.cisa.org/>
CISA is a society of executives and managers representing companies that supply equipment, materials, and services to the metalcasting industry. The organization's mission is to support member companies in order to facilitate growth and prosperity by providing information, education and business opportunities, and by interfacing with other industry associations around the world to benefit the casting industry while fostering rewarding professional and business relationships.
- Fabricators & Manufacturers Association, International (FMA)
<http://www.fmanet.org/>
FMA is a professional organization with more than 2,000 individual and company members working together to improve the metal forming and fabricating industry. Founded in 1970, FMA brings metal fabricators and manufacturers together through technology councils, educational programs, networking events, trade shows, and publications.
- Gasket Fabricators Association (GFA)
<http://www.gasketfab.com/>

The GFA is a trade association of members dedicated to providing custom fabricated components and materials for use in industrial, electronic and medical applications worldwide. Its membership is composed of the foremost companies in the industry, and includes many of the smaller specialized product fabricators.

- Industrial Supply Association (ISA)

<http://www.isapartners.org/>

The primary focus of the ISA is to improve the industrial supply channel through its mission-critical activities, including: conventions and forums for member interaction and education; gathering and dissemination of critical information; and development and implementation of channel performance initiatives, including e-commerce, standards, industry advocacy and education. ISA is committed to bringing channel partners together and fostering an environment that allows for a free flow of communication to better understand the needs of both the manufacturer and distributor.

- National Association of Manufacturers (NAM)

<http://www.nam.org/>

The NAM advocates on behalf of its members to enhance the competitiveness of manufacturers by shaping a legislative and regulatory environment conducive to U.S. economic growth and to increase understanding among policymakers, the media and the general public about the vital role of manufacturing in America's economic and national security for today and in the future.

- National Electronic Distributors Association (NEDA)

<http://www.nedassoc.org/>

NEDA is a not-for-profit trade association representing companies involved in the supplier authorized distribution of electronic components and parts, computer and computer peripheral components and test, measurement and control equipment, and their manufacturer-suppliers. Activities of the organization range from networking, advocacy, and conferences to task forces & roundtables, education, research, and industry guidelines & standards.

- Process Equipment Manufacturers' Association (PEMA)

<http://www.pemanet.org/main/home.aspx>

Organized in 1960, PEMA maintains an organization of capital equipment manufacturers that serve industries such as chemical processing, wastewater treatment, building products, and metal processing. Among its various services, PEMA provides a social/business base where members can meet to share and exchange views on common interests and collects and distributes statistical data relevant to the interests of the membership.

- Procurement and Supply-Chain Benchmarking Association (PASBA)

<http://pasba.com/>

The PASBA is a free association of procurement and supply chain organizations within major corporations that conducts benchmarking studies to identify best practices that improve the overall operations of the members.

- Steel Manufacturers Association (SMA)

<http://www.steelnet.org/>

SMA consists of 36 North American companies that operate 130 steel plants and employ approximately 40,000 people, accounting for over seventy percent of domestic

steel production. Main functions of the organization include: the development and support of public policy positions consistent with the interests of its members; providing a forum for the exchange of information on technical matters and operations among member companies; and serving as a source of information on the steel industry to suppliers, customers, and various government entities.

- Steel Stud Manufacturers Association (SSMA)

<http://www.ssma.com/>

The SSMA is the unified voice of the steel framing manufacturing industry, supporting the development and maintenance of quality product standards and specifications; and creating growth opportunities for cold-formed steel through research, marketing, and education.