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the all-industry average is 3.7% of sales. The picture appears to be similar in most other developed countries; Japan [2] and Sweden [3] are exceptions.

This is representative of the conditions that inspired the President of the United States, in 1993, to establish the National Science and Technology Council. Among the principal objectives of its Committee on Technological Innovation [4] are:

- Set national priorities for technologies that enhance U.S. industrial competitiveness.
- Coordinate federal R&D activities to minimize duplication.
- Involve the private sector in setting federal R&D priorities.
- Identify technology needs of industries particularly important to the U.S. economy.
- Encourage coordination with industry and academia.
- Monitor foreign technology advances.

The fundamental objective is not to increase government R&D, but to facilitate and increase industries' investments in highly competitive, innovative products and services.

In recognition of the importance of the industries of construction, the Subcommittee on Construction and Building (C&B) was formed in March 1994.

C&B, in order to demonstrate to policy makers in the private and public sectors the values of investments in innovation, and in consultation with leaders of the industries of construction [5], formulated goals for the life cycle performance of constructed facilities:

- 50% reduction in project delivery time.
- 50% reduction in operation and maintenance.
- 30% increase in productivity and comfort.
- 50% fewer occupancy-related illnesses and injuries.
- 50% less waste and pollution.
- 50% more durability and flexibility.
- 50% fewer construction illnesses and injuries.

The baselines are average performance of the industries in 1994. The targets are to have verified practices, capable of meeting the goals with reduced life cycle costs for owners, available for construction projects in 2003.

The construction goals are expressed in performance terms. An important challenge is to characterize and quantify the baselines and define measures for progress. C&B and its participating federal agencies are working with industry to establish these baselines and measures.

The construction goals are intended to express the desires of leaders of the industries of construction; they are not a government mandate to the industry. A focused workshop [6] with industry leaders defined the priorities of industry sectors and described the goals as National Construction Goals. C&B is encouraging industry to inform the federal agencies of the federal or federally-funded R&D needed to achieve the goals.

## ADDRESSING CONSTRUCTION GOALS

C&B, drawing on many research fora and interactions with industry, has identified the following technical opportunities to obtain progress toward the goals:

- Information and decision technologies. Advanced information technologies can improve the flow of information to decision makers, and improve understanding through multi-media information processing.
- Automation in design, construction and operation. Attention is needed to exploiting the potential of automation while avoiding unwanted side effects.
- High performance materials and systems. There are great opportunities for “designed” materials and systems fit to the specific project needs.
- Environmental quality. Objectives include energy conservation, air quality, and environmental sustainability. Needs and opportunities for remediation and use of contaminated sites provide particular challenges.
- Risk reduction technologies. Natural (fire, earthquake, wind, flood) and manmade (fire, terrorism, toxic discharges) hazards with increasing urbanization pose growing risks of losses requiring advanced, performance-based technologies for mitigation.
- Human factors knowledge. Performance ultimately is human functionality, safety and comfort; much research is needed to make human performance, as affected by the built environment, measurable and predictable. While the importance of human factors knowledge is evident, at present, many industry leaders are doubtful about our abilities to get valid and useful results from research. We should, at least, invest modestly and systematically in human factors research. When successful techniques are evident, this will be a most fruitful area for performance-oriented research.
- Performance standards system. The system of performance standards and conformity assessment is essential to acceptance of innovations and for focus of resources on effectively achieving construction goals.

Industry leaders, in all of our interactions, have emphasized that private investment in innovations is severely inhibited by the existence of barriers to profit from investments. The barriers most often cited are:

- Lack of leadership in private and public sectors. The current U.S. Administration, with its establishment of the National Science and Technology Council and its assignment of unprecedented high priority to federal R&D for construction [7], has shown leadership. This is not yet reflected in Congressional responses to Administration requests for appropriations. The construction goals approach is attracting extraordinary support of leaders of industry for improved construction technologies and for removal of barriers to innovation.
- Regulatory barriers result from the myriad, uncoordinated approvals required for a project from local, state and federal regulatory authorities. These generate long and costly delays for conventional projects; fear of yet longer delays inhibit innovations. Our Administration encourages federal agencies to work together and with state and local agencies to streamline regulatory processes. This work is beginning.
- Liability from real or imputed failure of products to perform over the service life as the customer or other injured party expected discourages investment in innovations. Federal agencies, and other organizations, can provide low risk test beds to reduce liabilities for innovators.
- Adversarial relations in construction projects often discourage each participant from innovating. Partnerships among project participants are needed.

- Financial disincentives for innovation exist because most construction organizations are too small to invest substantially in research, and because of the difficulty of protecting intellectual property when innovations are evident to observers and the workforce often changes employers. Some of these barriers can be overcome by consortia for innovation involving industry and researchers from academia and government.
- Lack of skilled workforce extends from shortages of replacements for retiring skilled tradesmen to the loss of knowledgeable corporate real estate executives from corporate downsizing. Solutions include education and training in conventional and innovative technologies, improvement of the work environment, automation and knowledge systems and the development of innovative professional and business services.

Knowledge from performance-oriented research must be transferred to practice so that it may be used to produce private and public benefits. Principal deployment activities include:

- Standards and practices are formulated to integrate new knowledge into the various contexts for its practical use.
- Education and training are required for the implementers of innovations. Collaborations between employers, employee organizations (such as professional societies and trade unions) and innovators are needed to fund and develop the educational syllabi.
- Demonstration projects, as noted above, can provide low risk test beds for innovations and show practical people the benefits to be obtained from and the techniques required in implementation.

#### COLLABORATIONS AND ACCOMPLISHMENTS

Leading U.S. private sector organizations have taken initiative to convene sector leaders to define: the goals most important to the sectors of the industries of construction, and the practices and research results that will be needed to achieve them. For each sector, many other organizations are participating with the lead organization. The sectors and their lead organizations are:

- Residential, the National Association of Homebuilders Research Foundation.
- Commercial/Institutional, the National Institute of Building Sciences.
- Industrial, the Construction Industry Institute.
- Public Works, the American Public Works Association.

The Civil Engineering Research Foundation is coordinating these private sector efforts and preparing a synthesis of their recommendations for guidance of the federal agencies participating in C&B. The findings are expected to include activities of:

- The industries of construction to:
  - Remove barriers to innovation.
  - Develop baselines and measures of progress toward goals
  - Invest in improved products and services.
  - Lead the world in quality and economy.
- Government Agencies and Researchers to:
  - Conduct R&D enabling private investments.
  - Help remove barriers to innovation.
  - Support deployment of innovations.

While the Subcommittee on Construction and Building is efficient in convening the federal agencies for planning with industry groups, actual cooperations in research will be accomplished by consortia involving one or more companies and one or more agencies. To guide industry and agencies in establishing such collaborations, a Collaborations Workshop [8] was held with leaders of industry and representatives of federal agencies. The workshop report describes: cooperative mechanisms protecting industries' intellectual property, research needs and opportunities, and the capabilities of the federal laboratories.

Example success stories are cited. Owners, designers, builders and suppliers for process plants are working with the National Institute of Standards and Technologies to develop international information exchange standards supporting automatic transfer of data among project participants throughout the life cycle. Manufacturers of seismic base isolation devices have worked with universities sponsored by the National Science Foundation, the Veterans Administration and the General Services Administration to develop systems for cost-effective retrofit of federal buildings. Five asphalt paving equipment manufacturers, the National Asphalt Paving Association, the Federal Highway Administration and the National Institute for Occupational Safety and Health have developed pavers that significantly reduce the exposure of workers to asphalt fumes. Global positioning system software developed by the Army has been integrated with controls developed by Caterpillar to provide autonomous construction vehicle navigation.

The delays and other costs of obtaining regulatory approvals for new products are great barriers to private investment in new product development. With support from federal agencies and industry groups, the Civil Engineering Research Foundation has organized evaluation centers to assist manufacturers to obtain a single, authoritative evaluation that will be recognized by regulators and users nationally and internationally. Centers include: the Highway Innovative Technology Evaluation Center, the Environmental Technology Evaluation Center, the Civil Engineering Innovative Technology Evaluation Center, and the National Evaluation Service Building Innovation Center.

Delays and costs of obtaining regulatory approvals are both a barrier to use of innovative products and practices in construction projects and an important factor in increasing costs and obsolescence of constructed facilities. As an element of the U.S. Innovation Partnership between federal and state governments, and with support from the federal agencies, the National Conference of States on Building Codes and Standards has organized a program Streamlining the Nation's Building Regulatory Process to develop and gain the adoption of a package of model reforms which when adopted by federal, state, regional or local governments will enhance public safety, economic development, and environmental quality while reducing by as much as 60% the amount of regulatory processing time it takes to move projects from the initial step of zoning approval through to the last step of issuance of the certificate of occupancy.

The High-Performance Construction Materials and Systems Program (CONMAT) has been organized by twelve materials trade associations to develop and commercialize the high performance materials and systems needed for 21st century infrastructure. CONMAT members have underway about \$250 million in R&D shared roughly evenly between the private sector and federal agencies. It will be desirable to create similar focal points for federal and industry cooperation in the areas of mechanical systems and furnishings.

The National Institute of Standards and Technology has established the Manufacturing Extension Partnership - a nationwide network of extension centers and experts co-funded by states and local governments that provides hands-on technical assistance to smaller manufacturers. The Manufacturing Extension Partnership is studying with industry the potential for establishing a Construction Technology Extension Program.

The residential sector has expressed two major goals: reducing housing costs and improving durability. Their Action Plans for Achieving High Priority Construction Goals in the Residential Sector [9] cites seven strategic approaches: information infrastructure, methods for assessing and increasing durability, improving production efficiency, streamlining regulatory processes, understanding the performance of light frame structures - particularly in high winds and earthquakes, fostering commercialization of innovations, and

expanding markets and marketability. The Subcommittee on Construction and Building is working with the residential sector to create a focused program for advancing housing technology.

The Construction Industry Institute is comprised of major owners of industrial and infrastructure facilities and the major contractors and suppliers serving these markets. It conducts research and implementation on best practices to improve the capital investment process and is exploring collaborations to achieve breakthrough improvements in practices. In a recent workshop with federal agencies [10], eleven priority topics were identified: business leaders' needs, technology transfer and implementation, global standards and conformity assessment, model based design, integrated project information to the field, information exchange protocols, production line techniques in construction, remediation of hazardous materials and sites, aids/ tools/robotics for the productivity and safety of construction workers, safety practices, and behavior modification for safety.

The American Institute of Architects, the International Association of Corporate Real Estate Executives, the International Facility Management Association, and Johnson Controls, Inc. have organized the Building Performance Consortium to address the goal for improvement of the productivity of building occupants. The Consortium is holding annual National Summits on Building Performance involving leaders of industry and government and cosponsoring with the federal agencies studies to better define the effects of building environments on their occupants' productivity.

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