PART ONE:

INTRODUCTION AND SUMMARY

CHAPTER ONE

INTRODUCTION AND SUMMARY

CONSTRUCTION AND MlATERIALS RESEARCH AND DEVELOPMENT FOR THE NATION'S PUBLIC WORKS

The nation's infrastructure is the physical framework that supports and sustains virtually all domestic economic activity; it is essential to maintaining international competitiveness as well. In its broadest definition, "infrastructure" includes all types of public facilities, such as highways, roads, and bridges; water resource projects and water supply and treatment systems; sewer systems and wastewater treatment plants; locks, dams, and waterways; ports; airports; railroads and mass transit facilities; public buildings; and resource recovery facilities.1 To meet the immediate concerns of the Senate Environment and Public Works Committee for a review of infrastructure research and development (R&D), this Office of Technology Assessment (OTA) Staff Paper focuses on construction technologies and materials for transportation and water-related infrastructure components --those commonly termed "public works,"2 Thus, public buildings, mass transit systems, railroads, airports, and the air traffic control system are not included, although significant Federal sums are spent on them.

OTA found that public and private expenditures for R&D related to infrastructure technologies and materials are very low--generally less than 0.3 percent of gross annual expenditures by Federal agencies or business volume for industries. Moreover, water and wastewater systems and advanced construction technologies receive virtually no Federal R&D funding. In light of

[1] See, Public Works Improvement Act of 1984, P.L. 98-501,

2 As used in this Staff paper, "construction" refers to new construction, reconstruction, repair, and maintenance unless specifically described otherwise.

this, Congress may wish to consider increasing support for R&D programs that focus on these neglected areas.

OTA also found substantial institutional barriers and economic disincentives to nonfederal R&D, especially in the movement of new technologies and materials off the research bench and into the field. These include procurement processes and issues related to risk that impede the adoption of new technologies and materials in public works projects, and splintered private and governmental roles. In addition, investments in public works are characterized by high fixed costs, lengthy planning and construction schedules, complicated public financing arrangements, and long payback periods, which lead to uncertain economic returns on R&D investment. Consequently, OT.A concludes that simply increasing R&D expenditures without also taking steps to alleviate these barriers and disincentives will do little to advance the materials. machinery, and methods by which we design, build, and maintain our Nation's public works.

BACKGROUND

Federal, State, and local governments are responsible for building, repairing, and maintaining public works. The magnitude of public works investments by these governments is very large--S97.3 billion in 1984--accounting for about 24 percent of all new construction annually. However, the growth rate of public works investment has slowed significantly' over the past three decades compared with the growth rate of net private capital formation. [3] Two studies have associated this trend with deterioration of the nation's infrastructure.

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[3] National Council on Public Works Improvement, The Nation's Public Works: Defining the Issues (September 1986), p. 47.

[4] Randall W'. Eberts, "An Assessment of the Linkage Between Public Infrastructure and Economic Development," prepared for the National Council on Public Works Improvement (July 1986); Therese J. McGuire, "On the Relationship Between Infrastructure Investment and Economic Development," prepared for the National Council on Public Works Improvement (July 1986).

Total real spending for public works increased from $60 billion in 1960 to $97 billion in 1984, but total spending as a share of GNP has declined. In 1984, total public works expenditures on construction, operations, and maintenance were 2.7 percent of GNP, down from around 3.7 percent in 1961. This decline reflects a marked drop-off in capital expenditures for new construction, and an increase in outlays for operations and maintenance. Thus the public sector has shifted its primary focus from building new stock to maintaining its existing capital base.[5] Construction of entirely new, large-scale public works projects has slowed substantially with the completion of the interstate highway system and the shift in national budget priorities toward defense-related projects.

Another important trend is the change in the types of facilities funded that occurred between 1960 and 1980. Highway projects dominated public works investment in the 1960s, with water resources and water supply systems a distant second. After 1970, highway spending began to decline as spending for other facilities--primarily wastewater treatment and mass transit--grew. In the 1980s, highway spending has continued its relative decline, while mass transit funding continues its relative increase. Expenditures for wastewater treatment, water supply, and solid waste have remained comparatively stable since 1980.[6]

Still another trend is the shift in spending by level of government. From 1960-1984, the relative role of States in funding public works declined, while the local share of infrastructure spending rose, with the greatest increase occurring since 1980. In 1984, local governments accounted for 50 percent of the total public works investments, the Federal Government 27 percent, and State governments 23 percent. While local governments have borne more of the responsibility for the construction costs for water supply, wastewater treatment, solid waste, and mass transit facilities, they also face rising costs for operating and maintaining all forms of

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[5] National Council on Public Works Improvement, supra note 3, at pp. 48-49.

[G] Ibid, p. 51.

public works. The Federal role has been characterized by periodic bursts of spending for highway, wastewater treatment plant, and mass transit facility construction.[7]

The concerns about the condition of the Nation's infrastructure that were so widely-publicized in the early 1980s prompted several recent studies[8] that attempted to define current annual infrastructure investment needs for adequate maintenance, repair, rehabilitation, and new construction. These estimates range from $52.6 billion to $118.2 billion.[9] Actual expenditures are expected to meet only 33 to 60 percent of the estimated public works construction and repair needs.

The relative decline in capital works expenditures and other concerns led the Senate Committee on Environment and Public Works to ask OTA to study a number of issues related to research and development for public works to determine the effectiveness of infrastructure R&D policy and programs. These issues include:

1. The major areas of construction, repair, and maintenance technology that could benefit from increased research and development and that are likely to yield valuable results in the short and long term;

2. The magnitude of research and development needs, and the point point at which increased funding for research and development would reach diminishing returns;

3. The present state of research and development in the private sector, and the advantages or disadvantages of government research and development programs relative to similar private sector efforts;

4. A comparison of research and development spending for infrastructure construction, maintenance, and rehabilitation and that in other major industries;

5. The research and development efforts of other countries, and the extent to which these efforts are underwritten by government agencies;

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[7] Ibid, p. 53.

[8] National Council on Public Works Improvement, supra, note 3; Congressional Budget Office, Public Works Infrastructure: Policv Considerations for the 1980's (.April 1983); The Associated General Contractors of America, America's Infrastructure: A Plan to Rebuild (May 1983).

[9] National Council on Public Works, supra, note 3, Table II-1, at p. 10. Estimates are for *ail* public works, including airports, mass transit systems, and solid waste disposal facilities.

6. The overlap between the areas of highways, water projects, sewage treatment, public buildings, and other types of construction that might warrant a more unified or coordinated research program for all of these areas;

7. The constraints on innovation caused by existing Federal contracting or administrative procedures; and

8. The adequacy and efficiency of technology transfer between government agencies and the private sector.

This OTA Staff Paper responds to the Committee's request. Part One of the Paper is this Introduction and Summary. Part Two examines R&D for construction technologies and methods, and Part Three focuses on materials-related R&D for public works. This is not an exhaustive review of all aspects of R&D for public works. OTA relied on an extensive literature survey supplemented with information obtained in meetings and telephone conversations with Federal agencies, trade associations, and companies. Several questions were impossible to address adequately within the time constraints of this survey, and would benefit from further study. In particular, we were unable to quantify the size of the R&D needs, or the point at which R&D investment reaches diminishing returns (question 2, above). Instead, we provide a brief qualitative review of the R&D areas that would deliver the "biggest bang for the buck," and discuss means of using the available research dollars more efficiently. In addition, we were unable to conduct a thorough review of the constraints introduced by Federal contracting policies and issues related to risk (question 7).

WHAT ARE THE POTENTIAL ECONOMIC BENEFITS OF R&D FOR PUBLIC WORKS?

The long-term cost savings from the development of new and improved technologies and materials for public works construction, repair, and rehabilitation, or of a better understanding of the properties and uses of currently available technologies and materials, could far exceed the short-term cost of an expanded commitment to R&D. Other benefits of public works R&D are less easy to quantify, such as the potential public health benefits of improved water and wastewater treatment, and the benefits of improved infrastructure systems for local economic development. While OTA was unable to quantify the potential R&D costs of achieving these benefits, we can offer several examples of research areas with potentially big "payoffs" that can be quantified.

The Transportation Research Board (TRB) estimates that the total cost of rehabilitating and replacing the nation's highways and bridges will be between $1 trillion and $3 trillion. According to the TRB, if research could improve the performance and durability of roads and bridges by just one percent, the direct savings would be $10 billion to $30 billion. Much of that payoff would come from advances in materials and improved understanding of materials performance, because materials absorb almost half of new construction costs.

The Federal Highway Administration estimates the repair and replacement costs for the more than 137,000 bridges rated as "deficient" at over $35 billion; an additional 85,000 bridges are in need of rehabilitation at a total of $15.5 billion.[11] Most of these repair costs are for replacement of concrete bridge decks. The decks are designed to last for 40 years, but because of weather conditions and the use of corrosive de-icing materials, they often require extensive repairs in 5-10 years and replacement at 15 years. Development of anti-corrosion protection systems that could extend the performance life of bridge decks from 15 to 20 years (only half the theoretical design life) would have a payoff in excess of $2 billion.[12]

For repair and reconstruction of *public works,* however, costs associated with redirecting traffic, site protection, and public safety are so large that the materials costs can shrink to be-

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10 Transportation Research Board, America's Hi~hwavs: Accelerating the Search for Innovation, Special Report 202, 1984, at p. 82.

11 Martin Tolchin, "$50 Billion Needed for Bridge Repair, Congress is Told by Federal Agency, " New York Times, April 12, 1987, p. 24.

12 TRB, supra note 10, *at* p. 109,

tween 3 and 4 percent of the total. Thus R&D to improve the durability and lengthen the effective life span of the materials used for repair and reconstruction could bring large construction cost benefits with little increase in the total project cost.

Asphalt paving materials account for over 20 percent of total highway spending in the U.S. The Federal Government alone is projected to spend over $200 billion on asphalt pavement by 2000. Even a one percent improvement in the performance life of asphalt pavement from research could save over $100 million annually in total highway repair and construction costs. This expected savings is not unreasonable, because many highway engineers believe that an increase of 3 to 5 percent in asphalt pavement life could be achieved now simply through better quality control in pavement design, construction, and maintenance. Similarly, asphalt cement represents roughly 20 to 25 percent of the cost of asphalt paving material. Use of improved asphalt cements in initial construction or overlay could save repair and repaving costs of more than four times the cost of the cement.[13]

Studies of buried sewer and water pipes by the Environmental Protection Agency (EPA) and the American Water Works Association Research Foundation have found that external and internal corrosion are roughly equal contributors to pipe deterioration. Neither mode of corrosion is well understood, but arresting either one could almost double the performance life of sewer and water pipe systems. Internal corrosion protection systems, such as slip liners and special coatings, avoid the much higher costs of excavating and repairing or replacing buried pipe, which can run as high as $80 to $100 per installed line foot of pipe. Although cost estimates for internal protection measures were not available, the American Water Works Association says they can be significantly less than excavation and repair/replacement costs. Continued R&D would lead to lower costs and improved performance of internal protection methods.[14]

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13 Ibid, at pp. 66-67, 82-83.

14 Personal communication to OTA by Jack Sullivan, American Water Works Association, April 1987.

As these examples show, the benefits of even modest increases in materials R&D for highway repair, maintenance and construction alone could be $15 billion to $35 billion over the next 10 to 20 years. Compare these savings to the current Federal and nonfederal investment in materials R&D for all types of public works of $53 million to $62 million, and the value of the investment in R&D becomes even more pronounced. Still more significant, much of this benefit could be obtained with materials that are available now, but are not used because of inadequate technology transfer, the perceived financial risks of using new materials, and government procurement practices.

Of particular importance is research into methods of improving the life of drinking water systems, which has a relatively low level of support. A focused research program to increase knowledge about the factors affecting the life cycle costs of clean water systems could bring rich benefits as the country embarks on a renewed effort to upgrade such systems.

Individuals contacted by OTA during the course of this survey cited three primary areas in addition to materials where R&D could offer great opportunities for public works benefits:

-- Robotics and automation for use in construction, particularly for applications in hostile environments and for remote sensing;

-- Computer applications creating efficiencies in construction processes and improving design. Advances in computer technology and software, such as integrated knowledge systems consisting of networked expert systems, simulation models, and databases, also could be invaluable in overcoming the inadequate information exchange among researchers and public works agencies, and thus in promoting the use of the best available materials and technology; and

-- Basic research into natural water processes, such as the effects of shoreline erosion and groundwater movements and characteristics on structures. So little is known about these natural processes that public works improvements often are undertaken with insufficient understanding to ensure structural longevity.

WHO IS FUNDING R&D FOR PUBLIC WORKS?

Research and development for public works are sponsored and carried out by a number of Federal agencies, and by State and local governments, universities and research centers, trade associations, and corporations. However, despite the economic importance of public works, and the magnitude of annual investment in construction, operations, and maintenance, R&D expenditures on construction technologies and materials are relatively small. Total Federal R&D for infrastructure was $103 million in FY85, or roughly 0.3 percent of total new infrastructure construction (see table 1- 1). Of this amount, OTA estimates that Federal agencies spent around $36 million on R&D for infrastructure materials; $14 million on incremental and advanced improvements in construction technologies and methods; and the remainder to improve design, evaluations, needs analyses, management systems, feasibility studies, information dissemination, etc.

The types of, and levels of funding for, Federally-sponsored R&D programs related to public works vary widely (see tables 1-2 and 1 -3). Domestic public works projects tend to borrow technologies and materials developed for other applications (e.g., fiber-reinforced concrete). Federal research agendas reflect this in their emphases on adapting available products for specific public works applications, on analyses of public works capacity, and on management support. OTA found no significant Federal R&D expenditures for advanced construction technologies, or to support the design or development of alternative infrastructure systems, such as a totally new way of delivering water.

Although reliable data on nonfederal R&D funding are difficult to obtain, OTA found that private sector R&D for infrastructure construction technologies and materials also is minimal. Based on the figures obtained within the time constraints of this survey, OTA estimates that total nonfederal materials-related R&D for infrastructure is about $18-$25 million annually. Similar figures were not available for construction R&D, but OTA estimates R&D expenditures by construction equipment and materials manufacturers to be less than 0.3 percent of the total annual value of new construction in the United States. Construction firms come in on the low end of this estimate, spending less than 0.04 percent of their annual construction sales on R&D. Materials manufacturers and suppliers spend between 0.1 and 0.3 percent of their annual sales on R&D. Data on R&D spending by State and local governments generally were not available for this survey.

Table I-l .-federal RAD Expenditures

YEAR	Value of New Infrastructure Construction in U.S. (mllflons of dollars)	federal R6D - Incremental and Advanced: Ml l l ions of Dollars	federal R6D - Incremental and Advanced: Percentage of Total Publlc Works Expenditures	Federal R&() - Total Reported: Mlllons of Dolfars	Federal R&() - Total Reported: Percentage of Total Publlc Works Expenditures
1985	34,370	14	0.1	103	0.
1986	38,742'	15	0.1	109	0.
1987	(unknown)	14	(unknown)	97	(unknown

[9] f'rel iminary d.dta.

SWltceb; Total v~lue of new infr~>tfucture construction ad~pted by OTA from U.S. Department of (kmmerce, Bureau of the Cen>us, v~[ue of NCW Clm~truction Put in Place, C30-86- 12, issued fetwuary 1987 (Washington, DC: U.S. Government Printing Off Ice, December 1986). ;-ederal R611 expenditures from OTA.

Iable I-2.–Ieder~l Expenditures on R6D for All Infrastructure Types
FY 1985-87 (3-Yecir>) Spending
(in mi I I ion> of ~01 Idr>)

	For Construction Technologies					
	Adv~nced R&L)	Incremental R&D	Lhsic Rese~rch For R&D	Re~e~rch to Improve De>ign, Evaluations, And/or Needs An~ly>es	Other Rti>carch	rOt,l
Federal Agencies:						
Corps of Engineers	$0	$28.2	$0	%35.6	532.8	596.6
Bureau of Reclamation	0	0.3	0	4.3	2. I[b]	7.4
Federal Highway Administration	0	7.7	0	14.5	9.8	32.0
5 ate HP&R Projects[a]	0	0	0	9.8	I30.0	I 40.4
Nell onal Bureau of Standards	0.3	0.4	1.9	4.7	2.9	10.3
1nv ronmental Protection Agency	0	0	2.0	6.0	3.0	1I.0
rJdl onal Science Foundation	0.3	1.4	0	3.3	1. 4[b]	6.5
Organization Using Federal Funds:						
Transportation Research Board (NCHRP)	0	0.2	0	3.3	1. 7[b]	5.2
TOTAL	$0.1	$38.3	$3.9	$81.5	$184.9	$309.4
PERCENT DISTRIBUTION	0.2$	I2.4X	1.3%	26. 3%	59.8$	100. ox

Note: Figures may not total correctly because of rounding.

[a]State Highway Planning and Research (HP&R) of the Federal Highway Administration funds also include research projects not directly related to construction technology or materials, such as studies on highway safety and traffic operations.

[b]Includes a small amount of basic research useful for R&D of construction technologies.

SOURCE: Office of Technology Assessment, from data provided by Federal agencies.

I~blc I-3.–Feder~l MI) Expenditures for Each Infrastructure Type

tY 1985-87 (3-Years) Spending

(in mltl ions of dollars)

	(or Construction Technologies					
	Adv~nced RI$I)	Incremental ~a~	tIdslc Research For RaO	Research to Improve Design, Ev~luations, And/or Needs Analyses	Other Re>edrch	Total
I)dnb	.5	1.8	1.9	11.0	4.4	19.4
Wdlcf supply Sybtclnb	.3	.4	1.9	6.7	6.7	16.0
Sewer Sy>tem>	.3	2.9	3.9	9.4	5.6	22.1
lligtlwijy> tilld OIl)ef liu{~dways	.6	8.0	1.9	28.3	146.6	185.0
of Idgeb"	.4	3.6	1.9	12.1	5.0	23.0
Iuflllicl>	.3	.4	1.9	4.6	2.1	9.3
Wdlclwdyb, including i'oi t>	.5	23.7	1.9	31.7	27.0	84.1

[a] iXI-!(~tIC> dII unkl~uwl) ~\IIIIIIIII ot expc[Id i t ures lor State Hf'&R projects; however, these expenditures are not for ~oil>tructlon teclinologlc "~.

tk) i c: t igures mdy fmt CIdd tl<)(izul~tdlly tlecdube of rounding and dre not added vertically bec~use >I 911 I f I Cdll t dIIILMIII I s (J t bpc IIct i ng dpp I y 10 more t t~dn one type of i n f r db t r uc t ure. Md t er i d I s C XDCIId i t UI c> df G I I It. I 11 dc d .

SOURCL: Office of Technology Assessment

Due to a number of institutional and economic constraints, research that would be considered advanced in industries such as chemicals and electronics generally is not undertaken by the infrastructure-related industries in the United States. Therefore, the low levels of private R&D funding contrast markedly with industries that sell defined products in commercial markets. For example, the chemical and electrical industries each spend about 4.3 percent of revenues for R&D, while the motor vehicle industry spends about 3.2 percent. However, R&D is proportionately lower for the electric utilities industry (0.4 percent of sales), which is a regulated monopoly but does cooperative integrated research, and for the mining and minerals industry (1.5 percent), which currently is depressed. Table 1-4 shows other comparisons.

CONSTRUCTION R&D PROGRAMS

For this analysis, OTA divided R&D on construction technologies into five categories: Advanced R&D; basic research; incremental R&D; research to improve design, evaluations, and needs (i.e., system capacity) analyses; and other research.[15] These are defined as follows:

Advanced R&D leads to a major realignment of how things are done or what product results, and brings substantial benefits in cost and quality. Two relevant examples are the introduction of tunnel-boring machines for transit construction and the use of computers in construction. These types of change make possible what would formerly have been unrealistic.[16] Of the agencies using Federal funds, only the National Bureau of Standards and the National Science Foundation (NSF) have spent substantial sums on advanced R&D. Less than 0.2 percent of all Federal infrastructure construction research dollars are spent in this category.

Incremental R&D brings about gradual and continual improvements and innovations for existing materials, processes, or pieces of machinery. The collective impact over time of these

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15 Materials-related R&D was not SO easy to categorize. Frequently one project would include elements of two or more of these categories. Therefore, in tables 1-2 and 1-3, much of infrastructure materials R&D is included in "other research."

16 "Research Needs in Transportation Facilities: Guideway Technology and Materials Research," Transportation Research, vol. 19A, No. 5/6, 1985.

Table l-4.-Private Sector R&D Expenditures Per Gross Sales

Industry	R&D Expenditures (As a Percentage of Gross Revenues)
Aircraft and Missiles	4.2
Electrical Equipment	4.3
Machinery	5.2
Chemicals and Allied Products	4.3
Motor Vehicles	3.2
Metals and Mining	l.s[a]
Electric Utilities (Investor-owned)	0.42[b]
Construction	<0.33[c]

a 1985 estimate from Business Week, "R&D Scoreboard," June 23, 1986, pp. 139-156.

b Sherman Feher, Planning Analyst, Electric Power Research Institute, personal communication, Apr. 28, 1987.

c OTA estimate for construction expenditures in 1985. According to NSF, they receive too few responses to their annual survey from construction firms to provide reliable expenditure figures.

Source: 1984 estimate from National Science Foundation, National Patterns of Science and Technology Resources 1986, NSF 86-309 (Washington, DC: 1986), p. 56, except as noted.

improvements is progress in the quality and service life or costs of the technologies. The Corps of Engineers, Federal Highway Administration, and NSF are the major supporters of this type of research. About 12.4 percent of total Federal infrastructure construction research dollars are spent on this type of research.

Basic research encompasses work aimed at new techniques essential for technology development, and does not address applications. The National Bureau of Standards project on building data protocols is an example. About 1.3 percent of Federal research dollars are spent here.

Research to improve design, evaluations, and needs analyses includes construction-related research that results in choices or applications among known and available technologies. This research does not advance infrastructure construction technologies, but can lead to more efficient and cost-effective results from known construction technologies. All Federally-funded research programs support this kind of research, which accounts for roughly 26 percent of Federal infrastructure research dollars.

Other research includes projects such as management systems and administrative studies, feasibility analyses, demonstrations, and transfer or dissemination efforts. All Federally-funded research programs also support this kind of research, which receives almost 50 percent of Federal infrastructure construction R&D dollars (i.e., excluding the materials research included in this category in tables 1-2 and 1-3).

Although the activities designated “other research” are valuable, the allocation of almost half of the available Federal construction R&D resources to research that does not lead to technological advances is a fact that Congress may wish to examine carefully. They also should consider reexamining the small size of Federal expenditures--14 percent--for advanced, incremental, and basic R&D, which has the greatest potential for advances in infrastructure technologies, and therefore the largest benefits.

MATERIALS R&D PROGRAMS

Based on our brief survey, OTA estimates total materials-related R&D to be $53 million to $62 million in FY86, with around $35-$37 million coming from Federal agencies and programs and the remainder from nonfederal sources. Nearly half of the Federal materials R&D (around $17 million in FY86) is sponsored by the Department of Transportation (DOT). Within DOT, the Federal Highway Administration (FHWA) conducts research on pavement performance, and evaluates new or improved materials for highway and bridge construction, repair, and corrosion protection. FHWA also participates in two Federal-State cooperative R&D programs--the Highway Planning and Research Program and the National Cooperative Highway Research Program.

The second largest chunk of Federal materials R&D for public works comes from the Department of Defense, Army Corps of Engineers ($12 -!$13 million). The Corps' research program supports their responsibilities for construction and maintenance of water resource projects, dams, locks, waterways, ports, flood control projects, and military support facilities. The latter includes demonstration projects on energy conservation, building maintenance and repair, pavements, railroad maintenance, wastewater treatment, etc. The Corps' research is carried out at dedicated laboratories.

Other Federal research efforts include:

-- The Environmental Protection Agency funds R&D on drinking water quality and waste water treatment to support its program and regulatory responsibilities under the Safe Drinking Water Act and the Clean Water Act (less than $3 million in FY86);

-- The National Bureau of Standards conducts basic research intended to advance the fundamental understanding of materials characteristics, composition, and performance, as well as projects designed to develop standardized testing methods and equipment (around $2.4 million in FY86);

-- The National Science Foundation is a major source of funding for university and other private sector research in civil and chemical engineering, primarily under their programs related to structures and materials engineering (around $1 million);

-- The Bureau of Reclamation within the Department of the Interior researches the performance of cement and concrete in dams, canals, and line pipe; corrosion prevention for metals and concrete; and materials evaluation methods (around $1 million); and

-- The U.S. Forest Service is the central source of R&D in the US. for low-volume roads, which are a major part of the public roads system in rural areas (around **$200,000).**

Of the $18 million to $25 million spent annually on nonfederal materials R&D for public works, around 60 to 65 percent is related to highways, roads, and bridges. This is funded by State and local governments and regional transit agencies, as well as professional organizations and trade associations and their affiliated research foundations (e.g., the American Public Works Association or the Asphalt Institute). The major materials of interest in this research are cement and concrete, asphalt, steel and other structural and reinforcing materials, protective coatings, sand and gravel, surface treatments, de-icing substances, and geotextiles.[17]

Materials are an important cost component in sewer construction and maintenance, and the larger municipal sanitary districts are a significant source of funding for materials-related research for sewers and wastewater treatment systems. Other sponsors include professional and trade associations; engineering, consulting, and construction firms; and equipment and materials suppliers. Together, these groups spend approximately $3 to $5 million annually on wastewater R&D.

Another $1 million in nonfederal funds for materials R&D is devoted to water supply and treatment, primarily by local governments. The major concerns are: the mechanics of internal and external corrosion; the long-term performance of system materials for pipes (concrete, plastic, ceramics, masonry, iron, lead, steel, copper, etc.), pipe foundations and liners, and seals; maintenance requirements and technologies; methods of failure prediction; nondestructive evaluation techniques; and the effects of materials and water additives on water quality and SyS - tem durability.

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17 Geotextiles are woven and nonwover synthetic fabrics used in geotechnical applications (see chapter seven).

Finally, around $100,000 to $500,000 is spent annually on materials for water resource projects, waterways, and ports. The primary materials of interest here--concrete, stone, aggregate, pipes, coatings, geotextiles, membranes, liners, filters, and structural and reinforcing metals--are shared with other infrastructure types. Moreover, the primary responsibility for these large and costly projects rests with the Federal government.

HOW DOES DOMESTIC PUBLIC WORKS R&D COMPARE TO RESEARCH EFFORTS ABROAD?

Comparing infrastructure R&D expenditures in the United States to those abroad is difficult because the funding processes and programs are so different. Government research support in dollars is not markedly lower in the U.S. than abroad, but foreign governments play a much more active role in facilitating R&D and in bringing technical innovations into common practice.

Successful development of construction materials and technologies, and their incorporation in public works projects, require a favorable climate and appropriate incentives--both of which are lacking in the United States. Strong incentives are available in other countries to work the "bugs" out of theory and move new ideas to the marketplace. In both Japan and Europe, for example, the governments encourage innovation and development through tax incentives or matching funds, and through flexible bidding concepts. Government- industry co-funding assures a company's willingness to commercialize results after research is completed. West Germany, for example, makes public grants available for the introduction of promising innovations into commercial markets. Also in Germany, special "linker" organizations facilitate innovation by expediting the flow of technical information and contributing to the stimulation of new ideas. The Japanese government also has agencies that coordinate research and disseminate information.

Also, relative to materials R&D, few U.S. universities have construction-related materials programs, and many civil engineers have little or no training in materials science. The opposite is true in Europe and Japan where specialty engineers receive cross-disciplinary training.[19]

An integrated approach to design, engineering, and construction would benefit infrastructure projects by identifying optimal technologies and materials for specific projects. An integrated approach also would help facilitate the transfer of information more readily. Although the U.S. is not presently pursuing this approach in any organized manner, other developed nations have established integrated research programs, such as Switzerland's efforts in concrete technology.[20]

WHAT ARE THE CONSTRAINTS ON EFFECTIVE R&D FOR PUBLIC WORKS IN THE U. S.?

The nature and effectiveness of R&D depend heavily on the environment within which new technologies and materials will be implemented. America's continuing inventive abilities are unquestionable, yet OTA found numerous institutional and economic factors that mitigate against increased R&D spending, make the available research dollars less cost-effective, and inhibit the adoption of advanced construction technologies and materials in public works projects. Over the long-term, this will mean increased construction, repair, and maintenance costs for public works agencies.

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18 Sherman Gee, Technology Transfer. Innovation and International Competitiveness, New York: J. Wiley & Sons, 1981.

19 Daniel W. Halpin, Technology in Architecture. Engineering. and Construction (Contractor Report to OTA, Tasks 1 and 2, Chapters 8 and 13, March 17, 1986.

20 Ibid., Chapter 8.

First, no national goals for public works infrastructure have been set, making it difficult to determine an optimum amount for Federal R& D expenditures. R&D has increased productivity in the past, and it is conventional wisdom that more R&D would improve productivity in the future. Within the public works context, however, productivity does not necessarily mean preparing materials or building structures more cheaply or with fewer workers, but may refer to the capacity or reliability of the system. Therefore, a redefinition of productivity goals for public works may help set public spending priorities. For example, some advances in materials and construction technologies, such as off-site road or bridge construction, simply move the time spent in materials preparation and handling to another location. However, off-site construction does shorten the time a road or bridge must be taken out of service for repairs, and thus increases the productivity of the transportation system markedly. This increase in productivity does not accrue large benefits to the industry, but it benefits the public tremendously. Thus it is probably appropriate that the public, through government expenditures, support R&D to increase the productivity of its vital systems.

Second, in order to make the limited R&D funding that is available more cost-effective, the research agenda needs to be targeted more directly to national needs. The initial step is determining what the most critical needs are. This is especially important for water supply and sewage and wastewater treatment systems, which traditionally have been local government responsibilities, and in which the R&D is more fragmented than other infrastructure types where the Federal role is larger. This would not require an exhaustive inventory of the condition of public works, but could be based on a survey of Federal, State and local agencies responsible for various types of public works about their most pressing problems. For example, the Strategic Highway Research Program (SHRP) began with a two-year planning and assessment process to further define gaps in current knowledge. A similar assessment for other infrastructure types (e.g., water supply, wastewater systems) could eliminate duplication in research efforts and facilitate coordination of projects, and thus get more “bang” out of the limited bucks available.

Innovation centers also can bean excellent means of targeting research. Examples highlighted in this survey include the NSF-funded Engineering Research Centers at Lehigh University, Carnegie-Mellon University, and the University of California at Santa Barbara; the Army Corps of Engineers' Construction Engineering Research Laboratory at the University of Illinois; the two newly-established, Army-funded Centers of Excellence in Building Construction Technology at the Massachusetts Institute of Technology and the University of Illinois; and the Air Force's Center for Cement Composite Materials, also at the University of Illinois. The SHRP also is an exemplary Federally-funded program in that it included transportation officials--the users--in the process of setting its goals and priorities. Moreover, it is the only program to focus specifically on one aspect of public works.

Although most of these programs are too new to have research results for evaluation, they share three important features:

-- they represent a specific allocation of resources over a period of time for research on construction technology and materials,

-- they require the research group to focus on advances in particular kinds of technologies and materials, and

-- they target areas of infrastructure R&D that have been identified as being likely to produce particular cost benefits and advanced or incremental technology improvements.

Third, a variety of factors combine to reduce private sector R&D. The industries that vie for public works contracts are sharply competitive and highly fragmented. Numerous small, local firms compete for every public works job. Moreover, foreign firms have begun to show an interest in the U.S. market, making the fight for market share increasingly ferocious. In this environment, and with the threat of merger or takeover hanging over even large companies, firms are forced to cut costs wherever possible to tide them over the irregular nature of public infrastructure spending. This economic climate does not support the large front end costs of developing innovations in construction technology and materials. Also important is the fact that public works construction materials generate a low rate of return and have a long payback period compared to other investments and, consequently, do not contribute much profit that can be allocated to R&D. Finally, there is a general belief in many industries that public works R&D is a governmental responsibility.

Fourth, government contracting and procurement policies place significant constraints on the amount of infrastructure R&D and the implementation of research results. The regulatory systems and procurement processes vary for different types of infrastructure. For example, highway construction standards vary according to the sponsoring government and anticipated traffic load. There is no guarantee that a generic innovation a company develops will be acceptable for all types of public works, or even all types of roads.

For materials, government agencies typically prescribe key project specifications (e.g., so many inches of a particular form of asphalt). Approval of new specifications or standards is a difficult process because it can be costly for public works suppliers and contractors to change their current materials and practices, and because testing, evaluation, and certification of new construction materials takes a long time. Standard test methods and specifications are vital for ensuring the quality of infrastructure materials and for facilitating the acceptance of new materials, but the development of good standards requires a lot of research. Federally-supported and other research to provide the basis for materials standards has been decreasing, which is a serious concern for materials innovation.[21]

Further, the contracting process itself is keyed to low bids. However, that process typically does not consider any potential long-term savings from reduced maintenance and repair costs. Because new materiaIs and construction methods often hav-e a higher capital cost than conventional ones, contractors are unlikely to propose their use for fear of losing the job. Also,

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21 Personal communication t. OTA by Geoffrey Frohnsdorff, Chief, Building Materials Division, National Bureau of Standards Center for Building Technology, June 1987.

existing life-cycle costing methods are not perceived to be sufficiently accurate to support procurement based on long-term performance.

Fifth, governments and corporations also perceive a high level of risk in using new infrastructure materials and construction methods. People place a high premium on the reliability of public works. If advanced technologies or materials turn out to be less effective than anticipated, the political and economic costs of repair or replacement can be high. At the extreme, there is a risk of personal injury or property damage liability in the event of system failure.

Sixth, because of the number of agencies and organizations that conduct R&D, and the problem-oriented nature of much of the research, information flow among the researchers is limited. Trade and professional associations, journals, and conferences provide forums for the identification of research needs and priorities and the dissemination of research results. However, the processes for information exchange among and between these groups are haphazard. OTA found that, despite sporadic efforts at coordination, even Federal agencies do not share research results with each other on a systematic basis. Professional societies provide for interaction to the extent that individuals may be members of more than one group. Trade associations often do not have even that small link. Corporations often treat information on their research as proprietary and do not release it.

A related problem is the slow rate at which new or advanced materials and technology are accepted by government agencies, architects/engineers, and contractors for incorporation into public works projects. The lack of information exchange probably accounts for at least some of the snail's pace at which innovations are adopted in the United States. However, (3TA concludes that a significant increase in information dissemination would not necessarily speed the diffusion of R&D results without programs to address the economic and institutional barriers discussed previously.

AS a result of the limited funding of infrastructure materials R&D, inadequate information and technology transfer, and procurement practices and perceptions of risk, there are gaps in the R&D agenda. These take the form of mismatches between R&D projects and public works needs, and of inadequate research on particular materials and technologies and their value in individual projects, and on evaluating tradeoffs between construction, maintenance, repair, and replacement. These are all difficult and complex problems, and are not likely to be tackled by the private sector alone.

In terms of basic research, the gaps in infrastructure R&D are substantial. There is almost no research on, or expectation of profit from, research toward developing totally new methods of delivering transportation, water supply, and wastewater disposal services. There even is little basic research on new materials, such as a totally new material for building roads. Moreover, few agencies or organizations are researching the public works applications of advanced technologies and materials (e. g., ceramics and composites) that were not developed specifically for infrastructure.

OTA also identified numerous issues related to public works that need further exploration.[22] Among them are:

-- Analysis of the interrelationships among design and construction and materials,

-- Further study of the government procurement and contracting processes to determine the extent to which they pose barriers to technology diffusion,

-- An in-depth look at the relative costs and benefits of design versus performance standards in public works procurement,

-- Development of certification standards for acceptance of new construction materials and technologies to facilitate their use in public works,

-- Identification of legal issues related to liability and shared risk,

-- Development of improved life-cycle costing methods for use in public works procurement,

-- Analysis of the tradeoffs among expenditures for maintenance versus repair versus new construction or replacement and how those trade-offs might be affected by the capital and maintenance costs of new technologies and materials,

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22 Specific research needs for construction technologies and for materials may be found in chapters five and eleven, respectively.

-- Analysis of means for facilitating the international exchange of information about construction technologies and materials R&D for all types of public works projects, and

-- Analysis of the return on investment for private sector R&D on infrastructure construction technologies and materials.