CHAPTER ELEVEN

INSTITUTIONAL ISSUES, RESEARCH NEEDS, AND POLICY OPTIONS

In conducting this brief survey of infrastructure materials R&D, OTA identified two sets of issues: those related to the quantity and quality of data about the Federal and nonfederal R&D budgets, and those related to the amount and scope of the R&D itself. The latter include reduced funding for R&D at all levels, insufficient information exchange about R&D projects and programs, mismatches between R&D projects and needs, and government policies and perceptions of risk that inhibit the application of materials research results in public works projects. Together, these limit the amount of research conducted, make the research less comprehensive in scope than it might be, and impair the cost-effectiveness of public works improvements.

This chapter discusses these issues and the constraints they place on materials R&D, and identifies options for addressing them. This should not be considered a complete list of policy options, but a brief discussion of those that are most apparent given the limited scope of this survey. Because calling for additional R&D funding is a relatively simplistic solution in the face of massive budget deficits, and because OTA was unable to quantify the R&D funding needs, the options discussed below focus primarily on means of making the limited funding that is available more effective. Specific materials areas that could benefit from increased research funding are discussed at the end of this chapter.

BUTDGET' DATA~ PROBLEMS

While Federal agencies were extremely cooperative (sometimes eager) in providing us with their budget figures for R&D, we are unsure about the accuracy and comprehensiveness of some of those figures for the purposes of this survey. Agencies whose primary mission is not infrastructure-related typically do not segregate their programs or expenditures in such a way that research relevant to public works can be identified easily. For example, the Department of Energy's Basic Energy Sciences Program is a major sponsor of advanced materials research in the U.S. Some DOE-funded research on advanced ceramics (including cements and concretes) and on composites clearly has potential applications in public works construction. However, that is not the defined goal of the research, and the precise amount that is relevant cannot be identified easily. Other organizations categorize their research by type of infrastructure (e.g., wastewater treatment). When materials R&D is a component of a general infrastructure research effort, its level of funding is not easily separated from a total project budget. In addition, some agencies include administrative expenses (salaries and overhead) in their R&D budgets; others do not. We have identified these reporting differences in the text to the extent possible.

Accurate and comprehensive budget data are hard to find for nonfederal infrastructure R&D. No single institution collects data on all nonfederal infrastructure research. Even within relevant industries or infrastructure categories, there is little independent data collection on R&D. Furthermore, companies often treat information on research efforts and funding as proprietary and do not release it. Options for addressing this problem are discussed further in the section on "Information Exchange," below.

GOVERNMENT POLICIES AND RISKS

Government contracting and procurement policies, and public and private sector perceptions of risk may place significant constraints on the amount of infrastructure materials R&D and the implementation of research results. As a result of these practices that impede innovation, and of the extremely high premium placed on the reliability of infrastructure systems, the gap between materials research and practice is more likely to be bridged through gradual adaptation of new methods and improvements, with elaborate testing and hesitant modification of existing specifications and acceptance criteria.[74]

Government construction standards, procurement specifications, and regulatory requirements shape the environment for research and innovation in public works. The U.S. contracting process divides public works projects into design and construction phases. Construction firms often must bid on projects for which the specifications and materials have been prescribed in regulations and/or selected in advance by design-engineering firms. Design-engineering firms may be unwilling to experiment with new materials because of high liability risks if the material does not perform as expected, or because government agencies may have already established key project specifications by prescription (e.g. so many inches of asphalt) instead of as performance specifications.

This division between designer and builder has, in some instances, led to an adversary relationship. Drawing upon a musical analogy, one specialist in engineering and construction technology compared the designer to the musical composer who said, "I only compose; it's not my fault if the note cannot be played on the tuba. You as a player must solve the problem." In some cases, the architect/engineer has taken a similar position by designing something that is either "unplayable" or inefficient from a construction and materials point of view.[75]

There is a general bureaucratic inertia in continuing to use established procurement specifications and materials testing and construction standards. Development and approval of new specifications or standards can be a lengthy and difficult process that requires substantial research. However, government and private research that might provide the basis for new standards has been declining. Furthermore, it can be costly for established public works personnel,

74 Committee on National Urban Policy, Commission on Behavioral and Social Sciences and Education, National Research Counc ii, (Royce Hanson, cd.) Perspectives on Urban Infrastructure, National Academy Press, 1984, at 206-207.

75 Halpin, supra note j, Tasks 1 and 2, Chapter 4.

suppliers, and contractors to alter current materials and practices, and any proposed change in procurement specifications and construction standards may become politically charged depending on whose ox will be gored by the change. For example, although granitic or basaltic aggregate may perform better and last longer in road construction than limestone aggregate, a State with a large limestone industry is unlikely to include out-of-state materials in their specifications.

The extent to which government contracting and procurement processes actually deter the use of new or improved materials needs to be determined. If significant disincentives are found, means for removing or mitigating them should be developed. The relative costs and benefits of design versus performance standards in public works procurement also merits further analysis. The lack of good performance standards hinders development of new materials because there is no reliable way of evaluating the materials' long-term service life and reliability. Because of the complexity of the problem, development of the needed standards requires a large investment in research.[76]

In addition, contracts usually are awarded to the lowest bidder, and new materials often have a higher capital cost than conventional ones. While over the long-term these materials might reduce repair and maintenance costs, few analyses of the trade-offs between front-end and life-cycle costs are available. Without some mechanism for considering potentially lower life-cycle costs in the procurement process, bidders proposing the use of improved, but potentially more expensive materials would place themselves at a competitive disadvantage. However, the accuracy of life-cycle costing systems is suspect, and needs additional research.

Governments and corporations also perceive a high level of risk in using new materials in public works. First, people place a high premium on the reliability of public works. When you turn on your water faucet you expect water to come out at a reliable pressure, you expect it to be of a consistently potable and healthful quality, and you expect to receive it at a reasonable

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76 National Materials Advisory Board, supra note 41.

cost. Local governments and their public works contractors are reluctant to use new materials in case the reliability of the system is in some way impaired, and either the quality or the cost of the service is adversely affected.

Any openness to innovative technologies that might be fostered by local financial responsibility for water or wastewater systems is countered by the strong emphasis placed on the reliability of those systems. It is easier for public works utilities to justify rate increases for repair and maintenance to preserve the immediate reliability of a system than for the use of innovative materials in construction that might prolong reliability at some time in the future. Moreover, if advanced materials turned out to be less effective than anticipated, the political and economic costs of repair or replacement can be high.

Public works agencies and their contractors also are very sensitive to liability risks. If people are injured or property is damaged as a result of materials failure in a public works project (at the extreme, the collapse of a bridge or dam), the liability costs for the materials producer and tester, the construction firm, and the public agency can be financially crippling. Although this risk is probably not so great a deterrent in the use of advanced materials as the possibility of having to bear greater repair costs, it is still a consideration.

Some form of incentive is needed to overcome the perceived risks of using new or improved materials in public works. These could take the form of the tax incentives and government co-funding used in Japan, or the grants used in West Germany, or simply some form of guaranteed "repair insurance" in the event the materials did not perform as well as expected. For example, the Environmental Protection Agency's Innovative/Alternative Technology Program has a 100 percent modification or replacement provision to prevent communities from having to bear the costs of failure of new waste treatment technologies.

Better quality control in project design and maintenance and better education for project architects and engineers also are necessary to address conflicts between materials designers and construction contractors, and to alleviate the perceived risks in using new materials. While these are difficult to legislate, relatively simple options such as requiring materials science for civil engineer certification and continuing engineering education would help. The German "Getachten" (expertise) system described in chapter ten also provides a model for improving quality control.

FUNDING FOR INFRASTRUCTURE MATERIALS R&D

Infrastructure materials R&D--whether Federal or nonfederal--generally is underfunded compared to the research priorities (based on perceived needs for better materials performance) and to the probable level of investment needed to meet current and anticipated future infrastructure maintenance, repair, and construction needs. There has been a general decline in all Federal civilian R&D during the 1980s due to the budget deficit and the administration's philosophy that civilian R&D is a private sector or State government responsibility. For example, internal FHWA funding for research on paving materials, including asphalt and concrete, has been cut considerably in the past eight years because FHWA believes that State work under the Highway Planning and Research Program (HP&R; see below) is sufficient, and in anticipation of the Strategic Highway Research Program's (SHRP) intensive efforts on pavement performance. Based on project summaries provided by FHWA, OTA estimates that FHWA materials-related research declined from $2.6 million in FY85 to about $0.9 million in FY87. In contrast, in the 1970s, FHWA direct contract research on asphalt alone was several million dollars per year.

Also, the Administration has repeatedly proposed the elimination of the National Bureau of Standards' Center for Building Technology (CBT). For FY88, the Administration proposes that CBT be combined with the NBS Center for Fire Research, and that the combined budgets be reduced by 40 percent. Congress has previously rejected efforts to cut or eliminate the CBT.

Moreover, Federal R&D funding often is tied to the need to evaluate available products for use in Federal projects or to solve particular problems. The Army Corps of Engineers and the Bureau of Reclamation have been somewhat insulated from this trend because of their continuing mission-related R&D responsibilities. In other Federal agencies, however, once a project has been completed or a solution for a problem has been found, continuing R&D in that area is more difficult to justify.

Nonfederal support for public works R&D by State and local governments and the private sector, also has been declining steadily. Beyond the general economic conditions in many industries today, the low level of nonfederal R&D funding can be attributed either to the lack of Federal support, or to the procurement and liability issues discussed previously, or to corporate perceptions about the low level of return from materials R&D for public works.

Although the relatively new trade association and university sponsored research institutes described in chapters eight and nine mark a small reversal in the overall trend, the level of nonfederal infrastructure R&D funding is still very low compared with identified research needs. Also, continuity of funding remains a problem for some private research institutes, which are increasingly dependent on declining Federal grants and contracts as their primary means of support. For example, the primary focus of trade associations historically has been on member services, publications, standards development, and, in a few cases, technology diffusion. Now that declining profit margins have led many companies to cut their contributions to trade associations, research efforts have been cut back.

Lack of Federal support is especially a problem for State and local governments. While Federal, State and local government research priorities and policies largely determine the materials and infrastructure needs to be examined, Federal priorities often differ markedly from those of the State and local governments who have to implement the Federal programs. There is little Federal R&D to support State and local programs in the areas of water supply and wastewater treatment, for example. Local governments bear the primary responsibility for drinking water supply, and contribute the bulk of the $6 billion spent annually on the construction, maintenance, repair, and rehabilitation of drinking water systems. Although the Federal Government (primarily the Bureau of Reclamation, Corps of Engineers, and Environmental Protec -

tion Agency) historically has conducted R&D on water supply systems and treatment processes and equipment, little Federal money flows to State or local research efforts. Local government officials have stated that they have refocused their waste water efforts from R&D to construction in order to capture Federal funding under the Clean Water Act's Construction Grants Program.[77] This lack of support for local R&D is compounded by the information exchange and technology transfer constraints discussed below.

In addition, as noted previously, internal FHWA funding for research on paving materials, including asphalt and concrete, has been cut considerably in the past eight years in anticipation of the SHRP research on pavement performance, and because FHWA believes that State work under the Highway Planning and Research Program (HP&R) is sufficient. Yet the States' commitments to research under HP&R varies widely, with individual State research allocations ranging between 5 and 55 percent of State HP&R funds (the remainder goes to planning). Moreover, States' definitions of "research" are very broad and often center on evaluative studies, such as the suitability of available materials and processes for road construction specifications.

The low level of private sector R&D on infrastructure materials is due more to corporate perceptions of the costs and benefits of R&D than the lack of government support. Infrastructure materials R&D, even more than most other materials R&D, does not fit the classic industrial or engineering pattern of integrated R&D management, in which process and product development precede a total technological and marketing effort. In the classical, idealized pattern, universities and government research laboratories perform basic research that serves as the foundation for goal-oriented R&D in industrial laboratories. In contrast, materials R&D efforts

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77 See, for example, remarks of Robert P. Miele, Los Angeles County Sanitation District, in American Public Works Association Research Foundation, Proceeding of Workshop: Defining the Role of Federal and Private Sector Activities in Solving Municipal Environmental Problems, Airlie House, Va., Aug. 11-13, 1983, at pp 50-52.

are highly fragmented and tend to be heavily problem-oriented, especially for infrastructure materials. Much of the necessary basic and systematic research that could lead to advances in materials properties and behavior has been neglected and underfunded. There are many small firms involved which do not have adequate resources to support extensive R&D, and the bulk of the effort is devoted to the evaluation of available products.

Further, the public works construction industry traditionally has had a low level of R&D because construction companies typically view themselves as brokers of services; they tend to believe that R&D investments will not confer any significant competitive advantage. They also tend to view these materials as commodities, which implies that any proprietary products resulting from R&D efforts will not have much market penetration (even if they are patented). This is compounded by the fact that public works construction materials, such as cement and concrete, generate a low return and have a long payback period compared to other investments and, consequently, not much profit to allocate to R&D. These are high-volume, low-value products, so that even low-cost materials substitutes or additives can add enough to costs to make them uncompetitive. In addition, as discussed previously, the slow certification process and potential liability risks for new materials are significant constraints on private sector R&D.

Finally, the construction materials industry does not sponsor much R&D because of local variations in the materials. Because constituent materials (sand, gravel, lime, asphalt, aggregate, etc.) are obtained from local sources and are highly variable in composition and quality, research often will have only limited geographic applicability, further limiting potential gain from R&D,

There is slightly more investment in R&D among equipment companies and materials suppliers associated with chemical companies, which traditionally have been more supportive of research. However, even these companies are deterred by the potential for a low return on investment. For example, as noted in chapter seven, du Pent has deferred further development of polymer concretes until a sufficient market develops.

A good start on making the limited R&D funding that is available more effective is to target the research agenda 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 waste water treatment systems, which traditionally have been local government responsibilities, and in which the R&D is more fragmented than other infrastructure types with a major Federal role. 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, SHRP is a targeted program that began with a two-year planning and assessment process to further define gaps in current knowledge (see chapter eight). A similar assessment for other infrastructure types (e.g., wastewater facilities, water supply 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 be an excellent means of targeting research. Examples highlighted in this survey include 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 funding for such centers requires that they focus on particular kinds of research, and thus helps to ensure that the research meets national needs.

Incentives also are needed to address the corporate perception that they will receive a low return on investment from infrastructure materials R&D. These could be introduced through tax incentives or the contracting process (e. g., waive the low bidder requirement for companies willing to demonstrate improved materials). Also, governments could co-fund the R&D with some form of guarantee that it would actually be used in projects and/or approved for procurement specifications.

INFORMATION EXCHANGE AND TECHNOLOGY TRANSFER

One consequence of the highly fragmented nature of the infrastructure materials R&D industries, and of their limited R&D funding, is that the exchange of information about ongoing and completed R&D efforts is inadequate. Trade and professional associations, journals, and conferences provide forums for the identification of research needs and priorities and the publication of research results. However, these forums usually are organized by type of infrastructure or material. Because the research itself tends to be problem-oriented, there may be little cross-over of information between research groups about new developments in particular types of materials.

Information exchange is even more difficult from non-infrastructure research. Thus, an improved form of concrete developed for a purpose not related to public works may be equally useful in dams, or pipes, or other infrastructure applications, yet the infrastructure materials researchers may be unaware of it. Further, corporations often treat information on research efforts and funding as proprietary and do not release it. Finally, local governments--the primary purchasers of infrastructure materials--often lack the resources to participate in trade associations and conferences, or subscribe to journals.

As with other issues discussed in this chapter, the lack of information exchange and research coordination is most pressing for water supply, and sewage and waste water systems. At present, highway materials R&D is the most coordinated area of research in the U. S., because of the cooperative nature of Federal and State programs. However, even this coordination is limited to highways, roads, and bridges; communication of the results of materials research for another infrastructure type that may be relevant to highways (e. g., concrete for dams, airport runway pavements) is haphazard.

A second problem is the slow rate at which new or advanced materials are accepted by government agencies, architects/engineers, and contractors for incorporation into public works projects. This slow rate of commercialization (or “technology transfer” from R&D program to public works project) is primarily attributable to the procurement and liability issues discussed previously. It also derives, however, from a lack of knowledge about the materials and how to design for and use them. The annual costs of not using the very best available materials could not be quantified, but must be very large (i.e., billions of dollars) for increased future repair and maintenance.

These problems with information and technology transfer result in an inefficient use of what R&D resources are available. Some materials research efforts may be unnecessarily repetitive. In other cases, research funds could be used more effectively in cooperative efforts.

At the extreme, a national clearinghouse on R&D for public works, would be most useful.[78] This should include information on planned, ongoing, and completed R&D projects, as well as on the results of using advanced materials and construction technologies in public works systems, both in the U.S. and abroad. Advances in computer technology and software, such as integrated knowledge systems consisting of networked expert systems, simulation models, and databases, could be invaluable in overcoming the inadequate information exchange, and thus in promoting the use of the best available materials. However, development and adaptation of these systems for public works R&D applications, and their acquisition by users, will be expensive.

At least, individual agencies or trade associations could provide information exchange and research coordination. Organizations such as the International Union of Research and Testing Laboratories for Materials and Structures (RILEM) and the International Council for Building Research and Documentation (CIB) are becoming increasingly important in facilitating the international exchange of information. including research *plans*. In the U. S., the National Bureau of Standards and the Army Corps of Engineers Construction Engineering Research Laboratory are particularly active in RILEM and CIB.

78 Compare the Japanese and German governments, which have agencies that coordinate research and disseminate information.

Domestic programs that provide information exchange include the Federally Coordinated Program of Highway Research & Development (FCP), which was set up in 1971 to coordinate State-Federal activities (see chapter eight), and the American Concrete Institute Committee 123. However, as noted previously, programs oriented toward either a specific infrastructure or material type cannot always capture advances in another area.

GAPS IN INFRASTRUCTURE MATERIALS R&D

As a result of the limited funding of infrastructure materials R&D, inadequate information exchange and materials commercialization, 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 materials needs, for particular materials and their value in individual projects, and for making decisions about maintenance versus repair versus replacement.

As the primary purchasers of infrastructure materials, Federal, State and local governments' research priorities and policies largely determine the materials and infrastructure R&D agenda. Their priorities typically are set by the need to solve specific local infrastructure problems. Yet, the fragmentation of the R&D efforts means that research aimed at special local problems is not coordinated, and limits application of the research results in public works projects.

Private sector R&D is stimulated by the existence or perception of a market for new infrastructure materials due to government investment in public works and the availability of funds. But, as discussed previously, infrastructure materials typically generate a low return on investment. Therefore, private infrastructure research has focused on new construction methods and technologies, and largely ignored research on maintenance and repair methods and materials that could prolong the useful life of materials and public works.[79] Although the long-term

[79] This is, in part, because public spending programs favored new construction. For example, road and bridge repairs did not qualify for much Federal or State assistance until recently.

market for these methods and materials could eventually be more profitable, new construction carries a higher short-term profit for suppliers and contractors. Moreover, deferring R&D until a sufficient market develops is a vicious circle, because the State and local governments, who are the primary purchasers of infrastructure materials, have a high sensitivity to risk and will not consider using a material until it is fully developed.

The differences in cost effectiveness between repair and maintenance versus new construction or replacement (e.g., filling potholes or resurfacing) also is a critical consideration in infrastructure investment. In assessing such tradeoffs, public works utilities need to be aware of the full range of materials and technologies and their costs. For example, new materials applied to road surfaces or used in sewer pipes could substantially prolong their lives and reduce maintenance and repair costs. This might make it much easier to amortize high-cost projects over considerably longer periods. Yet, few studies have analyzed the tradeoffs among expenditures for maintenance versus repair versus new construction or replacement, even for well-established materials. Information on how these trade-offs might be affected by the capital and maintenance costs of new materials-related technologies is not available. As noted previously, improved life-cycle costing methods would help to bridge this gap.

In terms of more basic research, the gaps in materials-related 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.[80] There even is little basic research on new materials, such as a totally new material for building roads. Many of the most important research areas are closely related and apply to all materials for public works--concrete, cement, steel, paints and coatings, asphalt, plastics, and organic matrix composites. These research gaps can be narrowed through a better understanding

80 A possible exception here might be the application Of superconductivity to mag-lev transportation.

of mechanisms of degradation and corrosion of materials in service, and development of methods for predicting material service life and the performance of materials under use. These are all difficult and complex problems, and are not likely to be tackled by the private sector alone.

For both asphalts and cements, there is now a renewed effort aimed at understanding what these materials are; how they derive their properties; and how variations in composition, additives, applications, or environmental conditions can influence their performance in use. However, a critical need continues to be funding of cooperative research efforts on developing international conventions for better standards and measurement for testing and describing asphalt and concrete. This would allow differing properties and compositions to be noted, research results communicated, and materials recreated.

Moreover, few agencies or organizations are researching the public works applications of advanced materials (e. g., ceramics and composites) that were not developed specifically for infrastructure. In part, this is because advanced structural materials typically are too costly to be considered for use in most public works applications.[81] Yet, as noted previously, virtually ‘0 analytical studies have quantified the tradeoff between the front-end costs of these materials and their potential long-term savings in maintenance and repair costs, and service life.

Other public works materials R&D needs include:

-- basic research on the mechanisms of corrosion in underground pipes to reduce repair requirements and the potential for water contamination;

-- basic research on correcting inflow and infiltration of water and sewer systems;

-- improved de- icing and anti-corrosion methods for highways and bridges;

-- the development of certification standards for acceptance of new construction materials and technologies to facilitate their use in public works;

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[81] See U.S. Congress, Office of Technology Assessment, New Structural Materials Technologies: Opportunities for the Use of Advanced Ceramics and Composites, Technical Memorandum, Sept. 1986.

- further analysis of the fieasibility of incorporating performance standards in public works contracting and procurement specifications;

- development of reliable methods, including nondestructive testing of materials, for assessing the quality or condition of materials in both new and old construction;

- testing methods to monitor the properties and quality of materials during construction and repair (e.g., asphalt or concrete as they set);

- cooperative research efforts on developing international conventions for better standards and measurement for testing and describing asphalt and concrete.

- research on the effects of materials on water quality (for example, the problems associated with solvent migration through certain types of plastic pipes and gaskets, toxicological problems from the interaction of direct and indirect additives to drinking water with materials in the water distribution system); and

- development of integrated computer systems (networked expert systems, simulation models, and databases) for improving the usefulness of materials research and facilitating the selection of materials for public works construction, maintenance, and rehabilitation.