The Partnership for Advancing Technology in Housing: Year 2000 Progress Assessment of the PATH Program

Committee for Oversight and Assessment of the Partnership for Advancing Technology in Housing, Board on Infrastructure and the Constructed Environment, National Research Council

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THE PARTNERSHIP FOR ADVANCING TECHNOLOGY IN HOUSING

Year 2000 Progress Assessment of the PATH Program

Committee for Oversight and Assessment of the Partnership
for Advancing Technology in Housing

Board on Infrastructure and the Constructed Environment

Division on Engineering and Physical Sciences
National Research Council

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Acknowledgments

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

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Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations nor did they see the final draft of the report before its release. The review of this report was overseen by Gary Byrd, appointed by the NRC Report Review Committee, who was responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Contents

Acronyms

BLS	Bureau of Labor Statistics
DOE	Department of Energy
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
FPL	Forest Products Laboratory
FY	fiscal year
HUD	Department of Housing and Urban Development
ICC	International Code Council
IMIS	Integrated Management Information System
NAHBRC	National Association of Home Builders Research Center
NES BIC	National Evaluation Service Building Innovation Center
NIST	National Institute of Standards and Technology
NOFA	Notice of Funding Availability
NRC	National Research Council
OSHA	Occupational Safety and Health Administration
PATH	Partnership for Advancing Technology in Housing
PD&R	Office of Policy Development and Research
R&D	research and development
RWG	Residential Working Group
SIC	Standard Industrial Classification
USDA	United States Department of Agriculture

Executive Summary

The Partnership for Advancing Technology in Housing (PATH) is the first major technology-based initiative in the U.S. housing industry in several decades. PATH is intended to stimulate the development and utilization of new technologies that will make American homes more affordable to own and maintain, more energy efficient, more environmentally sustainable, more durable, more resistant to natural disasters, and safer to build. PATH brings together key agencies in the federal government and leaders of the home building, product manufacturing, architectural, engineering, insurance, financial, and regulatory communities in a unique partnership focused on technological innovations in the American housing industry.

The impact of housing on the lives of Americans is enormous. According to the most recent consumer expenditure surveys, housing is the largest single expense for most Americans, and residential use constitutes a significant portion (11 percent) of national energy consumption. In addition, large numbers of accidents occur in the home. Falls in homes were responsible for almost 12 percent of all accidental deaths in the United States in 1998, and exposures to health risks in the home contribute significantly to health care costs. Cutting costs, reducing adverse environmental impacts and energy consumption, and promoting health and safety in the home could benefit all of society.

PATH has created a cooperative environment for bringing together industry, government, and consumer stakeholders to achieve common goals and to coordinate public and private funding for research and development to leverage limited resources. Publicly funded agencies can facilitate communications among researchers, manufacturers, designers, builders, and consumers, thereby increasing their understanding of housing technology and the potential benefits of new materials and products. Government can also facilitate demonstrations of key innovations by sponsoring field trials and participating in performance assessments, as well as helping manufacturers overcome regulatory barriers.

The PATH Program is administered by the U.S. Department of Housing and Urban Development (HUD) through the Office of the Assistant Secretary for Policy Development and Research (PD&R), which is also responsible for program evaluation and data collection. However, HUD believes that a multiyear oversight and assessment by an independent review body would be more effective. Based on the reputation and the expertise of the National Research Council (NRC) in performing independent program reviews of federal agencies, HUD requested that the NRC review and assess the PATH Program, develop a framework for evaluating program performance, and recommend specific performance measures.

SCOPE OF THE REVIEW

In response to HUD's request, the NRC assembled a panel of experts, the Committee for Oversight and Assessment of the Partnership for Advancing Technology in Housing, under the auspices of the Board on Infrastructure and the Constructed Environment. Over an initial term of three years, the committee was asked to review and

comment on the following aspects of the PATH program: overall goals; proposed approach to meeting the goals and the likelihood of achieving them; and measurements of progress toward achieving the goals. The committee determined that the task of assessing the overall goals of PATH also required that the fundamental need and precedents for such a federal program be assessed.

This report includes the committee's initial findings and recommendations on PATH's goals and proposed approach for achieving those goals. During the review, information was presented to the committee by officials of HUD, staff members of the PATH program office, and representatives of other participating organizations. The committee evaluated the precedents and need for PATH as a federal program, the validity and appropriateness of the program goals, the soundness of the management approach described in strategic and operating plans, and, based on the information provided and personal knowledge and experience, made an initial evaluation of several PATH initiatives. This report is a subjective evaluation of the PATH goals and the overall direction of the program. Future reports will focus on the development and application of criteria for evaluating, in detail, the progress toward achieving individual PATH goals.

PATH PROGRAM AND GOALS

PATH can play a vital role in coordinating ongoing activities and synergizing new ones, as well as providing direction for the future collection of information and its dissemination to researchers, industry, and consumers; providing seed money for the exploration of new technologies and leveraging public and private investments to provide the greatest benefit to society; and assisting in the deployment of new technologies and reducing the time required to bring them to market.

PATH is intended to accelerate the introduction of new technologies that could improve performance and reduce monthly housing costs. From the outset, PATH has embraced very ambitious goals defined in terms of overall performance of the housing sector without specifying technologies or other means of realizing them. An overarching goal, which is implied in all other PATH goals, is to make housing more affordable. *The PATH FY 2000 Strategy and Operating Plan*notes that the president has charged the program with developing technologies, housing components, designs, and production methods that will reduce by 50 percent the time required to move quality technologies to market by 2010. Four housing performance goals are to be achieved by the new technologies, housing components, designs, and production methods by 2010:

1. Reduce the monthly cost of new housing by 20 percent or more.
2. Cut the environmental impact and energy use of new homes by 50 percent or more, and reduce energy use in at least 15 million existing homes by 30 percent or more.
3. Improve durability and reduce maintenance costs by 50 percent.
4. Reduce by at least 10 percent the risk of death, injury, and property destruction from natural hazards, and decrease by at least 20 percent illnesses and injuries to residential construction workers.

The committee believes that the first goal, to reduce the monthly cost of new housing by 20 percent or more (exclusive of financing or land prices), is probably not attainable because the factors controlled by builders and consumers, such as construction, operations, materials, labor, and energy costs, account for less than half of monthly housing costs. Therefore, meeting this goal by using new technology would require that controllable costs be reduced by nearly 50 percent. The committee believes that improving affordability is an appropriate goal for PATH but that a 20-percent reduction in monthly costs solely through technology is not realistic.

The second goal is to reduce the environmental impact and energy use of new homes by 50 percent or more and reduce energy use in at least 15 million existing homes by 30 percent or more. The committee finds this goal difficult to assess because it combines associated but not necessarily congruent issues. For example, although energy use and the environment are obviously related, strategies for reducing energy use will not necessarily lessen environmental impacts. Reduction in the use of fossil fuels would reduce carbon emissions and the production of greenhouse gases (a positive environmental impact), but the technologies employed to reduce energy use in the home (e.g., reduced air infiltration) might unintentionally have adverse environmental impacts, such as diminished indoor air quality. An evaluation of environmental impact must also take into account water use, building materials, and construction waste. Finally, strategies for reducing energy use will differ, and differ significantly, for new homes and existing homes. Therefore, measuring overall progress toward achieving this goal is difficult, and determining environmental performance will require quantifiable measures that have not yet been developed.

The third goal is to improve durability and reduce maintenance costs by 50 percent. Although increased durability is achievable and would reduce maintenance costs, this goal may be at practical odds with the goal of reducing the monthly cost of new housing by 20 percent. Products with increased durability usually decrease maintenance and overall life-cycle costs but increase first cost—amortizing first costs is the major factor in monthly housing costs. PATH will have to resolve this conflict to achieve meaningful progress toward meeting these two desirable goals.

The fourth goal is to reduce by at least 10 percent the risk of death, injury, and property destruction from natural hazards and decrease by at least 20 percent illnesses and injuries to residential construction workers. Although substantial improvements could be made in the health and safety of workers on residential construction sites and in protecting homes from natural disasters, progress toward meeting the goal will be difficult to assess because it encompasses two unrelated aspects of housing technology. The lack of adequate baselines will also make measuring performance for either aspect of this goal difficult; baseline data will have to be compiled before meaningful evaluations can be made.

Overall, the committee believes that the PATH goals are laudable targets for improving the affordability, quality, and livability of American housing. However, as currently stated, they are not realistic, particularly for this relatively small, technology-focused program. They can provide overall policy direction for PATH but are not useful as performance measures for the program itself. The PATH goals are influenced by numerous and complex factors, many of which are beyond the scope of the PATH Program, and achieving the performance levels set for all of the goals may not be

possible. PATH's efforts should be focused and performance measures consistent with its mission and level of funding.

ORGANIZATION AND MANAGEMENT

PATH has established a comprehensive management structure to coordinate program activities at the federal level, between the public and private sectors, and among private sector interests. Based on the committee's initial assessment, this structure appears to provide all stakeholders the opportunity to participate in the program. However, the building codes and standards community seems to be underrepresented, despite the fact that building codes and standards are considered one of the main barriers to the adoption of new technologies. The committee believes that the apparent lack of involvement of state and local building officials could jeopardize the success of the program.

*Partnership for Advancing Technology in Housing (PATH): Strategy and Operating Plan*does not clearly distinguish between PATH initiatives and those of PATH-related programs in HUD and other agencies. The program plan includes 148 separate line items, which seems out of proportion to the size of the program. Programs related to PATH but independently funded and managed are not distinguished from programs directly funded and managed within the PATH program. The plan does not specify the relative level or duration of funding for projects or ongoing programs and provides no procedures for qualitative evaluations of projects and programs. A number of ongoing programs in different agencies are grouped together, but no strong central leadership is provided to coordinate their activities. The committee believes that the large imbalance between PATH funding and the funding for programs run by other agencies could undermine PATH's leadership role. The imbalance is reflected in the PATH strategic plan for the next few years, which emphasizes the role of energy and focuses less on reducing construction costs or improving safety. This appears to be due, in part, to the relatively higher levels of funding enjoyed by the programs of the U.S. Department of Energy.

IMPLEMENTATION OF PATH PROGRAMS

PATH is playing an appropriate role by bringing together the diverse groups involved in the U.S. housing industry and facilitating discussions of PATH-related issues. Despite the dual and difficult requirements of being open to all stakeholders and at the same time narrowly focused on achieving program goals, PATH has accomplished several important interim objectives. Perhaps most important are the communication and collaboration links that have been forged between government and the housing industry, which will be key to the ultimate success of the program. Links among U.S. government agencies have also been developed, and the organizational and management infrastructure to carry out coordinated projects and programs has been put in place. The committee recognizes that the relationships between the federal agency partners and the PATH Program are unresolved but is not yet prepared to recommend a specific structure

for resolving them. As a first step, the committee did resolve that there should be a distinction between PATH-initiated programs and programs controlled by specific agencies. The relationship between PATH and its federal partners will be the focus of future assessments. The committee also believes that the program must have a clearer understanding of its multiple audiences and the market dynamics of each in order to target its existing programs and plan future activities.

PATH has begun working on implementing the strategic initiatives designed to achieve individual goals, but it is too soon to evaluate the effectiveness of these activities. Similarly, some development of baseline data is also under way, but, as previously noted, it will be very difficult to develop meaningful baselines for several of the goals. PATH has made extensive use of field demonstrations, an effective method of showcasing and encouraging the use of new technologies. Although these demonstration projects have shown the economic viability of selected technologies, there is no evidence that they have influenced decisions in other projects or led to any long-term gains toward meeting the PATH goals. The committee believes that technology roadmapping is a good approach to identifying needs and influencing changes in the housing industry, but PATH's roadmapping process will have to be refined and expanded. Expanding the use of current off-the-shelf technologies is an important component of PATH's strategy. However, the committee believes that the technologies included in the current Technology Inventory should be further evaluated and information on their quality and effectiveness added to the database. The current inventory focuses more on individual products than on processes and does not address technologies for improved materials. PATH should evaluate the scope of the Technology Inventory and the effectiveness of the *ToolBase* program, among other strategies for transferring information to home builders and other audiences.

As a final note in this initial review of PATH, the committee finds that although PATH's overall objective is to change the way Americans think about and build housing, most of PATH's efforts are focused on incremental changes and applications of existing solutions by encouraging consumers, builders, and regulators to accept new products and technologies to replace existing products and technologies. The committee does not believe that this approach is commensurate with the grand vision of the program. A portion of the PATH Program could be dedicated to unconventional, high-risk schemes with the potential of revolutionizing at least one critical aspect of the housing industry, such as design, construction, materials handling, training, or methods of product evaluation.

RECOMMENDATIONS

Recommendation 1. The PATH Program should be continued as a partnership among federal agencies and between the federal government and the private sector. The program should be reviewed and updated continuously to ensure that it evolves into an effective, efficient vehicle for the development and deployment of beneficial technologies.

Recommendation 2. PATH should undertake market research on builders' and consumers' perception of new technologies. Information on the successes and failures of new technologies and processes for introducing them into the housing industry should be incorporated into PATH's technology development and deployment strategy. PATH strategies for disseminating information to its diverse audiences should be evaluated continuously and refined, as necessary.

Recommendation 3. More realistic and achievable goals should be developed commensurate with the size and mission of the PATH Program. Performance should be measured by criteria that are directly influenced by PATH initiatives, such as the rate of deployment of identified technologies and the level of investment by the housing industry in research and development.

Recommendation 4. PATH should develop credible baseline data so that the program's performance toward achieving its goals can be objectively and independently assessed.

Recommendation 5. PATH should maintain its current management structure but should be careful to maintain PATH's independence from ongoing programs and not become a surrogate for these programs. PATH strategic and management plans should focus on opportunities for synergies and collaboration in ongoing programs and should make a clear distinction between coordination and initiatives that are directly controlled and funded through PATH. PATH management objectives should measure the value added to ongoing programs by PATH initiatives.

Recommendation 6. PATH should continue to provide seed money for research and development of new technologies, foster PATH name recognition to promote PATH goals and technologies, and educate and transfer information among its diverse stakeholders.

Recommendation 7. PATH should expand its use of demonstration projects to help develop market recognition for the PATH Program. Demonstration projects should be planned to measure the performance and value of new technologies and disseminate information to promote and facilitate the use of the demonstrated technologies.

Recommendation 8. The roadmapping process should include basic and applied research, technology transfer, and process and planning issues in addition to materials and hardware. Participation in the roadmapping process should be expanded to include representatives of the financial, insurance, real estate, planning, and regulatory communities, as well as trade, labor, and consumer groups. The roadmapping should also identify opportunities for academic/business partnerships.

Recommendation 9. PATH should develop standard evaluation procedures, including the benchmarking of technologies that have been successfully integrated into the housing industry, to increase the usefulness of the Technology Inventory. The effectiveness of the *ToolBase* program in transferring information to home builders and other audiences should be evaluated.

1

Introduction

The Partnership for Advancing Technology in Housing (PATH) is an initiative of the U.S. government to stimulate the public and private sectors to develop and use new technologies that could improve the performance and reduce the costs of American homes. The program focuses on the materials, products, tools and equipment, subsystems, and systems that are incorporated into houses and the home construction process. PATH brings together federal agencies with leaders of the home building, product manufacturing, architectural, engineering, insurance, financial, and regulatory communities in a unique partnership focused on encouraging technological innovation in the American housing industry. This is the first major technology-based initiative in the U.S. housing industry in several decades.

Operation Breakthrough, an initiative by the federal government to promote research and development (R & D) in housing in the 1970s, failed to meet its overall objectives. Its goal was to develop and promote new technologies for housing but the government had neither the technical expertise nor the market experience to make the program a commercial success. Operation Breakthrough was an example of the public sector attempting to direct the development of specific technologies for a commercial market in which the government had little or no procurement interest. The lessons learned from Operation Breakthrough and other federal R & D projects are that successful programs have the following characteristics: association with government procurement or some other well defined public-sector objective; support of defined, nonproprietary research guided by a scientific community; and an institutional structure that allows potential users to guide the program (Langlois and Nelson, 1983). Because the PATH Program is a partnership with the private sector, it is positioned to avoid many of the problems encountered by Operation Breakthrough. Its success, however, will require that goals and objectives be carefully defined and cooperative relationships with both private and public sector partners be established.

PATH is an ambitious program that seeks to achieve many goals: improved durability of materials and components; reduced carbon emissions through reduced energy use; reduced water use; reduced construction waste; increased use of recycled, engineered, or alternative construction materials; increased use of renewable energy; improved disaster resistance; and improved safety for construction workers. The overarching goal of the program is to make housing more affordable.

PATH was initiated in fiscal year (FY)1998 when Congress appropriated $980,000 to the U.S. Department of Housing and Urban Development (HUD). In FY99, and again in FY00, Congress appropriated $10 million for the PATH Program. The program is administered by the Office of the Assistant Secretary for Policy Development and Research (PD&R).

The congressional conference report accompanying the Veterans Administration, HUD, and Independent Agencies Appropriation Act of 1999 (P.L. 105-275) directed HUD

> ... to cooperate with other federal agencies and the housing industry, and to engage in PATH activities that will provide research, development, testing, and engineering protocols for building materials and methods as described in the Industry Implementation Plan of the Residential National Construction Goals.

The conference report also directed that HUD provide an operating plan for the PATH Program and a draft evaluation report describing progress towards meeting PATH goals. The first operating plan was submitted on March 11, 1999, and the first progress report on meeting the objectives outlined in the operating plan was submitted to Congress on April 22, 1999.

Determining how well PATH is meeting its multiple program objectives will require both a framework for evaluating performance and specific performance measures. HUD believes that the evaluations should be part of a multiyear oversight and assessment process carried out by an independent review body; therefore, HUD requested the assistance of the National Research Council (NRC).

SCOPE OF THE REVIEW

In response to HUD's request for an independent review, the NRC assembled a panel of experts, the Committee for Oversight and Assessment of the Partnership for Advancing Technology in Housing, under the auspices of the Board on Infrastructure and the Constructed Environment. The committee was asked to review and comment on the overall goals of the PATH program, the proposed approach to meeting the goals and the likelihood of achieving them, and progress toward achieving the goals. The committee determined that assessing the overall goals of the PATH Program also required evaluating the fundamental need and precedents for such a federal government program. HUD will submit the reports produced by this NRC committee to Congress to fulfill part of the department's reporting obligation. The report will also have broader federal government interest in Congress and other Executive Branch agencies, as well as state and local governments, and the private sector.

The 14 members of the committee have expertise in housing design and construction processes, manufactured housing, social impacts of the built environment, sustainable building technologies, residential energy management, material performance and durability, recycled and engineered construction products, safety of the construction workplace, disaster resistance of housing, product certification, residential building codes, and program evaluation and performance measurement. Biographical information about committee members is provided in Appendix A.

ORGANIZATION OF THE REPORT

This is the first report of a planned multiyear assessment. The focus in this initial report is on the precedents and need for PATH as a federal program; the validity and appropriateness of the program goals; the overall soundness of the management approach described in the strategic and operating plans; and a preliminary evaluation of the

implementation of several PATH projects. The report does not include qualitative or quantitative analysis of the program budget or the results of PATH projects. Future studies will focus on developing and applying qualitative and quantitative criteria for evaluating the implementation of PATH projects. The committee held two meetings for this phase of the review, on May 23 and 24, 2000, in Washington, D.C. and on August 29 and 30, 2000, in Irvine, California. This report draws heavily on briefings provided by representatives of PATH management, participants and contractors, as well as the considerable experience of committee members.

Chapter 2 is a discussion of the need for the PATH Program; Chapter 3 is a review and assessment of the PATH goals and objectives; Chapter 4 is a discussion of the organization of the program and the management structure; and Chapter 5 addresses implementation issues and presents the committee's observations and recommendations regarding program implementation to date. Committee biographies, a list of presentations to the committee, and some historical case studies of the diffusion of housing technologies based on the knowledge and experience of committee members are included in the appendixes.

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2

Need for the Partnership for Advancing Technology In Housing

The federal government has a long history of involvement in housing policy and support of R&D on technological innovations. The residential sector of the construction industry provides unique opportunities for pursuing both social and environmental policy goals. The nation's new and existing housing stock are potential vehicles for reducing energy use, reducing accidents, promoting public health by reducing exposure to hazards, such as lead, radon, and molds, and reducing housing costs.

The impact of housing on the everyday lives of Americans is enormous. For example, according to the most recent consumer expenditure surveys, housing is the largest single expense for most Americans (BLS, 2000), and residential use constitutes a significant portion (11 percent) of national energy consumption (DOE, 1999). Illness and accidents on the work site are significant risks for the millions of people involved in housing construction (NAHBRC, 1998a). Although in-home accidents are not addressed directly by the current PATH goals, large numbers of accidents occur within the home (falls in the home were alone responsible for almost 12 percent of all accidental deaths reported in 1998) (National Safety Council, 1999), and exposure to health risks in the home contributes significantly to the cost of health care (NRC, 1993; IOM, 2000). Clearly, society could reap large benefits if the private sector were to work with the federal government to cut costs, reduce adverse environmental impacts and energy consumption, and promote health and safety in the home.

FEDERAL HOUSING POLICY

Federal involvement in housing policy dates back to 1892 when the federal government provided funds for an investigation of safety and welfare issues in city slums. More significant federal involvement dates to the early 1930s when Congress passed several measures to stimulate housing construction, renovation, and home improvements, created institutions to supply and insure mortgage credit, and provided emergency relief to homeowners.

The Housing Act of 1949 expanded the role for the federal government by declaring that the welfare and security of the nation required a decent home and suitable living environment for every American family (P.L. 81-171). Since then, the federal role in housing policy has taken on the fundamental goal of ensuring that affordable homes are available for all Americans. The federal government now directly subsidizes tenants and homeowners, provides tax incentives for homeowners and developers of low-income rental housing, insures mortgages, and provides block grants to state and local governments to improve housing and community development.

The federal government also engages in a wide range of other activities intended to reach national housing goals, including making homes more affordable to build, safer to live in, and less costly to maintain and operate. In 1992, for example, Congress passed the Lead-Based Paint Hazard Reduction Act (P.L. 102-550, Title X) and the Removal of Regulatory Barriers to Affordable Housing Act (P.L. 102-550, Title XII). As part of HUD's office of PD&R research portfolio, HUD has sponsored research on cost-effective construction techniques, energy-saving innovations, and designs that promote health and safety.

Historically, the federal government has also played an active role in the development and promulgation of standards for housing that address health, safety, and welfare issues. Federal laboratories and federally supported research have made contributions in the areas of materials development, structural design and testing, seismic resistance, tornado and hurricane resistance, flood resistance, and fire protection. Since the early 1970s, the U.S. Department of Energy (DOE) has been a leader in the development of model codes to reduce energy consumption. As a result of these and other efforts, houses built since 1987 consume only 60 percent of the heating energy of houses built before 1980 (DOE, 1999). HUD has also assisted in the development and enforcement of standards for manufactured housing that preempt local codes nationwide. The Environmental Protection Agency (EPA) is involved in identifying indoor pollutants and improving the quality of indoor environments. The PATH Program fits well within this long tradition of federal involvement in housing.

GOVERNMENT INTERVENTION IN PRIVATE MARKETS

Economists generally agree that some common market failures lead to deviations from the ideal of a perfectly competitive market and that correcting these failures may warrant government intervention. The most common failures are referred to as public goods, externalities, natural monopolies, and information asymmetries. Of these, only natural monopolies are not relevant to residential technology development and diffusion. Arguably, the other three are applicable and support the need for the PATH Program.

Public Goods

Public goods are goods that are nonexcludable and nondepletable (i.e., goods that are available to all but are not diminished by use). Information in the public domain is one such public good. Anyone can consume it, and consumption of it does not diminish its usefulness to others. The PATH Program could produce public goods that might lead to a broader diffusion of innovations, such as methods of measuring product performance. Because it is in the public interest that all manufacturers producing building materials and systems subscribe to similar standards, and because private producers will be unable to recoup the costs of creating standards, it is appropriate for the government to establish the standards for building materials and systems.

Externalities

Externalities arise when parties do not bear the full costs, or reap the full benefits, of their actions. For example, if early adopters of an innovation bear all of the risks of testing its performance and achieving market acceptance and competitors are likely to reap the future benefits, firms may be reluctant to be the first to use new technologies. Under normal market conditions, builders, as the main decision makers, have little real incentive and some disincentives for employing new technologies. The PATH Program could help overcome market failures in product diffusion resulting from externalities and encourage the rapid, widespread adoption of new technologies by ensuring that local barriers do not impede their adoption, by educating builders and consumers, and by developing testing standards and methods.

Information Asymmetries

Information asymmetries result when buyers and sellers in market transactions have different information. PATH could develop impartial, credible information that rates the quality and value of new technologies. PATH could support existing product evaluation programs and ongoing efforts to develop product evaluation methods. PATH could also assist in the development of programs to increase public awareness and to make information about housing technologies available to builders and consumers.

STRENGTHENING THE TECHNOLOGY INFRASTRUCTURE

The federal government already plays a productive role in the development of the nation's housing technology infrastructure; however, government efforts to increase the development and effective application of new technologies in the housing industry could be expanded.

Coordinating Technology Research and Development

According to the National Association of Home Builders Research Center (NAHBRC), public and private investment in R&D for residential housing has been modest. In 1992, it is estimated that total R&D spending was 0.2 percent of the total value of new housing construction. The private sector funds 85 percent of R&D in housing; the remainder is made up by the federal government (8 percent), state and local governments, universities, and nonprofit organizations (7 percent) (NAHBRC, 1998a).

Manufacturers and suppliers of construction materials and products account for 80 percent of private funding for R&D, but this represents only 0.6 percent of their sales. Home-building firms, contractors, and related trade associations spend less than $10 million on R&D annually, a large part of which is devoted to regulatory compliance (NAHBRC 1998a).

Historically, the home-building industry has been slow to adopt new technologies. Materials and product manufacturers face a stiff challenge in obtaining approval from building-code officials in thousands of local jurisdictions, and then they are faced with marketing and promoting the innovation to more than 50,000 builders. Innovations that reduce production costs are most likely to be accepted by the industry. Some past innovations now used routinely by home builders include: engineered roof trusses and other wood components; plastic panels around bathtubs; 24-inch stud spacing, preassembled plumbing trees; and prewired electrical components.

The annual federal expenditure for R&D related to residential technology is about $29.1 million. Government spending is distributed among many agencies, including PATH partners: HUD, DOE, U.S. Department of Commerce (DOC), U.S. Department of Agriculture (USDA), EPA, National Science Foundation (NSF), Federal Emergency Management Agency (FEMA), and others. Most federally funded research on residential construction is mission oriented and directed to regulatory matters, rather than focused directly on solving builders' problems or making housing more affordable (NAHBRC, 1998a).

Defining the federal role and coordinating public and private R&D will require a detailed inventory of existing housing technology, ongoing private and public R&D, and current data on technology transfer and technology diffusion.

Government and Private Research and Development

The United States has not established national priorities for housing R&D or a mechanism for coordinating housing technology diffusion. In other countries, such as Canada, Japan, and the United Kingdom, the government works closely with industry to develop research agendas, allocate pooled resources to meet consensus-based research objectives, and disseminate information. By contrast, the regulatory approach taken by some U.S. government agencies often creates an adversarial relationship with builders and manufacturers. A partnership among public and private interests would help to identify an agenda for residential construction R&D and develop programs to achieve common goals.

Barriers to Technology Research and Development and Technology Diffusion

Technology R&D is only a fraction of the answer to achieving the national construction goals for the housing industry. Benefits to the consumer also depend on overcoming barriers to technology diffusion, which include restrictive regulations, the risk of product failures, the lack of consumer acceptance, and the fragmented structure of the housing industry. Many technologies that could reduce energy costs, reduce maintenance costs, and improve worker safety and health have already been developed and tested but have not improved the overall productivity of the housing industry or affordability of housing. The failure to adopt new technologies not only limits the benefits they could bring, but also discourages investment in future R&D by private

companies. Therefore, it is essential that the barriers to the adoption of new technologies be identified and overcome.

Both consumer and builder markets for housing technologies are fragmented. Property owners number some 70 million, and the residential construction industry is comprised of more than 50,000 firms that build an average of 20 or fewer houses per year. The top ten builders in 1996 accounted for only 6.5 percent of total units constructed; the top 100 builders accounted for only 13.5 percent. More than 60 percent of builders construct 11 or fewer units per year (NAHBRC, 1996). This fragmentation inhibits the rapid adoption of innovative technologies for housing.

By contrast, in 1992, there were 155 producers of manufactured housing. The top two producers of manufactured housing shipped 35 percent of the total number of units shipped in 1996, and the top ten producers shipped more than 70 percent. Shipments of manufactured housing reached 363,000 units in 1996 (MHI, 2000). Because this segment of the housing industry is less fragmented and because there are more uniform performance-based regulations nationwide, technology adoption in manufactured housing has been faster than in site-constructed units. As a result, the costs associated with the diffusion of new technologies are higher for site-constructed units than for manufactured housing units, and the chances of success are lower.

The experience of past government efforts to encourage technology diffusion in the residential-construction industry, such as HUD's Operation Breakthrough in the 1970s, and current programs, such as DOE's Building America, could be used to direct future programs. Program resources could be targeted by selecting existing technologies with the highest potential for reducing construction, maintenance, or energy costs, and then analyzing their successful dissemination or the barriers to their adoption.

Role of Partnership for Advancing Technology in Housing

PATH provides the government with an opportunity to create a cooperative environment among industry stakeholders based on common goals and to coordinate public and private funding in R&D to leverage limited resources. PATH could facilitate communication among researchers, manufacturers, builders, and consumers to improve the understanding of new housing technologies and the benefits of new materials and products. Government could also facilitate the demonstration of key innovations by sponsoring field trials and participating in performance assessments. PATH could also assist manufacturers in overcoming regulatory obstacles.

PATH could also assist in the development of test protocols for the durability of building products and systems to provide more accurate estimates of product performance over their intended design lives. Better testing methodologies could guide manufacturers through the product design and development phase and reduce the frequency of in-field failures. A lower failure rate would increase builders' confidence in innovative building technologies.

CONCLUSIONS AND RECOMMENDATIONS

The federal government has a long history of involvement in housing policy and support for R&D on new technologies. PATH is a continuation of this tradition. The residential sector of the construction industry provides unique opportunities for fulfilling both social and environmental policy goals. The nation's new and existing housing stock are potential vehicles for conserving and reducing energy use, reducing accidents, promoting public health through decreases in exposure to hazards, such as lead, radon, and molds, and reducing housing costs.

Despite the potential of new technologies to improve the quality and lower the cost of housing, the assimilation of new technologies into the U.S. housing industry historically has been slower than in the overall construction industry and other industries. Several reasons can be cited for the low level of technological innovation in the housing industry. First, although technological enhancements have the potential to improve housing performance over the long term and reduce *life-cycle*costs, they typically increase *first costs,*perhaps the major concern of the majority of home buyers. Second, advances in housing technologies have been sporadic; no system has been established for identifying needs and subsequently developing and deploying new technologies to meet them. Finally, the benefits of improved housing technology have not been widely publicized among housing consumers or the housing industry itself. This reflects the collective view of the committee that the benefits of technology (e.g., increased durability, improved disaster resistance, and lower life-cycle costs) are not fundamental drivers in consumer preference or market demand. The committee believes that increasing consumer demand for improved housing is, therefore, a critical step in the advancement of housing technologies.

The PATH Program can be a vehicle for addressing many of these concerns. PATH, by definition, is intended to coordinate and focus various federal programs and increase cooperation and information transfer between the public and private sectors. The committee believes that PATH's vital role will be to coordinate ongoing activities, synergize new activities, and provide direction for future activities. Coordinating public and private funding for R&D can leverage limited resources. As a publicly funded agency, PATH can facilitate communications among researchers, manufacturers, builders, and consumers to educate them about the benefits of new materials and products. PATH's role can include: collecting information and disseminating it to researchers, industry, and consumers; providing seed money for the exploration of new technologies and leveraging public and private investments to create the greatest benefit to society; and assisting in the deployment of new technologies and reducing the time required to bring new technologies to market. The opportunities to further social goals, together with the precedent for federal action, provide a compelling case for the value of the PATH Program and on this basis, the committee offers the following recommendations.

Recommendation 1. The PATH Program should be continued as a partnership among federal agencies and between the federal government and the private sector. The program should be reviewed and updated continuously to ensure that it evolves into an

effective, efficient vehicle for the development and deployment of beneficial technologies.

Recommendation 2. PATH should undertake market research on builders' and consumers' perception of new technologies. Information on the successes and failures of new technologies and processes for introducing them into the housing industry should be incorporated into PATH's technology development and deployment strategy. PATH strategies for disseminating information to its diverse audiences should be evaluated continuously and refined, as necessary.

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3

Program Goals and Objectives

BACKGROUND

The Construction and Building Subcommittee of the National Science and Technology Council has developed seven national construction goals for the entire construction industry (NIST, 1995). The seven goals are:

- 50-percent reduction in project delivery times
- 50-percent reduction in operations, maintenance, and energy costs
- 30-percent increase in occupant productivity and comfort
- 50-percent fewer facility-related illnesses and injuries
- 50-percent less waste and pollution
- 50-percent greater durability and flexibility
- 50-percent reduction in construction illnesses and injuries

A residential working group (RWG) was then convened to refine these goals for the housing segment of the construction industry. The RWG's report, *Building Better Homes at Lower Costs: The Industry Implementation Plan for the Residential Building* (NAHBRC. 1998c) which is referenced in the congressional enabling legislation for the PATH program, identified two priority goals for residential construction:

- to reduce production costs through improved technology and shortened production cycle time
- to improve product durability.

The report noted that these priority goals are "inextricably linked to the role of technology, [and] both goals address the direct connection between the material and process inputs to housing and the performance of the structure as related to the home's cost-effectiveness and efficiency and its impact on the natural environment" (NAHBRC, 1998c).

The goals for the PATH Program were expanded beyond the limited goals developed by the RWG when PATH was established in 1998. The goals are defined in terms of performance but do not specify the technologies or other means of realizing them. PATH's four goals are listed below:

1. Reduce the monthly cost of new housing by 20 percent or more.
2. Cut the environmental impact and energy use of new homes by 50 percent or more, and reduce energy use in at least 15 million existing homes by 30 percent or more.
3. Improve durability and reduce maintenance costs by 50 percent.

4. Reduce by at least 10 percent the risk of life, injury, and property destruction from natural hazards, and decrease by at least 20 percent illnesses and injuries to residential construction work.

An overarching goal of affordability is implied in all of the PATH goals. The *Partnership for Advancing Technology in Housing (PATH) Strategy and Operating Plan* also notes that the president has "charged the program with developing technologies, housing components, designs, and production methods that will reduce the time needed to move quality technologies to market 50 percent by the year 2010" (HUD, 2000).

Several approaches to achieving the PATH goals could be adopted. Some would involve making institutional changes; some would involve education and training; and some would expand the use of products, systems, and technologies that are already commercially available. Major progress, however, is expected to require R&D leading to the demonstration, market deployment, and eventual diffusion of new technologies, as well as the diffusion of already developed technologies (NAHBRC, 2000).

REVIEW OF PATH GOALS

Reduced Monthly Cost

The first PATH goal is to reduce the monthly cost of new housing by 20 percent or more. The low interest rates and full employment of the 1990s resulted in a rise in home ownership rates from 64 percent in 1990 to almost 67 percent in 1999, a historic high (USBC, 2000a). Measures of the affordability of home ownership, such as *the Joint Center for Housing Studies Index,*suggest that the relative costs of home ownership are near the historic lows of the past 30 years.

Nevertheless, housing is plainly not affordable for millions of Americans, especially for the 23 million American households with incomes of less than half the area median incomes. HUD estimates that about 4.4 million very low-income homeowners spend more than half their incomes on housing. The Joint Center for Housing Studies estimates that about one-quarter of working-poor families devote half or more of their incomes to housing costs. In addition to these severely cost-burdened families, another 5.9 million very low-income families spend between 30 and 50 percent of their income on housing (USBC, 2000a). Affordability is also of interest to middle and upper income families, but for them affordability relates to the size of the house, the quality of finishes and furnishings, and the quantity of discretionary amenities. The level of income determines the level of need.

Factors affecting the cost of ownership include mortgage principal and interest (70 percent); property taxes and insurance (20 percent); and utilities (10 percent). The mortgage burden is highly sensitive to prevailing borrowing rates and the cost of construction. Typically, builders' costs are primarily influenced by land prices (25 percent), materials costs (21 percent), and labor costs (14 percent) (NAHBRC, 1998b). The relative cost of land is highly variable from region to region.

Housing operating expenses are dominated by utility costs. Gas and electric costs represent 8 percent of the cost of ownership. Primary energy consumption includes heating, cooling, domestic hot water, lighting, and appliances. Energy consumption for heating and cooling per household declined roughly 17 percent between 1970 and 1979 but increased 18 percent between 1990 and 1997. At the same time, total energy consumption per household (including energy for domestic hot water, and appliances) decreased 7 percent between 1970 and 1979 and again from 1980 to 1989 but increased 15 percent between 1990 and 1997 (DOE, 1999).

Discussions of housing affordability often ignore technology and focus on financing mechanisms or changes in regulations that affect land prices and other components of housing costs. Land prices, financing, and other soft costs are the province of policy, regulations, laws, and market forces. Construction costs, although relatively less important, are still significant (NAHBRC, 1998b).

Productivity gains in the overall U.S. economy played a vital role in containing inflation in the 1990s, but the housing industry lagged behind the rest of the economy in productivity gains. An earlier NRC study found that the lag in productivity and the low rate of investment in R&D in the housing industry were indeed related (NRC, 1988). Therefore, achieving more affordable housing in the U.S. will require increased investment in R&D to improve productivity. In addition, the housing industry must address barriers to technology adoption, including building codes, standards, and regulations, as well as technology-transfer mechanisms to manufacturers, builders, and consumers.

Environment and Energy

The second PATH goal is to reduce the adverse environmental impact and reduce energy use of new homes by 50 percent or more and to reduce energy use in at least 15 million existing homes by 30 percent or more. Reducing housing-related energy consumption has been a goal of federal programs for almost 30 years. Since the oil crisis of the early 1970s, several federal agencies have had active programs to reduce energy consumption in residences. Energy consumption in homes has been reduced through stringent insulation standards, weatherization assistance, and efficiency rating programs that promote the use of efficient equipment and appliances.

DOE administers the Building America Program, a private-public partnership to accelerate the development and integration of new technologies for energy efficiency into production houses (as opposed to custom-built houses). DOE and EPA co-manage ENERGY STAR, a program that identifies and promotes energy-efficient products, equipment, and homes, including design standards and building construction details. The goal of cutting energy use in at least 15 million existing homes by 30 percent or more can easily be achieved with wider adoption of existing technologies and designs. DOE and EPA are both participants in the PATH Program and their programs constitute a significant percentage of PATH activities.

The vast majority of the energy used in both new and existing homes is in the form of electricity or natural gas. The Energy Information Administration of DOE conducts periodic surveys documenting energy use in the residential sector. These data

could be used to set benchmarks for evaluating reductions in energy use in new and existing homes.

Durability

The third PATH goal is to improve the durability of materials and systems and reduce maintenance costs by 50 percent. Maintenance and repair costs for residential structures range from $300 to 500 per year depending on the age of the residence. Replacement costs, according to the *NAHBRC Baseline Data and Information Resource Guide,*average $1,175 per year per house (NAHBRC, 1998b).

The committee's experience suggests that the durability of materials and systems, however, is not usually of primary concern to home buyers. Nevertheless, durability has been a significant reason for the reluctance of the housing industry to adopt innovative technologies. The industry has been negatively affected by some rather large-scale failures of new materials and systems. Builders currently rely on performance information provided by manufacturers and suppliers, but manufacturers often do not have appropriate methodologies for making accurate predictions of the product or system's performance over its intended service. Because cost-effective predictive methodologies have not been available, durability characteristics have by necessity been determined in the field. One reason for past failures has been unanticipated incompatibilities of materials that make up a subassembly. For example, siding materials and systems must be compatible with windows and other exterior wall elements. Durability protocols should address compatibility issues for both products and systems.

Recent building product failures have resulted in class action lawsuits (Kinsella Communications, Ltd., 2000). Examples of failures include premature deterioration of products, such as fire-retardant treated plywood and particleboard siding, and building envelope systems, such as exterior insulation finish systems. Builders are often named as defendants in these lawsuits, and failures tend to make builders more resistant to trying innovative technologies. To overcome their perceived risk in deploying a new technology, builders need independent assessments of manufacturers' claims for product reliability.

Data relating to the maintenance, repair, and replacement of major systems in residential construction (through 1997) are included in the *NAHBRC Baseline Data and Information Resource Guide*(NAHBRC, 1998b). Progress toward meeting this goal may be difficult to measure in the short term because the service life of major construction systems, such as the furnace, roof, and water heaters, is more than 10 years. In addition, according to the *PATH Strategy and Operating Plan*for 2000, the cost of maintenance and system replacement was reduced from $857.28 to $420.42 per year from 1990 to 1997 (HUD, 2000). This trend might indicate that technological improvements and other factors have reduced costs without the PATH initiative. In any case, this market tendency, coupled with the 10-year time frame, will make measuring the impact of PATH on meeting the durability goal problematic.

Natural Hazards and Worker Safety

The fourth PATH goal is to reduce by at least 10 percent the risk of loss of life, injury, and property damage from natural hazards and to decrease by at least 20 percent illnesses and injuries during residential construction. This goal combines two unrelated aspects of housing technology, worker safety and disaster mitigation. The goal does not address owner/occupant health and safety at all. Risks from natural hazards and worker safety are discussed separately below.

Natural Hazards

In 1998, NAHBRC reported to PATH that "there is no systematic collection of data regarding damage, injuries and loss of life resulting from various natural disasters" (NAHBRC, 1998b). A representative of NAHBRC told the committee that "most studies indicate that modern communications and warning systems have dramatically reduced the loss of lives from natural disasters in recent decades, but property loss from natural disasters has increased" (Fuller, 2000). "Although studies (of hurricanes and earthquakes) have described the performance of residential construction in natural disasters, they do not provide baseline data on the extent of residential damage in any given year. Nevertheless, it may be possible to use the lessons learned from these studies to predict damage loss from future natural disasters" (NAHBRC, 1998a). It will be extremely difficult to establish a baseline for measuring year-to-year improvements, and the committee believes that PATH should make every effort to use all government and commercial data sources to develop credible baselines for property losses due to natural hazards.

Worker Safety

The goal of a 20-percent reduction in injuries to workers appears to be reasonable in view of the reductions in injuries and illnesses in other segments of the construction industry. For example, the U.S. Army Corps of Engineers claims that its injury and illness rates are one-fifth to one-sixth of those of the construction industry as a whole. The Associated General Constructors of America, Heavy and Industrial Construction Committee claims similar rates for its member companies (Center to Protect Workers Rights, 1998). Logically, therefore, a 20 percent improvement should be feasible in any subdivision of the industry. However, documenting improvements in residential construction may be difficult.

The Bureau of Labor Statistics (BLS), which maintains data on injuries and illnesses in the construction industry, has only limited data on residential construction. The NAHBRC baseline report describes the following limitations. BLS tracks the incidence of accidents and injuries by industry Standard Industrial Classification (SIC) code. The data for construction includes general contracting (residential and nonresidential), heavy construction (highways, streets and infrastructure), and special trade contractors. While the SIC identifies residential building construction, the data for specialty trade contractors cannot be sorted by residential versus nonresidential. This

means that an industry profile of workplace accident and injury data is not available for residential construction (NAHBRC 1998b).

The committee is aware of additional problems that are not identified in the NAHBRC report. First, self-employed builders are not included in the regular reporting by BLS. Second, reporting on the Occupational Safety and Health Administration(OSHA) Log *2*00, which is the source of BLS safety data, is not required of employers with 10 or fewer employees, except for the years when they are part of the BLS sample, and no general site log is required. Because of the OSHA record-keeping threshold, more than 82 percent of construction firms are not required to log injuries or illnesses. Third, it is common knowledge that residential construction is more fragmented than the other major subdivisions of the industry, which creates a major barrier to obtaining information on residential construction.

Although OSHA data indicate the general scope and magnitude of the problem for the residential industry, they do not provide sufficient detail to determine the incidence rates by job category for residential accidents and workplace deaths. In its current state, OSHA data cannot be used by PATH to track progress. NAHB has requested that OSHA change its methodology to collect data that segregates residential injury, illness, and fatality data from all other types of construction. This baseline data would help to identify the types of accidents occurring in construction and their overall incidence. Therefore, OSHA's integrated management information system (IMIS) includes information and data on the firms it inspects and the facilities it investigates. No statistical data are provided, however, on residential construction or on the incidence of injuries, either for residential or general construction. The IMIS does contain narrative information on some of the factors that contribute to work-related deaths.

Workers' compensation claims are another source of information on injuries and illnesses. For PATH to use these data, however, studies would have to be done in all states, or at least representative states, to obtain baseline data (Dement and Lipscomb, 1999). Unlike the BLS and OSHA data, workers' compensation data are segregated for specialty trades and include small contractors.

In its budget submittal for FY01, OSHA requested funds to support a data-gathering initiative for the construction industry. The proposal is for OSHA to collect logs from construction firms with 20 employees or more but would not identify residential contractors. OSHA logs (on a voluntary basis) from a sample of construction sites would list all injuries occurring on the site. PATH support for collecting these data could help orient OSHA's data toward residential construction. Other opportunities include tracking builder compliance with OSHA citations in residential construction and developing year-to-year comparisons; a special BLS survey of injuries and illness in residential construction; quantifying training initiated through OSHA special grants; and incorporating worker safety and health implications in proposals for new technologies.

CONCLUSIONS

The goal of reducing the monthly cost of housing by 20 percent, exclusive of financing or land prices, is probably not attainable through new technologies because the controllable factors account for less than half the monthly costs. For example,

construction costs represented approximately 53.3 percent of the cost of a new home in 1995 (NAHBRC, 1998b). If mortgage principal and interest represent 70 percent of the monthly cost of a home, the portion of the monthly mortgage payment attributable to construction costs will be approximately 37 percent (.533 x 0.7). When the 8 percent of monthly housing cost attributable to energy use is added, a total of 45 percent of monthly costs could potentially be influenced through the application of technology. Thus, achieving a 20 percent reduction in total monthly cost would require that the costs of construction and energy be reduced by approximately 44.5 per cent (0.2 ÷0.45). Although improving affordability is an appropriate goal for PATH, the performance measure should be more realistic.

The second goal is to reduce the environmental impact and energy use of new homes by 50 percent or more and reduce energy use in at least 15 million existing homes by 30 percent or more. The committee finds this goal difficult to assess because it combines associated, but not necessarily congruent, issues. For example, although energy use and the environment are obviously related, strategies for reducing energy use will not necessarily lessen environmental impacts. Reduction in the use of fossil fuels would reduce carbon emissions and the production of greenhouse gases (a positive environmental impact), but the technologies employed to reduce energy use in the home (e.g., reduced air infiltration) might unintentionally have adverse environmental impacts such as diminished indoor air quality. Evaluation of environmental impact must also take into account water use, building materials, and construction waste. Finally, strategies for reducing energy use will differ, and differ significantly, for new homes and existing homes. The committee believes that measuring overall progress toward achieving this goal is difficult, and determining environmental performance will require quantifiable measures, which have not yet been developed.

The third goal is to improve durability and reduce maintenance costs by 50 percent. Although the committee believes that increased durability is achievable and would reduce maintenance costs, this goal may be at practical odds with the goal of reducing the monthly cost of new housing by 20 per cent. Products with increased durability usually decrease maintenance and overall life-cycle costs but typically increase first cost—the amortization of first costs is the major factor in monthly housing costs. PATH will have to resolve this conflict to achieve meaningful progress toward meeting these two desirable goals.

The fourth goal is to reduce by at least 10 percent the risk of loss of life, injury, and property destruction from natural hazards and decrease by at least 20 percent illnesses and injuries to residential construction workers. Although the committee believes that substantial improvements could be made in both protecting the health and safety of workers on residential construction sites and protecting homes from natural disasters, progress toward meeting the goal will be difficult to assess because it encompasses two unrelated aspects of housing technology. The lack of adequate baselines will also make performance measurement for either aspect of this goal difficult; baseline data will have to be compiled before meaningful evaluations can be undertaken.

Overall, the committee believes that the PATH goals are laudable targets for improving the affordability, quality, and livability of American housing. However, as currently stated, they are not realistic, particularly for this relatively small, technology-focused program. The goals can provide overall policy direction for PATH but are not

useful as performance measures. The PATH goals are influenced by numerous and complex factors, many of which are beyond the scope of the PATH Program, and full achievement of the performance levels set for all goals may not be possible. PATH's efforts should be focused and its performance measures consistent with its mission and level of funding.

Currently, there is no method of evaluating the performance of PATH programs or individual technologies. A clearly defined method of measuring performance will be necessary for evaluating progress toward achieving the PATH goals. In the likely event that some PATH goals are difficult or impossible to achieve, PATH will have to prioritize its goals to determine where its emphasis should be placed and if certain goals should be reevaluated. For example, PATH's primary focus could be on innovations that are of value both to consumers in existing housing and to builders of new homes. In addition, goals could be established to shorten the product development cycle. In any event, assessing how a given project or technology would help PATH meet its goals will require a baseline for that technology.

Programmatic Barriers to Achieving PATH Goals

Several PATH goals appear to conflict with one another, which will render the achievement of all of them extremely difficult. This conflict is explicitly acknowledged in the *PATH Strategy and Operating Plan*(HUD, 2000). A major issue is that the goals do not distinguish between first cost and life-cycle costs but tacitly emphasize reducing first costs. For example, the difficulty of increasing durability and hazard resistance while decreasing monthly costs has already been discussed. Almost without exception, stronger, more durable products cost more. A window designed to resist a 150-mile per hour wind will inevitably be more expensive than a window designed to resist a 100-mile per hour wind even though over the life of the structure, the cost of the more expensive and durable window will probably be more than offset by reduced damages. In reality, this creates more of a logical than a practical dilemma, but it underscores the difficulty of concurrently achieving inherently conflicting goals.

Targeting PATH programs almost exclusively toward new single-family homes, when existing housing makes up the majority of the nation's housing stock, will create another barrier to achieving all PATH goals. The goal of reducing the risk of loss of life, injuries, and property damage from natural hazards by at least 10 percent provides an excellent example of the consequences of the focus on new construction. New construction represents about 10 percent of the housing stock over a 10-year period. Therefore, to meet this goal, PATH would have to improve the disaster resistance of *all* new construction during that period. Another consequence of the focus on single-family construction is that the program plan practically ignores multifamily housing. The committee believes this to be an unfortunate consequence because efforts to improve this component of the housing stock would particularly benefit low and very low-income populations.

Revised Goals

PATH is aware of some of the issues raised in this chapter and is attempting to address them. The *PATH Strategy and Operating Plan*restates the four goals originally announced by the president in the form of interim performance measures that may be more achievable (HUD, 2000):

- Goal A: Reduce the average monthly costs of new housing built in 2010 by 20 percent or more, relative to homes built from 1990 through 1997, where this reduced monthly housing cost reflects a 50-percent reduction in energy costs; a 50-percent reduction in maintenance and replacement costs; and at least a 10-percent reduction in construction and insurance costs.
- Goal B: Achieve safety, health, and environmental impact goals for new housing built in 2010, relative to homes built from 1990 through 1997, including a 50-percent reduction in environmental impact; a 20-percent reduction in residential work illnesses and injuries; and a 10-percent reduction in the risk of loss of life, injury, and property destruction from natural disasters.
- Goal C: By 2010, reduce energy use in at least 15 million existing homes (homes built before 1997) by 30 percent or more.

Although these revisions are an attempt to make the goals more attainable, they do not resolve the inherent problems of the original goals. Namely, they continue to be overly broad and ambitious, difficult to measure, and combine unrelated, and possibly conflicting, issues that are influenced by factors other than technology.

RECOMMENDATIONS

Recommendation 3. More realistic and achievable goals should be developed commensurate with the size and mission of the PATH Program. Performance should be measured by criteria that are directly influenced by PATH initiatives, such as the rate of deployment of identified technologies and the level of investment by the housing industry in research and development.

Recommendation 4. PATH should develop credible baseline data so that the program's performance toward achieving its goals can be objectively and independently assessed.

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4

Organization and Management

PATH PROGRAM STRUCTURE

PATH is a government-industry partnership to make housing more affordable through innovation, improved construction productivity, and improved housing performance. Although a number of agencies are involved in the program, HUD and DOE together set the general policy. A PATH Program Office, under the direction of the PATH executive director, is funded by HUD and staffed by employees detailed from several federal agencies and departments. The PATH Program Office facilitates interagency planning and dissemination for housing technology research, serves as the program liaison and major point of contact with industry and the general public, manages and organizes education and information dissemination programs, and coordinates issue-based working groups. HUD is responsible for managing and providing technical direction for PATH contracts, grants, cooperative agreements, and other research activities, in coordination with the PATH Program Office.

In addition to HUD and DOE, the following federal agencies are also involved in PATH: EPA, U.S. Department of Commerce, National Institute of Standards and Technology (NIST), USDA, Forest Products Lab (FPL), U.S. Department of Labor, OSHA, FEMA, NSF, Federal Housing Finance Board, and the U.S. Department of Defense.

The PATH Program Office is responsible for coordinating federal resources for R&D and other program activities. This is accomplished through a federal agency work group. Leadership roles for meeting specific PATH goals are divided as follows:

- affordability (HUD)
- energy efficiency for new homes (DOE and EPA)
- energy efficiency for existing homes (EPA and DOE)
- environmental impact (EPA, DOE, HUD, NIST, and FPL)
- durability (HUD, NIST, and FPL)
- disaster resistance (FEMA)
- worker safety (OSHA)
- time to market (PATH)

RELATIONSHIP BETWEEN FEDERAL PARTNERS AND INDUSTRY

The PATH Program is intended to coordinate both federal and private activities. Congress specified in the authorizing legislation that all industry participation was to be coordinated through the NAHBRC. In response to that mandate, an Industry Steering Committee composed of builders and product manufacturers has been established. Staff

support for this committee is provided by NAHBRC. The role of the steering committee is to identify gaps in advanced housing technology and recommend priorities for industry and government research.

In addition to the Industry Steering Committee, six working groups composed of government and private-sector representatives have been created to address specific issues. The goal of the working groups is to coordinate public and private activities and to accelerate the market acceptance and deployment of advanced housing technologies. The discussions of the Technology Working Group are the most advanced. The activities of working groups are described below and will be the focus of future committee assessments:

- The Technology Working Group is charged with developing a technology research plan and coordinating public and private investments to develop advanced housing technologies that will meet the PATH goals. This group is currently conducting a formal roadmapping[1] process to establish research priorities and recommend tactics and timelines for technologies for specific housing components and housing systems, as well as for specific industry segments.
- The Barriers/Insurance Working Group is charged with addressing regulatory barriers, including issues related to building codes, evaluation systems, product liability, and home owner's property insurance.
- The Quality Working Group is charged with facilitating quality assurance procedures to reduce code inspections and builder call-backs, and ultimately, to increase durability and affordability.
- The Labor Working Group is charged with evaluating labor supply, training issues, and worker safety procedures.
- The Finance Working Group is charged with determining how energy-efficient mortgages could be more widely used and how mortgage limits and insurance rates could be adjusted in recognition of lower operating and maintenance costs and enhanced performance of homes with PATH-evaluated technologies.
- The Consumer Education Working Group is charged with proposing strategies to encourage rapid market acceptance of new technologies. Consumer education includes teaching home builders and home owners how to identify opportunities for innovation and to demand high-quality housing technologies.

Innovative construction technologies are currently brought to market by ongoing programs, such as DOE's Building America and EPA's ENERGY STAR, which emphasize energy conservation and related environmental benefits. New programs

[1] Roadmapping is a process of brainstorming to define and organize potential R&D activities to facilitate decisions about resource allocation and achieve other specified ends. Roadmapping is used in many different organizations, industries and technological contexts. The types of technologies included can range from tangible new materials, products and systems to methods of production, software and information technologies. (NAHBRC, 2000)

initiated by PATH are intended to avoid duplications and emphasize coordination and synergies. However, the PATH Program does not address the issue of ownership of patents for advanced technologies. In some cases, PATH might be promoting proprietary products if they support the PATH goals. In contrast, the ENERGY STAR Program provides information on the relative expected costs of operation of particular appliances or homes rather than promoting specific products.

The appropriate role of the public sector in promoting new and potentially proprietary technologies should be clearly defined. Historically, public agencies have not been effective in bringing new technologies to market, which is usually best left to private enterprise. The public sector can and does provide a forum for convening stakeholders and facilitating the process. In addition, as barriers to the development and marketing of new technologies are identified, government can work to remove or reduce those barriers (Langlois and Nelson, 1983).

PROGRAMMATIC ISSUES

Participation by the Codes and Standards Community

The PATH Program has assembled a group of interested and committed individuals from a number of federal agencies. An open dialogue and exchanges of information have also been established with the private sector. The building codes and standards community, however, seems to be underrepresented, despite the fact that one of the main barriers to the adoption of new technologies identified by PATH is building codes and standards. The committee believes that the minimal involvement of state and local building officials could jeopardize the success of the program.

Leadership

The committee is concerned that although the PATH Program brings together a number of ongoing programs in different agencies, it does not provide strong central leadership to focus their activities. A possible reason for this is that DOE's large technology research budget clearly dominates the technology agenda. The PATH budget is $10 million, which is small in comparison to DOE's $266 million budget for energy-related activities and EPA's $15 million budget for its part of ENERGY STAR. This large imbalance between the relatively low level of PATH funding and the much larger program funding for other agency programs could undermine PATH's leadership role. For example, the PATH strategic plan for the next few years emphasizes the role of energy, which, in the committee's opinion, reflects DOE's funding. This will result in less effort being devoted to reducing construction costs and still less to addressing safety issues.

Quantity versus Quality

The PATH program plan includes 148 separate line items, which seems out of proportion to the size of the program. Programs related to PATH, but independently funded and managed, are not distinguished from programs directly funded and managed by PATH. Nor does the plan include the relative level of funding or the duration of the project or ongoing program. Nor does the plan include an approach to evaluating projects and programs qualitatively. The only effectiveness measures currently in use are simple quantitative ones (e.g., counting the number of products in the technology inventory or the number of times a web page is accessed).

Taking Risk

The overall objective is for PATH to change the way Americans think about and build housing, but most of PATH's efforts are focused on incremental changes and applications of existing solutions. The current plan emphasizes encouraging consumers, builders, and regulators to accept new products and technologies to replace existing products and technologies. This approach is not commensurate with the greater goal of finding new and creative solutions to housing problems. The committee suggests that at least a portion of the PATH Program be dedicated to unconventional, high-risk schemes that could potentially revolutionize at least one critical aspect of the housing industry, such as design, construction, materials handling, training, or methods of product evaluation.

Overall, the committee believes that PATH has established the organizational and management infrastructure necessary for effective public-private collaboration with the involvement of many federal agencies. The committee recognizes that the relationships between the federal agency partners and the PATH Program are unresolved, but is not yet prepared to recommend a specific structure for resolving them. The committee did conclude, however, that a distinction should be made between PATH-initiated programs and programs controlled by specific agencies. The relationship between PATH and its federal partners will be the focus of future assessments. Although the present infrastructure is by no means perfect, it is critical to maintaining the positive momentum already established. Based on this review of the PATH program organization and management structure, the committee offers the following recommendation.

RECOMMENDATION

Recommendation 5. PATH should maintain its current management structure but should be careful to maintain PATH's independence from ongoing programs and not become a surrogate for these programs. PATH strategic and management plans should focus on opportunities for synergies and collaboration in ongoing programs and should make a clear distinction between coordination and initiatives that are directly controlled and

funded through PATH. PATH management objectives should measure the value added to ongoing programs by PATH initiatives.

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5

Program Implementation

FORCES AFFECTING THE ADOPTION OF NEW TECHNOLOGIES

Market Forces

The adoption of new technologies by consumers and the housing industry will be crucial to the success of PATH. Regardless of the success of any one technology, PATH will not achieve its multiple goals unless many reliable technologies are developed and adopted quickly. Therefore, PATH will have to address market imperfections to encourage technology adoption, and will ultimately have to establish a hierarchy of products, materials, and systems based on their value for meeting the PATH goals and their probability of adoption.

Because PATH's goals are market driven, the program must be guided by a clear understanding of its customers and markets. Millions of dollars are being spent on developing technologies and delivery systems, integrating R&D into the existing government and industry structure, and analyzing government's role. However, primary research to define the characteristics of PATH customers, their motivation for adopting housing technologies, the influences of specific technologies, market dynamics, or the technologies most likely to be accepted is not being done.

At first glance, consumers should welcome technologies that perform better and either cost less or reduce the cost of ownership through short-term reductions in operation or maintenance costs. In other words, consumers should respond when the cost/benefit relationship is favorable and easy to see. If one looks more closely, however, home-buying decisions are very complex. Lifestyle, location, financing, and overall affordability are just a few of the factors that may take precedence over the attraction of new technologies.

Because the purchase of a house is a major, and complicated, buying decision, consumers generally gravitate toward known products that present no added risks or obligations. For PATH to achieve its goals, consumers must be made aware of the benefits of new technologies. A 1991 study, *Advanced Housing Technology Programs,* examined decision-making factors, such as consumer awareness, the formation of attitudes, trials and evaluations, and the adoption of new technology (NAHBRC, 1991). Increasing the general knowledge base is part of the implementation strategy for any new technology. However, reaping the full benefits of an expanding knowledge base greatly depends on the diffusion of that knowledge.

For consumers to have confidence in a new technology, they must be assured that it is reliable, as well as cost effective. Home builders, who are also consumers of new housing technologies, are driven by many of the same concerns as home buyers. Technological innovation in housing can only be successful if consumers somehow perceive it as providing greater value than the best available current practice. However,

new technologies substitute the unknown for the known, which increases the perception of risk. Recent introductions of some new home-building technologies have had mixed results. Solar cells, for example, have achieved only limited consumer acceptance because of performance-related concerns, real or perceived. Vinyl siding, on the other hand, achieved broad consumer acceptance because it mimics the familiar look of wood, costs less than wood to buy and maintain, and comes with extended warranties for improved durability.

Effective marketing by a builder can do much to mitigate a consumer's reluctance to accept a new technology. However, small and midsized builders, the majority of home builders, do not have large enough marketing budgets to promote innovations. Although small and midsize builders have often been innovators in advancing new technologies, a program directed at the diffusion of technology through large builders may have a more immediate impact on the achievement of PATH goals. Improving communications between consumers and manufacturers would go a long ways toward encouraging acceptance of new technologies.

The social and psychological sciences can provide valuable information on factors affecting changes in consumer attitudes and the correlation of various behavioral traits, which may be useful for planning market research. A multivariate analysis of market drivers would help identify the factors that drive the diffusion, market saturation, and implementation of new technologies in U.S. housing. The analysis should be based on many factors, such as the type of home builder; the size of the home and the quality of finishes; and the consumer demographics and geographical region. Market research could be used to establish a hierarchy of targets with the potential for the highest payback and/or the greatest influence on meeting the PATH goals. Market studies could include surveys, focus groups, and other tools of discovery to identify:

- types of products most likely to be adopted
- regional biases
- influence of the professional sector
- price-point influence
- regulatory influence
- method of education preferred by consumers
- promotion of initiatives
- incentives for change
- levels of acceptable risk

Technical Forces

The home-building industry has four major areas of concern about new technologies: performance issues, economic issues, regulatory issues, and environmental issues. Performance issues include durability, uniformity, safety, ease of installation, structural ability, warranties, availability of technical support, and ease of maintenance. Economic issues include delivered cost, benefits to builders that influence cost, installed cost, and life-cycle cost. Regulatory concerns include fire codes, building codes, historic preservation, health and safety issues, and environmental concerns. Environmental issues

include energy efficiency, resource consumption, waste stream generation, the ability to reuse and recycle, and impacts on natural ecosystems and the indoor environment. Examples of how these issues have historically affected the introduction of new technologies and products can be found in Appendix C.

Durability

It is difficult to inspire code official, builder, and consumer confidence in new products without adequate testing and evaluation methods to demonstrate product performance and durability. The newly formed National Evaluation Service Building Innovation Center (NES BIC) was established to assist manufacturers in obtaining acceptance by building code officials for innovative new materials and products and recognition for products that exceed the life-safety requirements of the model codes. This service is designed to assess durability claims by manufacturers by means of "expert panels" that draft acceptance criteria and evaluate performance claims for new products. If successful, NES BIC could improve the prospects for technology diffusion in the housing industry. In addition to NES BIC, several laboratories, including the Building and Fire Research Laboratory of NIST and FPL, also have programs for developing durability test protocols for use by manufacturers.

Regulatory Barriers

Local Agencies

Local regulatory agencies play a significant role in technology diffusion by incorporating national model building codes into local laws and regulations that govern residential construction. The acceptance of a new technology depends to a large degree on the cooperation and support of local regulatory officials, who in many jurisdictions have the authority to enact significant amendments to national model codes. These local modifications can create barriers to widespread change and economies of scale by limiting opportunities for uniform approaches to code compliance.

The absence of uniform policies and procedures can affect the adoption of new technologies in many ways. For example, although the model codes encourage the use of performance-based design approaches, some local building-code officials prefer traditional prescriptive requirements. New model codes promulgated by the International Code Council (ICC) and other national organizations are increasingly being written from a performance perspective. These new codes provide detailed statements of intent and objectives, and the performance-based provisions go significantly beyond the options for alternative materials, methods of construction, modifications, and tests found in the current, more prescriptive codes. Nevertheless, the benefit of the performance-based approach will not be realized until local building officials feel comfortable approving performance-based approaches. One possible reason for their resistance is that it is more difficult to determine if a performance than a prescriptive standard has been met. The lack of support from local code officials for new technologies, although unwarranted, can

undermine a builder's motivation to try new and innovative technologies. However, there are also examples of new products (e.g., polybutylene pipe) being accepted that later proved to be unreliable (or total failures) in service.

The indirect impact of regulations can be an even greater barrier to widespread diffusion of innovative technology. For example, zoning regulations often exclude factory-built housing in certain areas. Factory-built housing, including modular homes built to state codes and manufactured homes built to federal standards, generally make greater use than site-built housing of innovative technologies both in construction practices and in the application of materials and equipment. Thus, a regulation with little apparent technology impact can greatly influence the rate at which new technologies find their way into practice.

A 1991 study prepared by NAHBRC for the Oak Ridge National Laboratory noted:

> Procedures for updating and amending land-use/zoning codes are often slow and cumbersome and are dominated by small groups at the local level. As a result, local officials are frequently slow to acknowledge the latest technological advances, and innovations are not reflected in the updating of codes or are not readily accepted as new products. An extension of this line of reasoning claims that codes, by directly impeding innovation and delaying construction, add substantially to housing costs. In particular, one study that focused on the cumbersome regulatory process concluded that variations in codes reduced the size of potential markets, dampened profitability, and, therefore, discouraged investment in research and development.
>
> On the other hand, it has been argued that codes do not directly impede technological innovation. Codes seldom prohibit the use of newer materials and processes; and, even if specific restrictions are imposed, codes assume secondary importance. As shown by the case of plastic pipes, most innovations are able to survive regulatory obstacles. Nonetheless, the time and expense necessary to obtain code approvals was one of the factors that hindered commercialization of metal framing systems and corrugated steel tubing for the distribution of gas. Evidence on the importance of increased costs resulting from regulation is conflicting, but the substantial resources of a major firm or institution are often required to sustain the time and expense of obtaining code approvals for innovations.

The committee believes this observation is as valid today as it was in 1991.

Administrative procedures used by local building departments can also inhibit the introduction of new technologies. Many builders hesitate to use new technologies even if they meet the performance requirements of the codes because they might generate a confrontation with the regulatory environment. Builders using unconventional or unfamiliar technologies are often required to substantiate the performance of these technologies through expensive testing, evaluations, and engineering analysis. The process for securing approval of new technologies varies in extent and format from one jurisdiction to another. Some jurisdictions set the burden of proof so high that using innovative technologies becomes too difficult and not cost effective.

The development of more efficient, collaborative administrative procedures could facilitate the diffusion of new technologies. For example, in appropriate situations, innovative quality-assurance approaches could allow the manufacturer or builder to self-certify the construction using a preapproved methodology. Manufacturers or builders

with a poor record of quality control could be monitored more closely and charged accordingly for this service. Manufacturers or builders with a history of consistently good quality control could be monitored less frequently, with progressively greater opportunities for self-certification.

HUD codes for manufactured, modular, and industrialized buildings[2] have encouraged the rapid adoption of new technologies. A one-step approval process based on performance standards and a uniform and streamlined oversight mechanism has contributed to continuing improvements in manufactured housing. The federal government is able to apply a preemptive code to manufactured housing through its authority to regulate interstate commerce. State and local governments regulate conventional housing and generally resist federal intervention. Federal involvement in the local regulatory framework for conventional housing may not be feasible, but PATH could identify the aspects of the HUD Code that would encourage the diffusion of new technologies for conventional site-built construction.

The certification of new technologies through a credible testing and evaluation program would also help reduce regulatory barriers. Historically, testing laboratories have certified building products in laboratory settings under carefully controlled conditions, but problems occurred when products were deployed in the field. Approvals and certifications based on limited performance data may have some value to the engineering community but do not necessarily inspire confidence in code officials and consumers. The federal government, through PATH, could play an important role in improving the evaluation of new technologies by developing methods and promulgating standards for tests that simulate actual-use conditions. If resulting performance information and product certifications are easily understood and accepted, they could facilitate the acceptance of innovations.

Education and training would encourage the acceptance of performance-based regulations and regulatory procedures that support the diffusion of innovative technologies. The federal government, through PATH, could play an important role in the development of comprehensive educational and technical assistance programs for local officials and other interested parties. Technology-related educational programs could build on the effective training and educational tools currently offered by model code organizations. The committee believes that greater participation by the codes and standards community in PATH will be necessary.

Federal and State Agencies

Although federal and state governments are generally not perceived as direct barriers to the advancement of new technologies, their actions or inaction in the areas of comprehensive planning, building codes and standards, infrastructure administration, taxation, and impact fees can have a significant impact on the realization of PATH goals. For example, federal and state governments enact broad enabling legislation for land use

[2] The federally mandated Manufactured Home Construction and Safety Standards or HUD Code, which is administered by HUD through independent third party inspection agencies, is the federal counterpart to nationally recognized private-sector model building codes. Individual states throughout the country have adopted one or more of the model codes for site-built homes. The HUD Code is the only code mandated to be nationally recognized, with preemptive status for manufactured homes.

and zoning that frequently become barriers to the use of new technologies. The authority to address land-use issues is generally delegated by states to local governmental bodies. Although state governments and, in some instances, the federal government have the authority to intercede in local regulatory issues, this rarely occurs. The committee believes that a viable alternative would be for federal and state governments to approach regulatory issues through a cooperative process by providing educational and technical assistance to local governments. Educational programs could help local governments understand the potential social and economic advantages of changes in their regulatory approach to technological innovation (COSCDA/NCSBCS, 1994).

Federal and state governments could create an atmosphere conducive to innovation and provide leadership to ensure that changes were applied consistently across various jurisdictions. PATH has already initiated some demonstration projects at the state level that have the potential of reducing regulatory barriers. Associations representing state and local interests, such as the Council of State Community Development Agencies, the Association of Major City Building Officials, the American Planning Association, and the National Conference of States on Building Codes and Standards, could provide valuable assistance by encouraging PATH-related efforts at the state level.

PRELIMINARY EVALUATION OF PATH IMPLEMENTATION ACTIVITIES

According to the PATH strategic plan, the program strategy consists of the following initiatives designed to achieve the PATH goals (HUD, 2000):

Technology Needs Assessment

S1.	Identify cost-effective technologies that will further PATH goals but are under-utilized.
S2.	Identify technologies with demonstrated technical potential for furthering PATH goals but limited market share, and evaluate potential for achieving broader market acceptance.
S3.	Identify research gaps in advanced housing technology development to set priorities in support of industry and government research and development that will further PATH goals.

Technology Development

S4.	Encourage basic research and testing of new housing technologies through better coordination and documentation of government, university, and industry research.
S5.	Assist in the development and testing of new technologies that contribute to meeting the PATH goals.
S6.	Facilitate communication and partnering agreements between housing technology innovators, housing component manufacturers, and builders to accelerate the development of new technologies.

Technology Adoption

S7.	Promote the use of advanced housing technologies that further PATH goals in “real life” housing developments to familiarize builders with innovations, capture installation, cost and performance data, and gain consumer feedback.
S8.	Develop and maintain a communication infrastructure that provides reliable, useful information to the consumer, builder, and other key stakeholders regarding the use and acceptance of advanced housing technologies.
S9.	Identify institutional barriers to housing technology deployment and provide solutions.
S10.	Integrate the use of advanced housing technologies in specific federal housing programs, and develop local and regional public/private PATH partnerships.

Resource Coordination

S11. Coordinate government program efforts to work more effectively with each other and the housing industry to create outcomes that are more than the sum of individual efforts.

S12. Coordinate efforts to leverage public and private resources for achieving the PATH goals.

This comprehensive strategic approach addresses all of the issues the committee believes are necessary to the development and deployment of new technologies in housing. This approach will take time to implement fully but should yield positive results over time. In this chapter, the committee comments on performance in several specific implementation areas. In subsequent reports, the committee will evaluate in more detail how well the PATH goals are being met and, if necessary, suggest alternative approaches for meeting them.

Funding for Research and Development

Cooperative Research

The strategic and operating plan for the PATH Program notes that the rate of investment in R&D for the housing industry (0.2 percent of total revenue) is low compared to other industries and that the ultimate success of PATH will depend on increasing investment in basic and applied R&D. The major reasons suggested for the lack of investment are unresolved liability issues, restrictive building codes, market fragmentation, and the lack of consumer awareness. The strategic plan suggests that by shortening the time from development to widespread market adoption, PATH could improve the return on investment for industry and thereby encourage increased investment. Several of HUD's Notices of Funding Availability (NOFA) have included requirements that proposals address several PATH goals concurrently. These multiple requirements are confusing and make an effective response to an NOFA difficult.

National Science Foundation

In FY00, NSF issued a solicitation for research projects to be undertaken by university investigators, with possible private sector collaboration. An additional call for proposals from private entities was also solicited through NIST. NSF announced its first round of PATH grants in September 2000. Grants totaling $1.35 million ($0.9 million form PATH funds) were awarded to 10 of the 82 research proposals submitted for consideration. The proposals were judged on their impact on at least two of the four PATH goals. The topics of the selected projects[3] are shown below:

- fragility methodology for performance-based engineering of light-frame residential construction (two projects)
- optimized frp-reinforced osb panels for disaster-resistant construction
- the interdependency of the fire protection membrane and the structural response of light-frame engineered wood floors and ceilings
- skill-driven optimization of construction operations
- prediction of manufactured home durability using field experiments in hazardous winds
- eave icing of residential buildings
- precast post-tensioned clay masonry walls for high performance modular housing
- modeling of manufactured housing production and material utilization
- experimental assessment of site integrated planning and information technologies in residential construction

[3] Abstracts of these projects may be viewed on-line at: https://www.fastlane.nsf.gov/a6/A6AwardSearch.htmand entering “advanced technologies for housing” as the keyword.

NSF-funded projects are generally funded for two years but it will probably take many more years before the new techniques, materials, or applications developed, have an impact on housing.

Demonstration Projects

PATH partner agencies conduct field evaluations and demonstrations to introduce technology to the home building industry and consumer groups. The primary purpose of *field evaluations,*which are structured as a controlled field experiment, is to gather data to fill information gaps. *Demonstrations projects*normally integrate several technologies into actual homes in working subdivisions and typically involve 25 to 100 units. Their purpose is to illustrate and evaluate how technologies perform on a community-wide or production scale. The PATH program office generally serves as the information broker for these projects.

The committee believes that field evaluations and demonstrations are critical elements in the PATH strategy for several reasons. First, they can demonstrate that the technologies actually perform as described. Even though this is not equivalent to long-term performance experience, it does provide prompt feedback to the building community on new technology. Second, the demonstrations can introduce the local code and regulatory community to new technologies. This is significant not only for raising the confidence level of this important group but also for developing approaches for addressing regulatory concerns. The committee believes that PATH should be particularly cognizant of the value of "lessons learned" and should document and share them as part of its technology diffusion efforts.

Roadmapping

In May 2000, the Industry Steering Committee designated three technology areas to be examined in detail by roadmapping task groups made up of builders, housing remodelers, manufacturers, and researchers. The three technologies chosen to start the roadmapping program are: information technology to accelerate and streamline home building; advanced panelization systems; and whole-house and building-process redesign. Roadmapping is currently envisioned as the critical guide to planning future PATH activities. However, the roadmapping program involves a relatively small population that should be expanded to include a wider cross section of stakeholders from industry segments, geographical regions, and consumer income levels.

Technology Inventory

PATH's Technology Inventory is a database of information on technological innovations in the housing industry. The inventory includes technologies currently considered to be "emerging" (i.e., with a market share of 5 percent or less) in a wide range of categories, including new materials, components, systems, and complete houses.

Each entry in the inventory presents a review of how the technology contributes to PATH's overall goals. Technologies are added to the inventory based on information on a Technology Entry Form submitted to PATH for review. Submissions are chosen if they contribute to one or more of the PATH goals.

The committee believes a program focused on existing, underutilized technologies could be very productive. Existing technologies can be cost effective because they have usually passed through the introduction phase, and overcome some major obstacles in the building codes. However, it is important to determine why a technology has been underutilized and if there are market imperfections or other barriers the government could help to remove. Technologies in the PATH inventory should be screened and ranked by a composite index of the effectiveness of their impact on meeting PATH goals and the likelihood of their adoption.

ToolBase

NAHBRC publishes *ToolBase News,*an internet-based newsletter that combines two former publications, *Building Excellence*and *HOMEBASE NEWS.*A related program, *Toolbase Services,*provides a database of solutions to construction problems, technical information on building products and systems, and benchmarks for business practice.[4]

In the *Path FY2000 Strategy and Operating Plan, ToolBase Services*is described as PATH's primary information delivery system. The committee believes PATH should evaluate the effectiveness of *ToolBase Services*and determine the audiences it has reached and how they have responded. *ToolBase*should be evaluated for its impact on PATH's overall information dissemination objectives.

CONCLUSIONS AND RECOMMENDATIONS

The committee believes that PATH is playing an appropriate role in advancing technology in housing by striving to bring together the diverse groups involved in the U.S. housing industry and facilitating discussions of PATH-related issues. Despite the dual and difficult requirements of being a program open to all stakeholders and, at the same time, narrowly focused on achieving its program goals, PATH has accomplished several important interim objectives. Perhaps most important are the communication and collaboration links that have been forged between government and the housing industry, which will be key to the ultimate success of the program. Links between U.S. government agencies have also been developed, and the organizational and management infrastructure necessary to carry out coordinated projects and programs has been put in place. However, the committee believes that the program must have a clearer understanding of its multiple audiences and the market dynamics of each in order to target its existing programs and plan future activities.

Implementation of the strategic initiatives designed to achieve individual goals has begun, but it is too early to evaluate its effectiveness. Similarly, some baseline

[4] *ToolBase*and *Toolbase Services*are available on line at *http://www.toolbase.org.*

development is under way, but as previously noted, developing meaningful baselines for several of the goals will be difficult because of the lack of data. PATH has made extensive use of field demonstrations, which the committee believes are an effective method of showcasing and encouraging the use of new technologies. Although these demonstration projects have successfully shown the economic viability of selected technologies, there is no evidence that they have influenced decisions in other projects or led to any long-term gains toward meeting the PATH goals. The committee believes that technology roadmapping is a good approach to identifying needs and influencing changes in the housing industry, but PATH's roadmapping process should be refined and expanded. Expanding the use of current off-the-shelf technologies is an important component of PATH's strategy. However, the committee believes that the technologies included in the current Technology Inventory should be further evaluated and information on their quality and effectiveness added to the database. The current inventory focuses more on individual products than on processes and does not address technologies for improved materials. The scope of the Technology Inventory and the effectiveness of the *ToolBase*program, among other strategies for transferring information to home builders and other audiences, should be evaluated.

Recommendation 6. PATH should continue to provide seed money for research and development of new technologies, foster PATH name recognition to promote PATH goals and technologies, and educate and transfer information among its diverse stakeholders.

Recommendation 7. PATH should expand its use of demonstration projects to help develop market recognition for the PATH Program. Demonstration projects should be planned to measure the performance and value of new technologies and disseminate information to promote and facilitate the use of the demonstrated technologies.

Recommendation 8. The roadmapping process should include basic and applied research, technology transfer, and process and planning issues in addition to materials and hardware. Participation in the roadmapping process should be expanded to include representatives of the financial, insurance, real estate, planning, and regulatory communities, as well as trade, labor, and consumer groups. The roadmapping should also identify opportunities for academic/business partnerships.

Recommendation 9. PATH should develop standard evaluation procedures, including the benchmarking of technologies that have been successfully integrated into the housing industry, to increase the usefulness of the Technology Inventory. The effectiveness of the *ToolBase*program in transferring information to home builders and other audiences should be evaluated.

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Appendixes

A

Biographies of Committee Members

C.R. "Chuck" Pennoni(chair) is chairman and chief executive officer of Pennoni Associates, Inc., a consulting engineering firm based in Philadelphia. Mr. Pennoni is a member of the National Academy of Engineering; past president of the American Society of Civil Engineers; a trustee and past president of United Engineering Trustees; past president of the Accreditation Board for Engineering and Technology; and a member of the U.S. Council for International Engineering Practice. Mr. Pennoni is currently chairman of the Board of Trustees of Drexel University and was president of the university for the academic year 1994–1995. He has served on the engineering advisory boards of several universities and is a member of the board of Jefferson Bank, DHA Engineers, and the Greater Philadelphia Chamber of Commerce. He is a licensed engineer in 11 states and has lectured at several colleges and universities on engineering, planning, ethics, and professional development. Mr. Pennoni holds a B.S. and a M.S. in civil engineering and an honorary doctorate from Drexel University.

Eric Belskyis executive director of the Joint Center for Housing Studies at Harvard University and he has extensive expertise in housing policy, economics, and finance. He has more than 17 years of experience conducting research on a wide range of housing and urban topics for public and private sector organizations and clients. Dr. Belsky is also an adjunct lecturer in public policy at the Kennedy School of Business, Harvard University. Prior to his appointments at Harvard, Dr. Belsky led the Housing Finance and Credit Analysis Group at Price Waterhouse LLP, where he focused on developing analytic methods to manage housing finance risk. Before that, he was director of housing finance research for Fannie Mae. He has also served as senior economist at the National Association of Home Builders and assistant professor of urban geography at the University of Massachusetts at Amherst. Dr. Belsky is the author of dozens of articles on housing economics and finance in trade publications and academic journals. He is currently a member of the editorial board of the *Journal of Housing Research*and is a research associate at the Center for Economic Studies at the U.S. Bureau of the Census University. He holds an M.A. in international development and a Ph.D. in economic geography from Clark University.

Robert Blancett is director of the Materials and Construction Laboratory at the USG Research and Technology Center, where he oversees the operation of five laboratories involved in product development, systems engineering, and code certification for building materials. Prior to joining U.S. Gypsum in 1987, Mr. Blancett held various product engineering and research management positions with Owens-Corning, a large building materials manufacturer. He is coauthor of a number of publications on energy utilization in buildings and sustainable construction. He is a member of the Building Environment and Thermal Envelope Council Board of Direction, the National Evaluation

Service Building Innovation Center (NESBIC) Board of Direction, and chair of the Membership Committee of the Industrial Research Institute. He holds a B.S. and M.S. in mechanical engineering from Ohio State University.

Eric Burnett is the director of the Pennsylvania Housing Research Center and the Hankin Professor of Residential Building Construction at Pennsylvania State University. Dr. Burnett was selected for his competence in the broad areas of building science and technology and his expertise in construction and structural engineering. He has worked with and been a consultant to a number of research and development agencies in the United States, Canada, and elsewhere. At Penn State, he has cross-appointments to the Departments of Architectural and Civil Engineering and Environmental Engineering. His research interests include the performance of building enclosures and the integration of structural and control functions. As director of the Pennsylvania Housing Research Center, Dr. Burnett oversees research projects ranging from the development of innovative technologies and processes to fundamental research on building systems and materials. Dr. Burnett has a B.Sc. in engineering from the University of Cape Town, a D.I.C. and M.Sc. in engineering from the Imperial College, and a Ph.D. from the University of London.

Paul R. Fisette is director of the Building Materials and Wood Technology Program at the University of Massachusetts at Amherst. Mr. Fisette was selected as a member of this committee for his expertise in light-frame construction, residential energy efficiency, sustainable building practices, and the performance of residential building materials. He has developed an innovative web service that provides technical advice to builders and researchers regarding the performance, specifications, and use of building materials. Mr. Fisette frequently contributes articles to regional and national publications on building materials and the residential construction industry. Previous to his current position, Mr. Fisette was senior editor of *Custom Builder Magazine,*which covers technical information and information about innovations of interest to small and medium-sized residential building firms. He holds a B.S. and a M.S. in wood technology from the University of Massachusetts.

Karen L. George is director of Residential Services at E Source, Inc., an information service for utility companies that provides strategic business analyses, technology assessments, and market research. Ms. George is also principal author of the *Residential Appliances Technology Atlas*(E Source, 1999), a reference book for those engaged in energy efficiency programs. Ms. George was selected for this committee for her experience in the residential energy and housing markets and her focus on product analysis and technology transfer. Prior to joining E Source, she was a consultant to many firms, such as R.W. Beck and Associates and RCG/Hagler-Bailly, Inc. She was also an independent consultant to other clients, including the National Renewable Energy Laboratory, the China Association of Science and Technology, and the Pacific Northwest National Laboratory. In addition, Ms. George was manager of the Residential and Renewable Energy Programs for the Colorado Office of Energy Conservation and a professional research assistant for the Joint Center for Energy Management at the

University of Colorado's Civil, Architectural, and Environmental Engineering Department. Ms. George holds a B.S. in education from California State College.

Manuel Gonzalez is principal at KTGY Group, Inc., in Irvine, California, an award-winning planning and design firm focusing on single and multifamily residential projects. Mr. Gonzalez was selected for his experience and expertise in architectural design and technology innovations for the home building industry. Prior to joining KTGY, Mr. Gonzalez was executive director of architecture for Kaufman and Broad Home Corporation where he was in charge of residential planning and design. Under Mr. Gonzalez' direction, Kaufman and Broad received widespread industry recognition and design awards. Prior to this position, Mr. Gonzalez was a partner with Johannes Van Tilburg and Partners where for 10 years he directed the design of award-winning single-family and multifamily residential projects and master-planned communities. He holds a B.S. in architecture from the University of California at Berkeley and an M.S. in architecture from the University of Southern California. Mr. Gonzalez is a registered architect in seven states and recently served as chair of the Housing Committee for the Los Angeles Chapter of the American Institute of Architects.

Ashok Goswami is director of the Housing and Building Technology Division of the National Conference of States on Building Codes and Standards, Inc., a nonprofit organization dedicated to promoting quality and innovation in the building environment through technical services, education, and training. Mr. Goswami was selected for this committee because of his promotion of safe new technologies in building construction and interstate acceptance of modular buildings. He oversees a program that provides third-party monitoring and associated services for state and local governments, the construction industry, and home owners. He is a participant in the Industrialized Buildings Commission, which provides similar services to the modular-building industry. His division also performs plan reviews and product assessments and evaluates the performance of building systems and new construction technologies and products. He is a certified quality auditor and a registered professional engineer with a B.S. and M.S. in civil engineering from Punjab University and an M.S. in business and public administration from Southeastern University.

Charles J. Kibert is the interim director and CSR/Rinker Professor in the M.E. Rinker, Sr., School of Building Construction at the University of Florida. He was the director of the Center for Construction and Environment at the University of Florida from 1991 to 1999. He was selected for his research and expertise in construction-waste management, environmental impacts of construction, and recycling of residential construction debris. Dr. Kibert has published more than 90 papers and books and edited several publications on construction and the environment. He is a cofounder and chairman of the Cross Creek Initiative, a nonprofit industry/university joint venture seeking to implement sustainability principles into construction and has worked with neighborhood-based housing corporations on the renovating derelict structures into high performance homes. Dr. Kibert has created an innovative educational outreach program and several continuing education classes for building contractors; he teaches a newly developed graduate course on sustainable construction. He is a registered professional engineer and a chartered

engineer in the United Kingdom and a mechanical and electrical contractor in Florida. He has a B.S. in engineering from the U.S. Military Academy, an M.S. in nuclear engineering from Carnegie-Mellon University, and a Ph.D. in mechanical engineering from the University of South Florida.

Tricia Parks is founder and president of Parks Associates, a consulting firm that studies, analyzes, and forecasts the home networking and broadband industries, in addition to many other industries involved in service markets for residential and light-commercial technologies. She was appointed for her understanding of automation, electronic, and communication technologies in residential environments. Ms. Parks founded Habitech, a trade and training show for home systems, which was sold to the Electronic Industries Association. Parks Associates owns and cohosts Forum, an annual state-of-the-nation overview of current and emerging residential systems and services markets, and cohosts Connections, a showcase event for in-home networks and gateways. Previous to starting her own firm, she was a founder of MARTECH and a senior vice president of Future Computing. She is a contributor to industry trade magazines and a frequent speaker at trade events. She is the founder of Wiring Americas' Home Campaign, which was launched in 1997, and a board member of the Home and Building Automation Association. Ms. Parks has a B.A. from Sweet Briar College and completed graduate studies at the University of Texas.

Robert Pleasure is executive director of the Center to Protect Workers' Rights, Inc., established by the Building and Construction Trades Department, AFL-CIO. Mr. Pleasure was appointed for his expertise and understanding of safety and health issues in construction environments. He is currently the principal investigator for a multiyear National Institute for Occupational Safety and Health (NIOSH) cooperative agreement on construction safety and health interventions. Mr. Pleasure's responsibilities include: safety and health planning; basic and advanced training; and education in safety and health emphasizing OSHA policies and standards, hazard recognition, and hazard abatement. The center is involved in injury and illness prevention in residential construction and funds projects, such as the cost-benefit analysis of ergonomic interventions. Mr. Pleasure holds a B.A. from the University of Pennsylvania, an M.Sc. from the London School of Economics, and a J.D. from the University of Michigan Law School.

Michael Pyatok is principal of Pyatok Associates, Inc., and professor of architecture at the University of Washington. He was selected for his expertise in the design of high-quality affordable housing and his knowledge of related policy, finance, regulations, and the construction and design processes. Mr. Pyatok, who has been a practicing architect and professor of architectural design for 33 years, is a Fellow of the American Institute of Architects. He has designed more than 9,000 units of affordable housing for lower income households, for which he won numerous local and national design awards. He recently coauthored the book, *Good Neighbors: Affordable Family Housing,*which documents the ability of communities to build excellent affordable family housing. More than half of the book is a series of case studies of high-quality affordable housing from all regions of the United States; the case study projects are thoroughly documented in terms

of residents, project scale and unit mix, financing and cost, and construction type and design. Mr. Pyatok has a B.Arch. from Pratt Institute and an M.Arch. from Harvard University.

Timothy Reinhold is associate professor of civil engineering at Clemson University. He was selected for his expertise in wind effects on structures, structural dynamics, reliability engineering, and structural analysis and failure investigations. He is currently involved in wind-load studies for low-rise and specialty structures, including the resistance of structures to wind effects. Dr. Reinhold's research has included projects on improving the simulation of wind loads on residential and low-rise structures, wind-loads for coastal structures, and retrofiting solutions for existing structures subjected to high winds. Dr. Reinhold is a member of the Wind Effects Committee of the American Society of Civil Engineers (ASCE), the Southern Building Code Congress International Wind Loads Subcommittee, and the ASCE-7 Standard Wind Loads Subcommittee. He received his B.S., M.S., and Ph.D. in engineering mechanics from Virginia Polytechnic Institute and State University.

Walter R. Young, Jr., is chairman of the board, president, and chief executive officer of Champion Enterprises, Inc. Mr. Young was selected for his experience and expertise in all aspects of housing and his leadership of the nation's largest producer of manufactured housing. Since he joined Champion Enterprises, the company's annual revenues have escalated to $2.3 billion. The company built more than 70,000 homes in 1998. Several national business journals have cited Champion Enterprises as one of the most improved and productive companies in the United States. Mr. Young was honored by his peers in 1999 for the third straight year as “Industry Person of the Year.” He began his career in 1968 with BF Goodrich, where he quickly progressed and turned around the European tire operations, North American retail chain, and various chemical operations. In 1983, he joined the Budd Company to head the Aftermarket Division. In 1989, he joined the Henley Group, where he led the turnaround of the Wheelabrator Corporation. Mr. Young holds a B.A. in liberal arts from Muskingum College and an M.B.A. in management and marketing from Pennsylvania State University.

B

Presentations to the Committee

Presentations May 23–24, 2000

U.S. Department of Housing and Urban Development (Sponsor)

William C. Apgar, Assistant Secretary for Housing-Federal Housing Commissioner

Susan M. Wachter, Assistant Secretary for Policy Development and Research

Ayse Can Talen, Deputy Assistant Secretary for Research, Evaluation, and Monitoring

David Engel, Director, Affordable Housing Research and Technology Division

Executive Office of the President

Henry Kelly, Office of Science and Technology Policy,

Partnership for Advancing Technology in Housing (PATH) Program

Diane Dorius, Senior Financial Advisor, PATH Program

National Association of Home Builders Research Center, Inc.

G. Robert Fuller, Senior Engineer, and PATH Field Evaluation Coordinator

Building and Fire Research Laboratory (BFRL) of the National Institute of Standards and Technology (NIST)

Joel Zingeser, Manager, Standards and Codes Services, BFRL

U. S. Department of Energy

John Talbott, Office of Building Technology, State and Community Programs

Steven Winter Associates, Inc.

Steven Winter, President

PATH Roadmapping Strategy

Scott Hassell, Science and Technology Policy Institute, RAND Corporation

David Dacquisto, NAHB Research Center

PATH Performance Measure Development

Rick Nevins, ICF Consulting, Inc.

Presentations August 29–30, 2000

HUD Housing Technology: Policy and Research Directions

Susan M. Wachter, Assistant Secretary for Policy Development and Research, HUD

Status and Direction of the PATH Program

Elizabeth Burdock, PATH Executive Director

Program Perspective From an Industry Steering Committee Member & PATH Demonstration Site Builder

Mike Chapman, Chapman Homes, Santa Fe, NM

Overview of the Village Green PATH National Pilot Project & Partnership

Jay Starke, Lee Homes, Marina Del Ray, CA

Program Perspective From a PATH Cooperative Partner/Organization with Multiple PATH Evaluated Technologies

Deborah Weintraub, Southern California Edison

C

Historical Case Studies of Technology Diffusion

The following case studies illustrate the factors that influence the diffusion of new technologies in the housing industry. They predate the PATH Program but may provide some insight into how PATH can influence the acceptance and deployment of new technologies in the future.

VINYL SIDING

Issues related to PATH goals: affordability and durability.

Vinyl siding has a growing share of the U.S. housing market for a number of reasons, including low up-front costs, simplified installation, easy waste disposal, appealing appearance, and consistent availability and pricing. Regional bias is also a factor.

When vinyl siding is properly installed, it has a decisive advantage over most competitors: is less expensive in terms of initial and life-cycle cost; does not need painting; and it will not rot. Therefore, home owners do not have to spend time and money scraping and painting. Reduced maintenance is also a big selling point. The attributes of vinyl siding are unusual in that reduced life-cycle costs are usually offset by higher initial costs. For example, brick and stone have the lowest life-cycle cost because of low maintenance costs, but they have the highest initial cost. Another significant feature of vinyl is that it usually comes with a 50-year warranty compared to wood and stucco, which have no warranties. However, the true value of a 50-year warranty is questionable if product failures occur. In these circumstances, the manufacturer or contractor may simply declare bankruptcy, nullifying the warranty.

The length of time for ownership of a home is decreasing. On average, home owners sell and move every five years. Lifetime costs have less influence when owners do not bear all of the life-cycle costs. Therefore, if market-share expectations were based on installed costs alone, the market share for wood siding would be undiminished because of its competitive initial cost. But vinyl is gaining market share and wood siding is decreasing. Vinyl's new-home market share has risen from 1 percent to 30 percent in the last 20 years. At the same time, the market share of wood has dropped from 40 percent to less than 20 percent.

Vinyl is attractive to remodelers because a major portion of the cost of re-siding is the removal and disposal of the existing siding. With vinyl, builders can overlay existing siding and avoid much of the removal and disposal cost. Perhaps this attribute should be considered a new technical improvement for the repair and remodeling sector.

Style is also important. Virtually every vinyl manufacturer tries to mimic the look of wood. “Real wood grain” is a market goal. Satisfying consumers' desire to maintain an accepted architectural style appears to compensate for the substantive change in material. The message here is: lower up-front installed costs (especially in price-sensitive market segments, such as starter and low-end homes); simple installation, disposal and handling; attractive appearance; consistent availability and pricing; and reduced life-cycle and maintenance costs will result in the successful diffusion of a new technology.

Market shares for vinyl siding are also influenced by regional bias. For example, vinyl captured 30 percent of the national new-home siding market in 1998. However, to achieve that average, it captured 51 percent in New England, 71 percent in the Mid-Atlantic region, and less than 10 percent in the Rocky Mountain and Pacific markets during the same period. It is worth noting that, even though aluminum siding has many of the same qualities as vinyl, it has had a reversal of fortune. Aluminum, which held 14 percent of the national new-home market in 1978, has decreased to 1 percent in 1998. It would be interesting to know exactly why aluminum siding has lost market presence.

ORIENTED-STRAND BOARD

Issues related to PATH goals: affordability, environmental protection, disaster resistance, and durability.

Although adoption rates of oriented-strand board (OSB) have not been uniform throughout the United States, it is a good example of a very different, technically advanced product that has been rapidly adopted. OSB provides environmental benefits by using new-growth timber, although the glue used to hold it together has raised environmental concerns about air quality and recycling. The rapid adoption of OSB is attributable, in part, to builders' confidence in its performance and affordability. The preference of some builders for OSB over plywood illustrates the importance of promotion of a product and the development of performance standards by a trade association.

Plywood, the once dominant structural panel product, gained popularity because it provided significant labor savings, as well as improved structural rigidity and uniformity. OSB looks like, and is, wood chips glued together. A popular misconception among the uninitiated is that “OSB falls apart.” This opinion is based partly on experience with waferboard, which is a similar product. Ironically, plywood suffered the same criticism not too long ago. Delamination of early plywood sheathings gave plywood a reputation as a nondurable material. As a result, many old-timers demanded solid board sheathing for the homes they built. Not many builders share that view today. Board sheathing is virtually nonexistent.

In spite of widespread acceptance, some OSB product performance concerns remain. Swelling and deterioration of floor structures when they are exposed to rain during construction have caused in some builders to limit their use of OSB to vertical applications. Also, research in a Canadian laboratory has indicated that OSB swells indefinitely when exposed to water vapor and that it is much more impermeable than plywood, making it much more difficult for water vapor to escape from a building.

Moisture can build up in wall cavities, which promotes the growth of fungus and decay that can damage the structure. Moisture exposure for OSB components, as with all construction materials, can be controlled with appropriate construction detailing.

History

Portland Manufacturing Company made the first structural plywood from western woods in 1905. Like all structural plywood made until the mid-1930s, this plywood was bonded with nonwaterproof blood and soybean glue. Delaminations were routine until waterproof synthetic resins were developed during World War II. The adoption period for the use of plywood sheathing was long, and its acceptance was slow. Builders largely avoided plywood until the late 1950s when a technical fix for delamination was developed. In the late 1960s, advances in adhesive technology brought southern pine plywood to residential builders. Southern pine plywood experienced a rapid growth phase, and today it accounts for about half of all structural plywood.

MacMillan Bloedel opened the first viable waferboard facility at Hudson Bay, Saskatchewan, in 1963. Aspenite, the first generation waferboard (called chipboard by many builders), was manufactured from the abundant supply of aspen in the region. Technology involving the random alignment of wood fibers in waferboard soon gave way to the development of structurally superior OSB, in which the wood fibers are aligned into layers that mimic the “plies' in plywood. Elmendorf Manufacturing Company, Clairmont, New Hampshire, made the first OSB in the United States in the 1980s. In just 15 years, OSB passed plywood, accounting for more than 55 percent of the structural sheathing market.

Technical Merits

All three model building codes use the phrase “wood structural panel” to describe plywood and OSB. Codes recognize these two materials as the same, and APA- The Engineered Wood Association (APA EWA), the association responsible for certifying more than 75 percent of the structural panels used in residential construction, treats OSB and plywood as equals in published performance guidelines. Wood scientists agree that the structural performance of OSB and plywood are equivalent. Perhaps this is the reason OSB took less time to be adopted than plywood.

A builder's reputation often depends on new technologies delivering on their performance claims. Home owners expect builders to select materials and systems that perform well. Builders, in turn, need assurance from manufacturers that new products will work. OSB has the support of manufacturers and assurances from the associations that certify its performance and national code acceptance. Also, OSB has earned a reputation as a reliable, low-cost substitute for plywood.

The development of a single, widely accepted standard by APA EWS created significant economies in the manufacture, marketing, and use of structural panels and became a catalyst for the growth of this industry sector. OSB is replacing plywood as the structural panel of choice. Twenty-one OSB plants opened between 1995 and 1997. No

new plywood plants were built during this period. Production of structural plywood dropped by 7 percent in 1996, while production of OSB increased by 25 percent. The increase in OSB production is expected to lower prices for all structural panels. Reliable supplies, low prices, and reduced price volatility are expected to increase demand for OSB technology.

Regional Bias

Market data show that the conversion from plywood to OSB among builders is irregular. The northeastern and southwestern housing markets are still predominately plywood markets. The north central and southeastern regions have largely converted to OSB. In some areas of the Pacific Northwest, where plywood originated, plywood-skinned houses are hard to find.

ENGINEERED WOODEN I-JOISTS

Issues related to PATH goals: affordability, environmental protection, disaster resistance, and durability.

The adoption of engineered-wood products illustrates the critical influence of consumer demand and design, as well as the crucial role of manufacturers, in diffusion of a new technology. The adoption of I-joists also illustrates the barriers that must be overcome in the development of performance standards and product labels.

Trus Joist Corporation (TJ), the company that invented the wood I-joist, started production in 1969. TJ not only pioneered the development of this industry but has also maintained a clear leadership role in a hotly contested market. Weyerhaeuser purchased the company late in 1999. Stiff competition, rapid technological advancement, and broad-based acceptance of this product are evident in the new-home market. It has taken nearly 30 years for I-joists to capture 35 percent of the residential floor-framing market, and it is expected to capture up 60 percent by 2005.

Cost and performance drove the development of wood I-joists. Contemporary designs, first made popular in the 1970s, demanded open floor plans that required long clearspans. Lumber joists longer than 20 feet were expensive, hard to find, and lacked the load-carrying capacity required for long spans. Early versions of I-joists were also expensive, but they were straight, lightweight, and achieved the desired performance. Recently, because timber markets have been unstable, the stable price and availability of engineered-wood products have made them more attractive to builders.

Market Profile

TJ essentially shaped the I-joist industry. TJ, which has always dominated the I-joist market, claimed roughly 55 percent of the estimated $750 million national I-joist market in 1999. The company positioned itself as the industry leader through smart

marketing and abundant high-quality technical support. TJ also developed an entire family of engineered-wood products to build a complete floor system. MicroLam (laminated veneer lumber [LVL]), Timberstrand (laminated strand lumber), Parallam (parallel strand lumber) and TJI (I-joists) were all developed under the TJ umbrella. The technology required to manufacture LVL and I-joists has been adopted by a host of newcomers. More than a dozen manufacturers are now manufacturing I-Joists at a rate exceeding 300 feet per minute.

Exact market shares are closely guarded, but it is safe to say that five manufacturers sell 80 percent of I-joists. TJ clearly leads with about 55 percent. Boise Cascade, Louisiana-Pacific, Willamette Industries, and Georgia Pacific share 20 percent to 25 percent of annual sales. A growing number of smaller companies are fighting hard for market position. In this highly competitive marketplace, builders are the winners as manufacturers are offering products at low prices.

Performance

I-joist manufacturers identify dimension lumber as their biggest competitor. About 65 percent of all floors are still framed with dimension lumber, although the performance of I-joists is clearly superior to the performance of dimension lumber. I-joists have the following advantages:

- design flexibility with increased span potential
- increased on-center spacings and longer lengths that save time
- greater strength
- greater stiffness
- more consistent sizes, appearance, and performance
- dimensional stability
- lighter weight
- webs that are easier to drill
- less waste

Some aspects of I-joist performance have raised concerns. For example, fire marshals almost generally oppose the use of wood I-joists because the web sections (1/2 inch) burn through more quickly than solid lumber (1 1/2 inches), which accelerates structural collapses that endanger both occupants and firefighters. Also, some environmental and health officials are concerned that the resin in the glue will be released as an off-gas during a fire and degrade air quality.

High prices and unfamiliarity with a new product have kept I-joists from being deployed on most job sites. Until recently, it was difficult for I-joists to compete with sawn lumber for starter homes and houses with a basic design. A recent market survey found that 80 percent of builders want to learn how to use engineered wood. Through training provided by manufacturers and builder associations, I-joists are gradually becoming more familiar and builders less intimidated. During the last five years, the I-joist market has grown rapidly, and sales are predicted to increase by 50 percent in the next four years.

Standardization

Perhaps the major issue (aside from fire safety) concerning I-joists involves product standardization. Currently, each manufacturer provides specifications and span recommendations. APA EWA believes that a uniform standard for all I-joists would accelerate the adoption of I-joists. APA EWA has a long history of advancing the quality of structural-wood products used in the building industry. Consumers have benefited from the standardization of plywood, OSB, and other panel products. In large part, APA EWA is credited with the reliable high performance of structural panels.

APA EWA began exploring the idea of standardizing I-joist production in the mid-1990s. The APA EWA Performance Rated I-Joist (PRI) standard was introduced in 1997. Manufacturers can participate by using the PRI standard. Subscribing APA EWA members stamp the maximum allowable spans for each of 12”-, 16”-, 19.2”- and 24”-inch on-center spacing on every I-joist they produce. This practice is good for builders, but not widely accepted by manufacturers. So far, only 20 percent of I-joists manufacturers follow this standard. In market studies conducted by a variety of research organizations, APA EWA, retailers, builders, and building officials overwhelmingly supported the standardization of sizes, performance, and span tables. One study showed that nearly 100 percent of building officials want a uniform identification system for I-joists.

Manufacturers who produce 80 percent of the I-joists do not support APA EWA's plan. Georgia Pacific and Willamette are the only two large manufacturers participating in the PRI program. The political motives for choosing sides is clear. APA EWA wants to increase membership revenue, and established manufacturers want to maintain control of the market share they have fought to pioneer.

There are also more substantive issues. First, some people fear that setting a standard will drive products to the lowest common denominator, and superior products will not receive the credit they deserve. A standard might remove the incentive for innovation and the development of new products. Second, many argue that I-joists are structural elements that require careful engineering. But, I-joists are not direct substitutes for lumber joists. Installation of I-joists requires special consideration of point loads, offset loads, and special fastening requirements. Standardization would not eliminate the need for technical support and design services. Builders will still need expert advice for structural design.

COMPACT FLUORESCENT LAMPS

Issues Related to PATH: affordability, durability, life-cycle cost, and energy efficiency

Compact fluorescent lighting (CFL) is slowly increasing its market share in the U.S. housing market because it is a durable product that lasts 15 to 20 times longer and uses less electrical energy than incandescent light bulbs, the product it replaces. Market penetration has been very slow because of the product's high first costs and relatively low energy prices. Supplies and increased demand for energy, coupled with increased

environmental concerns and electrical energy deregulation, are likely to cause an increase in energy prices and, perhaps, an increase in the use of CFLs.

Lighting, which accounts for about 20 percent of the electrical energy consumed in the United States, accounts for 15 percent of electricity used in residences and is therefore a significant component of the average home owner's electrical utility bill. CFLs have the potential to greatly reduce electrical energy costs and, by extension, make homes more affordable. CFLs are simply variations of the linear fluorescent lamps used in a wide variety of residential and commercial buildings. CFLs are actually conventional fluoresecent lamps that have been reduced in size and configured in geometries that can be used in place of incandescent lamps.

Performance

CFL lamps have two distinct advantages over comparable incandescent lamps: a service life of 20,000 hours compared to 750 to 1,000 hours; and they provide the same light output as incandescent bulbs using less than 30 percent of the energy. Thus a 27-watt CFL has the same light output as a 100-watt incandescent bulb. In addition, a CFL produces just 10 percent of the thermal energy of an incandescent bulb, thus lowering cooling costs. A single CFL saves almost $63.00 in electricity and replacement costs over a period of four-and-one-half years, the lifetime of a typical CFL.

The first demonstration of fluorescent lighting took place in April 1938 at the Chicago World's Fair, but the principle of this technology dates back to 1896 when Edison first integrated it into a lamp. It was perfected and mass produced during World War II, initially for commercial and industrial uses. CFL was developed in the 1970s and has been used in Europe for more than 20 years. In Korea and Japan, where there are significant energy shortages and high energy prices, CFL lamps account for about 80 percent of residential lighting. CFL lamps were not significant in the U.S. market until the late 1980s, when electric utilities promoted them through demand-side management programs.

CFL lamps are highly dependent on magnetic or electronic ballasts for the high initial voltage required for starting and regulating their operation. Because of their energy and functional advantages, miniaturized electronic ballasts, which were developed at Lawrence Berkeley Laboratory, are beginning to dominate the CFL market. With these ballasts, CFLs can be connected to dimmers, thus solving one of the early problems with this technology. Additional technical developments improved color rendering and eliminated flickering.

CFL lamps appear at first glance to be a sure technological winner, yet their market penetration is very low. The fundamental reason is the high initial cost. A typical 100-watt incandescent bulb costs just $0.50; the equivalent 27-watt CFL sells for $14.00. For a typical new house with 20 lighting fixtures, CFL lamps would cost $280 (versus $10 for incandescent bulbs). However, CFLs are now being offered by a small but growing number of home builders involved with ENERGY STAR.

A variety of factors are likely to lead to the dominance of CFL lamps in the residential lighting market over the next decade: higher energy prices; price spikes, such as those that recently occurred in southern California; tighter environmental regulations,

especially around major metropolitan areas, to address air quality problems; and recognition of the long-term advantages of energy-efficient housing by financial markets. Awareness will increase through the emergence of government-sponsored programs, such as Energy-Efficient Mortgages and ENERGY STAR. CFL lamps have the potential to become the lighting technology of choice in the future.