PATH
Partnership for Advancing Technology in Housing

TECHNOLOGY ROADMAP: ADVANCED PANELIZED CONSTRUCTION

2003 Progress Report

U.S. Department of Housing and Urban Development
Office of Policy Development and Research

PATH (Partnership for Advancing Technology in Housing) is a private/public effort to develop, demonstrate, and gain widespread market acceptance for the "Next Generation" of American housing. Through the use of new or innovative technologies, the goal of PATH is to improve quality, durability, environmental efficiency, and affordability of tomorrow's homes.
PATH is managed and supported by the U.S. Department of Housing and Urban Development (HUD). In addition, other federal agencies that engage in housing research and technology development are PATH Partners, including the Departments of Energy, Commerce, and Agriculture, as well as the Environmental Protection Agency and the Federal Emergency Management Agency. State and local governments and other participants from the public sector are also partners in PATH. Product manufacturers, home builders, insurance companies, and lenders represent private industry in the PATH Partnership.

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Prepared for:

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Office of Policy Development and Research
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Disclaimer

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Preface

The Partnership for Advancing Technology in Housing (PATH) is pleased to present the *Advanced Panelized Construction Roadmap*. Much progress has been made since the Year 1 Progress report in helping to develop the next generation of advanced panel systems for the benefit of the American home buyer.

The PATH program, administered by HUD, is focused on improving the affordability and value of new and existing homes. Through private and public cooperation, PATH is working to improve energy efficiency, environmental impact, durability and maintenance, hazard resistance, and labor safety relative to new and existing homes. To accomplish this, PATH has identified priority strategies and activities that will enable government and industry to jointly fulfill the PATH mission. We refer to this priority-setting process as roadmapping. The *Advanced Panelized Construction* Roadmap is one of five roadmaps under development to date. The other roadmaps are: 1. *Information Technology to Accelerate and Streamline Home Building* 2. *Whole-House and Building Process Redesign*, 3. *Energy Efficiency in Existing Homes*, and 4. *Technology Roadmapping for Manufactured Housing.*

Panel technologies offer promise to the building industry in several ways. The introduction of advanced factory-built components can create labor efficiencies, reduce cycle time, and improve the overall efficient use of materials. Other benefits include less waste and on-site theft.

We invite manufacturers, builders, trade contractors, researchers, and others to examine this roadmap and encourage their participation in the development and adoption of the next generation of building panel technology.

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PATH PROGRAM GOALS

The Partnership for Advancing Technology in Housing (PATH) encourages the use of technology to improve the affordability and value of new and existing homes. Through public and private efforts in technology research, information dissemination, and barrier analysis, PATH is adding value to seven of the nation's key housing attributes:

- affordability
- energy efficiency
- environmental impact
- quality
- durability and maintenance
- hazard mitigation
- labor safety

As such, four overarching goals have been established that all bear on those attributes:

To remove barriers and facilitate technology development and adoption

PATH will investigate the barriers, including regulatory barriers, that impede innovation, and will actively propose and develop programs to overcome those barriers. This work will guide the other goals and efforts.

To improve technology transfer, development, and adoption through information dissemination

PATH will coordinate dissemination of innovation information directed to the housing industry and consumers.

To advance housing technologies research and foster development of new technology

PATH will support "background" and applied research as well as technology development activities in the housing industry. This research will be complemented by short-term and long-term assessments of specific technologies that are on the market.

To support the program through appropriate management and resource allocations

Partners in the PATH program - U.S. Department of Housing and Urban Development, Department of Energy, Environmental Protection Agency, Department of Agriculture, Department of Commerce, Federal Emergency Management Agency, home builders, researchers, and manufacturers of building materials and products - have long recognized the importance of injecting current and emerging technologies into the home building process. The PATH program has identified many of the relevant technologies and has facilitated implementation of research, pilot, demonstration, and evaluation projects across the United States. In addition, PATH program partners recognize the importance of planning research and setting priorities for technology development that will enable the housing industry to work toward the PATH mission. This priority setting is known as "Roadmapping."

ROADMAPPING PROCESS

The objective of PATH technology roadmapping is to identify technological research in home building to serve as a guide for research investments by government and industry. The PATH Industry Committee (IC), comprised of builders and manufacturers of building products and materials, enabled the development of all technology roadmaps.

As the premier planning activity for PATH's research, the roadmaps dictate the main areas for research and development in PATH's research portfolio (which includes background, applied, and development activities) as well as provide the home building industry with a strategic plan for future technology development. Roadmaps will be provided to private sector interests to guide their technology development and to guide investment in research and development. Through this process, new technologies and additional research work will be generated as the roadmaps are implemented.

The IC initiated the overall roadmapping process during early 2000. A group of 40 builders, material and product suppliers, academics, researchers, and other stakeholders identified and prioritized technologies that hold promise in achieving PATH's goals. The IC then grouped the technologies with the greatest potential benefits into broad portfolios. These portfolios represent three initial technology roadmaps for new home construction. Concurrently, additional roadmaps were initiated by the manufactured housing industry and the remodeling industry to address PATH goals and objectives relevant to these sectors of the home building industry. The result is the following five roadmapping activities currently in different stages of development:

1. *Information Technology to Accelerate and Streamline Home Building*
2. *Whole-House and Building Process Redesign*
3. *Energy Efficiency in Existing Homes*
4. *Advanced Panelized Construction*
5. *Technology Roadmapping for Manufactured Housing*

Each of the roadmaps has a separate report. This report deals specifically with Advanced Panelized Construction.

The Advanced Panelized Construction activities were initiated during a meeting in December 2000. Since that time, a series of activities and meetings of participants have been held to set the framework for the development of the roadmap. In December 2001, the group met in St. Louis to fine-tune a draft of the roadmap and to establish priority strategies and activities. Subsequent input via the internet was obtained from the participants and others over the first few months of 2002. These activities resulted in a Year 1 Progress Report. A set of short-term priorities was also established, many of which PATH has turned into R&D projects.

In December 2002, the group met in Baltimore to better define several of the activities described in the Year 1 Progress Report. Subsequent activities were conducted in early 2003 to get broader input from current and potential users of panel products. This Roadmap is the result of these activities. Although this should be viewed in many ways as a final product, the process of roadmapping will continue. Like any good R&D program, the *Advanced Panelized Construction Roadmap* will be re-examined periodically to measure progress and re-assess the direction of the roadmap.

PATH Roadmapping in Progress

VISION

The vision for Advanced Panelized Construction is to develop building panels that perform multiple functions and integrate multiple tasks into a single process or step. The panels should be accompanied by generic material specifications; provide consistent levels or grades of performance from the basic level to the highest; and be easy to order, deliver, assemble, and integrate into the building process.

Ideally, advanced panels should achieve lower in-place cost of labor, materials, and overhead than the individual parts and tasks they replace. Panels should be equally attractive for use by all types of builders including small volume and large volume production, as well as factory-built homes. Ultimately, advanced panel construction should contribute to PATH's goals through lower in-place costs, increased energy efficiency and durability, and safer means to construct homes.

SITUATION TODAY

Stick-built construction is the predominant type of construction in the U.S. home building industry. The U.S. Bureau of Census estimates that only 2.6% of homes were built completely with panelized systems in 2001. When looking specifically at walls, the Wood Promotion Council has determined that panelized wall construction captures about 8% of the market.

In some sectors of the market, such as production building, panelized wall construction has seen increased use. But, overall, there has not been any discernable upward trend in panel use across the industry over the past five years. This is surprising to many in the building community who expected a tightening labor supply to produce an increase in the use of panels.

Builders and framing contractors use wall panels for a variety of reasons. Some of the more frequently reported benefits include reduced need for skilled labor, shorter installation time, reduced waste, and less risk of theft. Manufacturers often claim that factory-built panels cost less than stick-building a wall, but builders frequently counter that they pay at least as much and usually slightly more when they use panels as opposed to stick building their walls. The benefits of panels to those who currently use them appear to justify any premium in their cost.

Available Products

The wood-framed, open wall panel is the predominant type of panel used for walls. It represents the closest product to a "standard" that exists today. Typically, this panel is built in the factory in nearly the same fashion as one would on-site by using platform framing. Either 2x4 or 2x6 studs are used for the frame. Typically, oriented strand board (OSB) or another sheathing material is applied in the factory. As opposed to other manufactured products, panels are typically built locally by lumber yards or by regional forest product suppliers. There is no dominant national company in the panel business.

Many large volume builders produce panels in their own facilities. Some sell these to other builders.

Open-wall wood panels

A few companies have taken panelized construction beyond the wood-framed, open wall panel. Companies such as Wausau Homes have built factories where they produce the entire home package as components. Others have been producing closed-wall panels that come with an inside and exterior facing or sheathing already in place. Perhaps the best known closed panel is the Structural Insulated Panel (SIP). These are basically a composite sandwich panel that uses a layer of foam insulation with an OSB or other skin on both sides. One advantage of a SIP is the opportunity for a higher overall R-value compared to stick-built construction.

SIPs used in PATH Field evaluation

Other examples of current panel technologies include cold-formed steel panels, precast concrete systems, and Insulating Concrete Forms. These systems are expanding their market share but still are only used in a few percent of homes each year.

Although steel framing is a small part of the overall housing market, panelizing of building walls is not uncommon with steel. This is analogous to the wood-framed, open wall panel system but with steel in place of wood members. Several factory-built steel panels have also appeared on the market in recent years. As an example, the ThermaSteel system incorporates the steel members within a foam insulation panel, thereby creating a thermal break inherent to the panel.

Perhaps the best known concrete panel technology is more often applied to foundations, although they are also being used for above grade walls. One example is by Superior Walls,

Thermasteel wall panel from the PATH Technology Inventory

whose suppliers manufacture a 5000 psi concrete face panel that has concrete studs and a top and bottom plate built into it. A separate concrete footing is not necessary with this system. The bottom plate distributes the load to a gravel base. Foam insulation is built into the panel between the studs and the outside skin to provide a thermal break.

Precast wall panel by Superior Walls from PATH Field evaluation

Others have adapted concrete technology from the transportation industry to homes. A recent example is in Chicago, where Affordable Construction Concepts LLC partnered with a pre-stressed manufacturer of highway soundwalls. The firms worked together to build inter-city homes which featured pre-cast panels that came from the plant with a facade cast to look like brick.

Insulating Concrete Form (ICF) systems are not a panel product in the traditional sense, but they do combine functions of the structure and insulation into a single product. ICFs consist of a foam insulation form into which concrete is cast on-site. They come as blocks, planks, or panels. At least one company produces an ICF that folds flat during shipping.

More advanced panels do exist but their use on homes has been limited to scattered demonstrations. For example, the composite materials industry has been producing honeycomb and foam core panels with fiber-based composite skins for other industry applications including airplanes, subway cars and boats. A small number of companies have attempted to apply these technologies to home building. Perhaps the most significant advances in these industries relate to forming capabilities and finishes.

Honeycomb panel system from US Army Research Lab

Composite materials have been used primarily in flat panel applications. PATH-sponsored technology scanning results are showing that forming, molding, and pultruded processes are now being used to produce panels of various shapes, including panels with built-in flanges or shapes. Several companies have also combined high-end finishes onto honeycomb panels. These products are a step closer to pre-finished, multi-function panels for homes.

Codes and Standards

There are a number of ways to obtain code approval and thus remove one of the significant barriers to the introduction of innovative technologies. Three approaches have been successfully used by building product manufacturers.

Direct code adoption is the approach of submitting a code change to one of the code-writing organizations and thus having your product recognized in the text of a code. Open-wall wood and steel-framed walls fall into this category, since they are often built to the requirements of the locally-adopted code.

A second approach is to obtain a code evaluation report. These reports typically contain the supporting design or testing results and specify installation procedures, spans, connections, and related information. Evaluation reports are accepted as equivalent to code approval by most building code officials.

Like all building products, the manufacturers of more advanced panels and other components are in a period of uncertainty regarding code approval. The merger of the three model building code groups into the International Codes Council (ICC) and the changes that are occurring with the code group's evaluation services will impact some panel products more than others.

Reports from the evaluation services can be viewed online at several locations. These include the BOCA Evaluation Service (www.bocai.org/boca-es), the National Evaluation Service (www.nateval.org), the SBCCI Evaluation Service (www.sbccies.org), and the ICBO Evaluation Service (www.icbo.org/ICBO_ES). These services consolidated in January 2003 into one service under the International Code Council as the ICC Evaluation Service (www.intlcode.org/es). The ICC began accepting applications for evaluation reports in early 2003.

The types of products that are represented by evaluation reports include SIPs, ICFs, and precast concrete systems. As new products are developed by manufacturers, the ICC Evaluation Service will be a necessary participant in getting the product accepted in the marketplace.

A third approach is to develop a consensus standard through ASTM or another

standards-writing organization and then submit it to a building code as a reference standard. One downside to this approach is that it can take 3-5 years or even longer to produce a standard.

Given the wide variety of panels and even the variations within the same type of panels, it can easily be supported that the panel market is anything but standardized. The closest product to a standard is the open-wall wood-framed panel, and there does not appear to be a discernable upward trend in the use of these panels. The situation today will need to change in regard to product types and materials, as well as on the design and approval side, if the vision of the *Advanced Panelized Construction Roadmap* is to be achieved. The next section of this report reviews some of the related barriers that will need to be addressed.

BARRIERS / CHALLENGES

The Advanced Panelized Construction roadmapping group recognized that there are many barriers that must be overcome if we are to make progress toward achieving the vision of this roadmap. Many of the barriers are industry level and apply to other roadmaps and areas of construction as much as they do to the development and adoption of advanced panels. These include the fragmented nature of the home building industry, regulatory requirements, and insufficient training and education. Issues related to barriers and challenges can be divided into two groups - those that describe why today's panel systems have not been more widely adopted and the barriers that must be overcome if we are to develop more advanced panels. Of course, the issues that affect today's panels will also be challenges for developers of advanced panel systems.

Barriers that impact today's panel systems include:

- Lack of familiarity with panels. This relates to the basic understanding of what types of panels exist and their benefits as well as to the need to eliminate negative perceptions about panels. On this later point, the roadmap group cited examples including potential consumer, builder, framer, designer, and specifier skepticism about panels. For example, framing contractors will often cite out of square foundations as a problem that is magnified when using panels. Although these can be real problems, many builders who provided feedback on the roadmap believed these are not large issues and often represent the views of those who just don't want to change current practice. In any case, education and training is the key to overcoming these issues.
- Initial cost of panels do not compare well with stick-built construction and are highly variable by panel type and region. Open-wall, wood panels are the most competitive but even these panels tend to cost slightly more than stick-built construction. The cost difference grows wider with many of the closed-wall systems on the market today. Many builders prefer panels over site-built construction for reasons other than lower initial cost such as less waste, shorter cycle time, and reduced theft.
- Wiring requirements in homes have become much more complicated compared to homes of a decade ago. Home offices, entertainment, computers, and other needs for specialty wiring have driven this trend. Raceway systems, which are often proposed as the solution for running wires when using panels, will face stiffer resistance to adoption due to the increased complexity of wiring in homes.

- Lack of standardization overall and within categories of panel types. For example, the connections for a concrete system are vastly different than with a steel panel. Likewise, most SIPs consist of a foam core with OSB skins. Yet different SIPs can have different connection methods. These limitations will clearly be challenges toward the development of panels that are interchangeable and compatible with other systems or products in the home.

  The issue of standardization has many sides to it. Some manufacturers or industry groups representing them have taken steps to develop standards for their particular product or type of product. Other manufacturers believe their building panels or components should not be standardized to the point where they are sold as commodities. Often, the design of panels must be specific to the home under consideration. The advanced nature of many engineered panel systems will limit the ability to develop prescriptive-type standards for many systems.

There is reason to believe that advanced panel systems will face the same issues elaborated for today's panel systems. However, there are some additional issues that new or innovative technologies will face including:

- Lack of regulatory acceptance and design inefficiencies. The roadmap group believes these issues relate to a combination of our limited understanding of system performance and the lack of training for code officials who evaluate panelized products. Although these issues have always been a problem with products or technologies that are not specifically described in the codes or are otherwise common practice in a given area, the burden of proof will be much higher for the types of products that may be necessary to meet the vision of this roadmap. For example, analytical design methods do not always correlate well with actual performance. This is not so much a problem for "accepted" practices used in today's homes since they have a track-record to rely upon. For advanced panel technologies, we may first have to fill in the gaps in our understanding of conventional practices and apply this knowledge to the design of innovative systems. This will likely require an extensive testing component in the development of new technologies if they are to be competitive in the marketplace with existing practices.
- The reliance of many manufacturers on franchise-type distribution systems. A limited distribution of products may serve an individual manufacturer well, but it tends to restrict growth in the home building market when the distributors are outside the typical channels a builder or trade contractor uses. Further, the design of an engineered system is important to its successful distribution. Some products, with I-joists being a good example, have overcome this by integrating their products and designs into the traditional building supply outlets.
- Potential damage during transportation and handling. As more advanced panels are developed, they will incorporate materials that could be more sensitive to damage from physical movement and moisture. For example, with today's concerns over mold litigation, new products will be held to a high standard in proving they will not create additional problems.
- Factory inspections. Although there are ways to address inspections of factory-built products, there will be a greater responsibility on manufacturers of innovative panels to address inspections that otherwise would have been the responsibility of the builder or trade contractor.

These barriers represent the major issues affecting panel technology and played a significant role in the development of the roadmap that follows.

ROADMAP

OVERVIEW

The participants in this roadmapping process identified three strategies for achieving the vision of the *Advanced Panelized Construction Roadmap*. They are as follows:

1. Develop Advanced Building Panel Design
2. Establish Common Standards, Specifications and Interfaces
3. Improve Production, Delivery Systems, and Site Assembly

Throughout the roadmapping process, the participants generated ideas that addressed both existing panel products and the need to create innovative systems that move the technology closer to the vision of the roadmap. The strategy *Develop Advanced Building Panel Design* is intended to push the development of advanced panels through the identification of new materials and processes. This could include entirely new products or major modifications to existing panel systems. This strategy tends toward revolutionary change and implies a long time frame for product development. However, it does not exclude incremental improvements toward achieving the roadmap's vision.

In developing the second strategy, *Establish Common Standards, Specifications and Interfaces*, the roadmap participants were most concerned with advancing adoption of panels, with greater immediate benefits for existing panel products. However, this strategy is also important for the development of new products, since it will lay the groundwork in terms of performance and functional requirements that both current and future panel systems will need to meet.

The third strategy, *Improve Production, Delivery Systems, and Site Assembly* is similar in its intent to the second strategy. That is, the short-term benefits from activities under this strategy would be most applicable to existing panel systems. However, there is clearly a long-term benefit in this strategy for all types of panels.

With the last two strategies, there is an underlying assumption that panels will be more widely accepted if there are improvements in the design and infrastructure system. Thus, these two strategies were derived directly from the barriers that relate to a lack of standardization and training.

Throughout the roadmap process, a diverse group created a healthy debate over which direction the roadmap should take and which strategies should be the highest priorities. Among the tough questions asked were: Should we work on improving or even promoting existing panel systems as the primary solution? Or should we start from scratch and develop a panel from the basic performance and functional requirements? Should we focus on panels that can be used for multiple applications (i.e., floors, walls, and roofs from the same panel)? Or should we focus on one part of the home such as new roof panel technology?

Follow-up activities initiated during 2002 and continued into early 2003 helped to address some of these questions. The roadmap group, along with others in the industry, weighed in on the importance of various approaches during this time frame. From the input the reviewers provided, it is clear that the industry views all of the activities as important. However, in an effort to provide a starting point for the roadmap, the group recommended that PATH focus its near-term attention on the improvement and development of panel technology for load-bearing exterior walls.

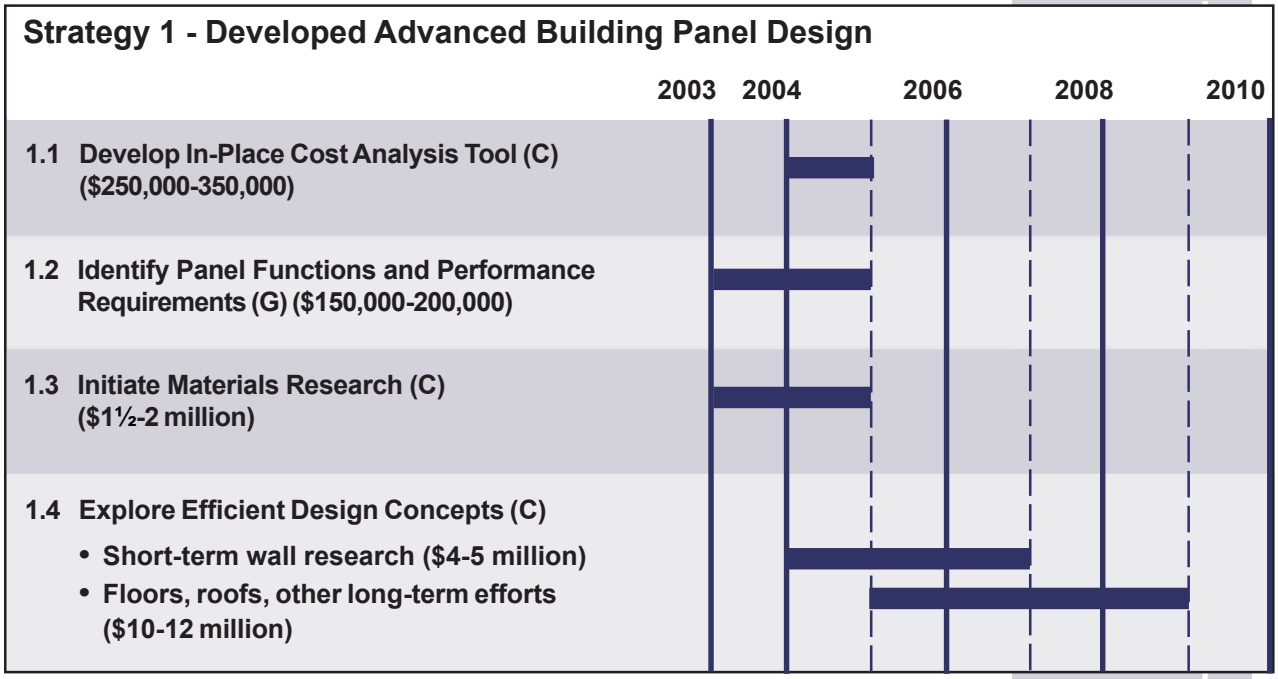
The emphasis on technology improvement and development implies a somewhat higher priority on the first two strategies than the third strategy. At the same time, the participants viewed Strategies 1 and 2 as equally important. Because much of Strategy 3 depends upon the results of Strategies 1 and 2, it is by nature a lower short-term priority. This is reflected in the schedule of activities which shows Strategy 3 activities starting in the later years of the PATH program.

Some of the feedback from end users obtained outside of the roadmap meetings questioned the emphasis on walls. Although all participants agreed that a good wall panel system could improve construction greatly, many builders and trade contractors tended to believe there are less barriers and greater opportunities with floors and roofs.

The roadmap that follows attempts to take all of the comments into consideration. PATH is taking steps to implement an initial set of projects from this roadmap. Activities will expand to eventually address the complete list of projects under each strategy as funding and cooperative R&D partners are identified.

1 Develop Advanced Building Panel Design

The *Advanced Panelized Construction Roadmap* working group identified the need to pursue technological research and related activities that will result in the development of advanced, adaptable, standardized panels that achieve multiple functions for walls, roofs, and floors of a building. The group established a short-term priority to focus on wall panels. This strategy may require the use of multiple materials in a composite structure, or it may be possible to develop homogeneous materials that serve the same functions. Finding these materials will require searching beyond the traditional building industry. The approach for achieving this strategy is contained in the following steps and is shown graphically in Figure 1.



Note: Letter designation after each activity refers to likely funding sources as follows: G=Government, P=Private Sector, C=Combination

Figure 1

The ultimate goal of this strategy is to develop efficient systems and designs as defined in activity 1.4 for use by the building industry. The activities in 1.1, 1.2 and 1.3 should be completed first. Thus, the four activities under this strategy should be conducted in a linear fashion. The lone exception is that 1.1 and 1.2 could be conducted simultaneously.

1.1 Develop In-Place Cost Analysis Tool

An initial step in the development of advanced panels is to enable manufacturers to determine a baseline of today's building practices in order to establish a target for their own costs. The roadmap group determined that a tool that describes the average cost of construction for a typical home placed in different locations would be highly valuable. Manufacturers should be able to determine the range of costs

for different phases of construction such as rough-in or finish stages. Material and installation costs should both be apparent in the tool. The tool should include a framework for manufacturers to input the costs of their system to compare with conventional construction.

1.2 Identify Panel Functions and Performance Requirements

An important step in the development of an advanced panel is to identify the various functions that must be served by wall, floor, and roof systems. Panel functions are interdependent on their associated performance requirements. Thus, it will be necessary to identify functions and performance requirements as part of the same process. The identification of performance requirements is necessary prior to the exploration of efficient design concepts as described in 1.4. It is also a key activity in the second strategy to this roadmap, *Establish Common Standards, Specifications and Interfaces*. In addition, activity 1.2 should be closely linked to the activity *Define Expected Performance Requirements* identified in Section 2.1 of this roadmap.

Once functional and performance requirements are identified, they should be analyzed to identify common requirements that all panel types would need to meet as well as the requirements distinct to specific types of panels. Particular attention should be paid to the way that panels interface with each other and other parts of the structure and finish.

1.3 Initiate Materials Research

Research should be initiated to identify materials that are candidates for meeting specific functions and performance attributes identified in 1.2 above. This activity will result in concepts and ideas that can be the basis for longer-term research to eventually develop advanced panel systems. PATH will need to bring manufacturers from other industries into these efforts. Much of this can build on the scanning activities being conducted by PATH to identify candidate technologies. Partnerships should be formed to facilitate the development of panel systems and to set the stage for efficient design concepts as described in 1.4.

1.4 Explore Efficient Design Concepts

This set of activities will build on the materials research and the identification of functional and performance requirements to facilitate design concepts that will work efficiently in the field. The group stressed the importance of coordinating efforts of this task with those from the PATH *Whole-House and Building Process Redesign Roadmap*. The group identified a variety of projects that could be undertaken, but ultimately suggested the short-term work should focus on wall panels. Other recommended long-term project ideas include:

- Roof panel systems with high insulation levels and pre-finished exterior surfaces.
- Roof panels capable of wider spans and incorporating advanced features such as photo-voltaics in the roof surface.

- High insulation wall panels designed to take utility installation out of the critical path.
- Floor panels that provide structural support, a subfloor, and finish surfaces, and that allow for ease of utility installation.

2 Establish Common Standards, Specifications, and Interfaces

The objectives of this strategy are to develop performance requirements at various levels and engineering methods to analyze, design, and specify panels systems. This should include connection and interface protocols or standards. This strategy will require activities to address code and regulatory issues.

The group's emphasis was on improving the support system for panel products (e.g., approaches or tools that make it easier or more efficient to design, approve, and use panels). Central to this is the desire to develop standards that will enable panels to be interchangeable with each other. This is, in effect, an effort to standardize as many parts of different systems as is possible and practical. The roadmap group's view is that these activities will help panel products to work better together and with the products they surround.

The Roadmap for implementing this strategy calls for activities in six distinct areas as shown in Figure 2. For the most part, the first three activities under this strategy are geared toward creating a baseline for the performance that we accept today for conventional construction. The goal is to better understand current practice and use this understanding to set expected performance requirements for new panel technologies. Once these three initial activities are completed, we will then be in a position under activity 2.4 to model behavior of specific panel systems under the given performance requirements. Likewise, the first four activities are prerequisites for panel-specific testing in 2.5 and development of standards in activity 2.6.

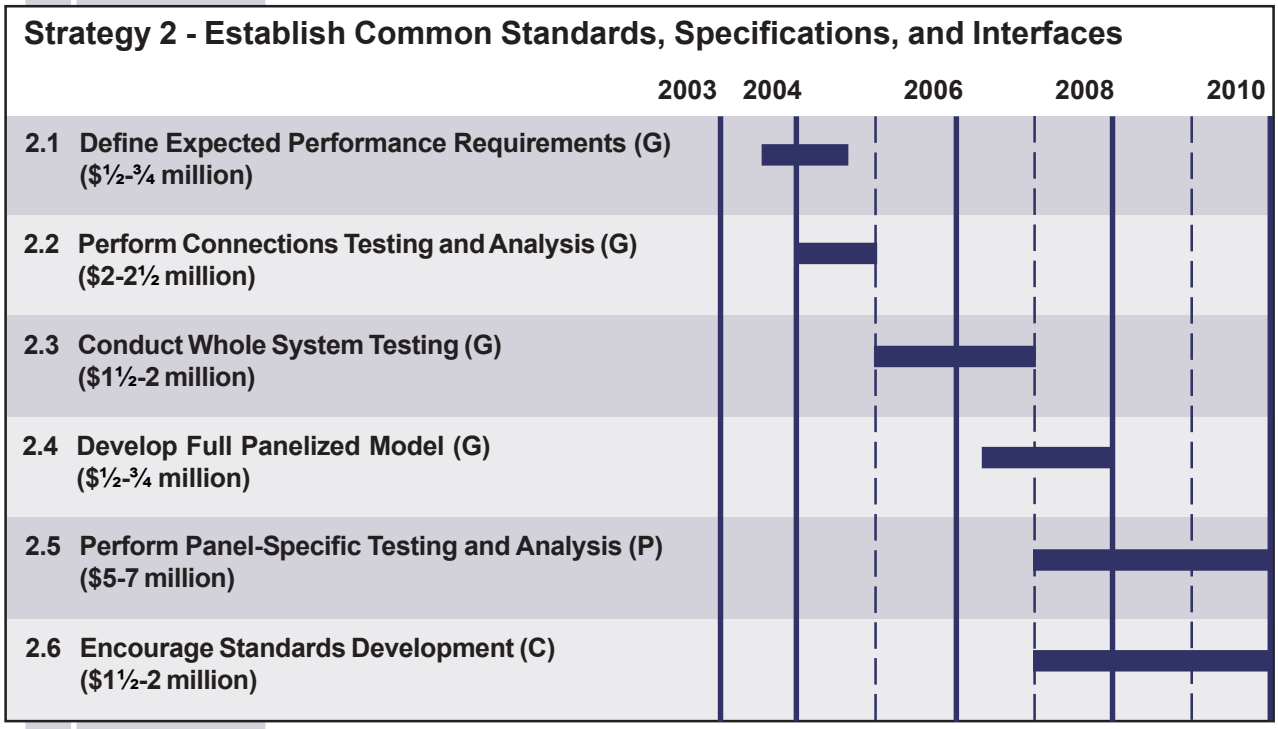


Figure 2

Note: Letter designation after each activity refers to likely funding sources as follows: G=Government, P=Private Sector, C=Combination

2.1 Define Expected Performance Requirements

If panelized construction is to match up with current prescriptive methods, we must first clearly understand the performance of today's practices. One activity is to conduct a review of the known requirements including codes and standards that guide building design. From past experience, we know that many of these requirements are overly conservative or otherwise contain gaps. Fortunately, some of the research community has been focused in recent years on better understanding these issues as they relate to housing and have been working to fill these gaps.

The research that has been completed or is on-going needs to be assembled or otherwise brought together for the benefit of the advanced panelized roadmap participants. The group suggested a forum as one possibility for bringing the research together. Once our baseline understanding of the performance of conventional construction is better understood, then the gaps can be addressed through analysis and testing as defined in the next two activities.

2.2 Perform Connections Testing and Analysis

Analysis will need to be conducted to identify the performance of elements in a panel system. Where analytical methods are insufficient to accurately characterize an element, testing of specific elements will yield information on the strength of the connector and its interface with the panel. Such information will then be compared to "systems" tests conducted under Activity 2.3 to determine system factors that are not typically recognized in design approaches. This activity should initially focus on conventional methods used today and then be expanded to cover the broad range of methods that can be applied to panels manufactured from different materials.

2.3 Conduct Whole System Testing

The panel systems addressed at the element level in Activity 2.2 need to be further tested to identify their performance as part of a larger building component. For example, a full-scale wall with corners and floor attachments will typically perform better than performance determined by analytical methods. The results of this testing will allow for the development of "system" factors which would be used in developing design models.

2.4 Develop Full Panelized Model

Once a systematic analysis approach based on whole structural systems is tested and verified, a simplified, panel-specific model needs to be developed. This model should follow the approach taken by the truss industry where the analytical backbone resides in the public domain.

The front end of the model could address common design elements such as the determination of design loads. It could consist of an accounting system for gravity loads and also address a variety of design (building) configurations for lateral loads. Then, commercial entities can develop customized approaches tailored to specific applications and materials. The model could also address the full design for

commodity-based products. It could be built to allow add-on modules that address the design of panels made from more advanced materials. The inputs for more advanced or proprietary materials could be derived from panel-specific testing as described in Activity 2.5.

2.5 Perform Panel-Specific Testing and Analysis

In order to extend the model above to more-advanced panels, the manufacturers or others will need to conduct testing and/or analysis specific to their panel technology. This information will need to be integrated into the model in Activity 2.4 to allow users and specifiers of the panels to design them for the homes they build.

2.6 Encourage Standards Development

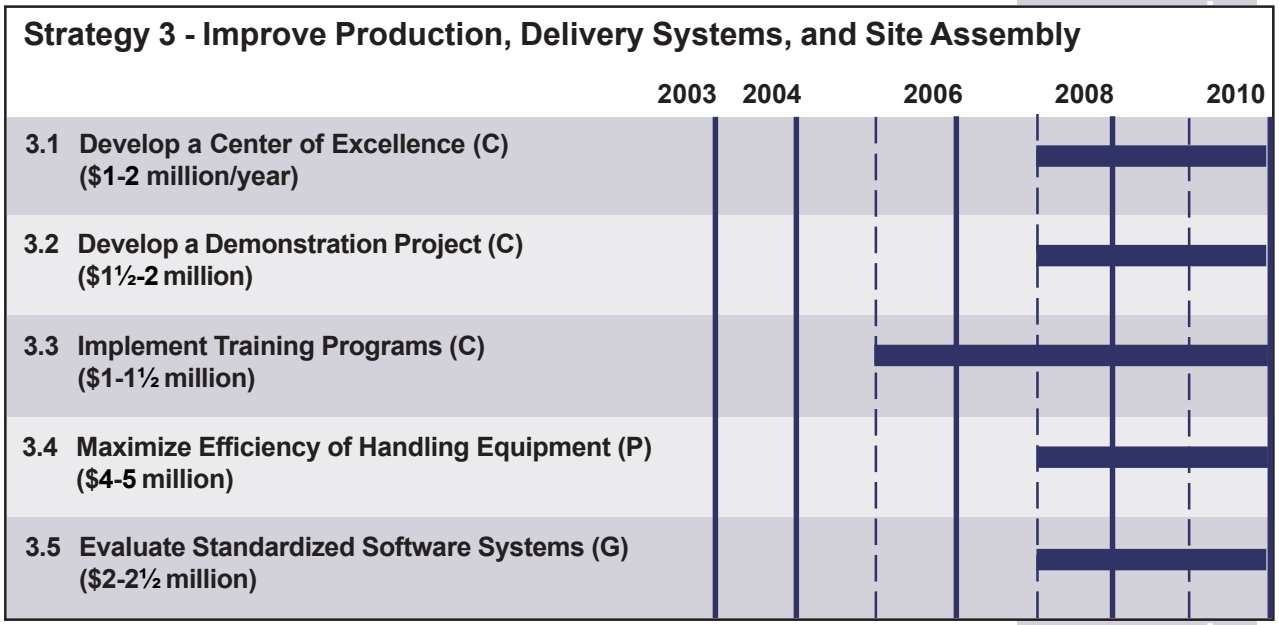
Standards for panels, including connections, sizes, performance, and specifications, will facilitate the application of panels more broadly across the industry by making them easier to incorporate in designs, and less complicated to distribute. Standards will also make it easier to train field personnel.

Development of standards will require extensive coordination with consensus standards-writing organizations in the initial stages to set up specific standards activities. To be successful, this set of activities will also need to have an extensive dissemination component to get recognition of the standards by industry.

Some of these actions will require significant effort and are very closely dependent upon other activities. For example, the scope of the testing and analysis efforts will likely be influenced as much by the questions raised during the standards-writing process as by technical performance or construction issues.

3 Improve Production, Delivery Systems, and Site Assembly

The objective for this strategy is to create a more effective and efficient production, delivery, and site assembly process for panelized building systems. Improvements in this area will be made possible by technological advancements in the panel design and standardization topics covered in the first two strategies. Activities necessary to successfully complete this strategy are shown graphically in Figure 3.



Note: Letter designation after each activity refers to likely funding sources as follows: G=Government, P=Private Sector, C=Combination

Figure 3

Although activity 3.1 is important and would provide a central resource for the industry, it was the lowest short-term priority in this roadmap. It also will require a significant amount of the overall PATH funding to establish a center of excellence. In the later years, private funding could support on-going activities of the center. The tasks that follow in 3.2 through 3.5 could be conducted through existing organizations involved in PATH and other building-related private and public programs, without the need to create a new entity. There is no particular order or priority to these activities. However, the training in 3.3 could be implemented as soon as results from Strategies 1 and 2 start to become available.

3.1 Develop a Center of Excellence

A central resource for showcasing breakthroughs in production, delivery, and site assembly for panelized building systems would help to accelerate innovation. Innovative connection details and panel designs can be evaluated to determine

their impact on production efficiency, delivery cost and efficiency, and site assembly techniques. This center could serve as a resource for builders, product manufacturers, and trade contractors.

3.2 Develop a Demonstration Project

New techniques for designing, manufacturing, transporting, and setting building panels can be showcased in demonstration projects around the country involving builders, trade contractors, and panel manufacturers or suppliers. The emphasis during these activities should be on evaluation of labor efficiencies and overall costs.

3.3 Implement Training Programs

As new building panel designs, production processes, and installation techniques gain acceptance, the builders and trades need training to understand how to maximize the efficiency of on-site production. Training materials will need to be developed and delivered to the users of panel products.

3.4 Maximize the Efficiency of Handling Equipment

Although, it is becoming more common to see heavy equipment on a residential job site, most builders still try to avoid cranes altogether or minimize their time on the work site. Thus, the use of cranes for panel installation can add significantly to overall cost, especially if required for extended periods of time. Techniques for improving the efficiency of panel handling and erection on-site could lead to lower overall production costs. These techniques should be identified and worked into the demonstrations in 3.2.

3.5 Evaluate Standardized Software Systems

New software for designing panelized systems and managing the overall production process must be identified and evaluated to determine how effectively it facilitates product design, manufacture, and erection. Improvements to software could be undertaken as necessary to specifically address panelization.

Status of Roadmap Implementation Activities

The publication of a roadmap is only the beginning of a process that will ultimately lead to achievement of the PATH goals. The implementation and successful execution of the strategies and activities are the next steps. To date, PATH has made great strides in this area. Relative to the *Advanced Panelized Construction Roadmap*, the following activities have been completed or are now underway.

Activities relative to Strategy 1 – Develop Advanced Building Panel Design

- In early 2003, PATH conducted a series of forums and interviews with builders to help identify end-user functions. The forums were targeted to builders and trade contractors. This information will be used in the development of performance requirements.
- Initiation of materials research has been an ongoing part of PATH since its inception through a series of "technology scanning" activities. In 2002 and 2003, the focus of the technology scanning was shifted to emphasize identification of technologies that could assist in the achievement of the visions outlined in the roadmaps. Results of scanning directly related to this and other roadmaps are available on the PATH web site.

Activities related to Strategy 2 – Establish Common Standards, Specifications, and Interfaces

- As cited above for Strategy 1, preliminary assessment of panel functions for walls was initiated in 2003 to help define the scope of the performance requirement activities.
- The PATH program issued an RFP in early 2003 to solicit proposals for a project to define the expected performance requirements for wall panels. The project is expected to be complete in mid 2004.

Activities related to Strategy 3 – Improve Production, Delivery Systems, and Site Assembly

These activities will begin in later stages of the PATH program.

Future Roadmap Activities

Technology roadmapping has been employed by many public and private groups to establish strategies and priorities across a broad range of topics. In order to be successfully implemented, a roadmap should be viewed as a living document, always subject to revision in order to reflect accomplishments, technological changes, and even changes in priorities due to outside influences.

In some ways, the *Advanced Panelized Construction Roadmap* has been easier than the other PATH Roadmaps to bring to the point where implementation can go forward. This is primarily because panelization, though not an uncomplicated topic, is much more narrowly-defined than *Whole House and Building Process Redesign*, *Energy Efficiency in Existing Homes*, and the other PATH Roadmaps under development. None-the-less, in keeping with the need to continually re-evaluate a roadmap, the following future activities are recommended for the *Advanced Panelized Construction Roadmap*:

- As projects under this roadmap are completed, the PATH Industry Committee (IC) should review the results and work with HUD and other participants to ensure effective dissemination of results.
- Similarly, results of projects from other related roadmaps, particularly the *Whole House and Building Process Redesign Roadmap*, should be coordinated with the activities under the *Advanced Panelized Construction Roadmap*.
- A periodic (at least annual) assessment of the progress on roadmap strategies and activities should be prepared and presented to the IC.
- The Roadmap Working Group members who helped develop this report should convene at least once every 18-24 months to review progress and make appropriate revisions to this document.

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