PATH

Partnership for Advancing Technology in Housing

Technology Roadmap:

Advanced Panelized Construction

Year One Progress Report

U.S. Department of Housing and Urban Development

PD&R

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, all 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 (EPA) and the Federal Emergency Management Agency (FEMA). 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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PATH

PARTNERSHIP FOR ADVANCING TECHNOLOGY IN HOUSING

TECHNOLOGY ROADMAP:

ADVANCED PANELIZED CONSTRUCTION

Year One Progress Report

Prepared for:

U.S. Department of Housing and Urban Development
Office of Policy Development and Research
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About the NAHB Research Center

The NAHB Research Center, located in Upper Marlboro, Md., is known as America's Housing Technology and Information Resource. In its nearly 40 years of service to the home building industry, the Research Center has provided product research and building process improvements that have been widely adopted by home builders throughout the United States. The Research Center carries out extensive programs of information dissemination and interchange among members of the home building industry and between the industry and the public.

Disclaimer

FOREWORD

This document, *PATH Technology Roadmap: Advanced Panelized Construction*, is one in a series of technology roadmaps created to serve as guides to help the housing industry make decisions about research and development investments.

The Partnership for Advancing Technology in Housing (PATH), administered by the Department of Housing and Urban Development, is focused on improving the affordability and value of new and existing homes. Through public and private efforts, PATH is working to improve affordability, energy efficiency, environmental impact, quality, durability and maintenance, hazard mitigation, and labor safety. To accomplish this, PATH has identified research and established priorities for technology development that will enable the home building industry to work toward the PATH mission. This priority setting process, known as "Roadmapping," has brought together many industry stakeholders, including builders, remodelers, trade contractors, material and product suppliers, financial representatives, codes and standards officials, and public sector R&D sponsors. To date, the group's work has led to the development of three technology roadmaps: *Information Technology to Accelerate and Streamline Home Building*, *Advanced Panelized Construction*, and *Whole House and Building Process Redesign*.

This document focuses specifically on panelized construction systems and processes. Advanced panelized construction can bring the benefits of mass production into the highly customized residential market through the pre-production of components and integration of parts into subsystems. This technology roadmap identifies research needs to develop advanced building panel design; establish common standards, specifications, and interfaces; and improve production, delivery systems, and site assembly.

By addressing these issues through research, the home building industry will continue to play a key role in providing affordable, durable housing for America's families.

Lawrence L. Thompson
General Deputy Assistant Secretary for
Policy Development and Research

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PATH PROGRAM GOALS

The Partnership for Advancing Technology in Housing (PATH) advances technology in the home building industry 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, and labor safety.

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

- **To determine the needs for improved housing technology development and provide relevant strategic services.**

  PATH will investigate the institutional barriers that impede innovation; will propose alternative, improved, or negotiated services to overcome those barriers; and will develop networks and agreement among participants to implement these services.

- **To develop new housing technologies.**

  PATH will support and perform technological research at all R&D levels of the home building supply chain with governmental and industrial funds and resources.

- **To disseminate new and existing technological information.**

  PATH will coordinate dissemination of innovation information (both for specific technologies and for industry-wide technological information) that remains unbiased, technically accurate, and relevant to specific housing audiences to increase the familiarity with, availability, and use of technologies in the home building and homeowner communities.

Partners in the PATH program—the U.S. Departments of Housing and Urban Development (HUD) and Energy (DOE), the Environmental Protection Agency (EPA), the Department of Agriculture (DOA), the Department of Commerce, the Federal Emergency Management Agency (FEMA), 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 home building 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 technology areas for immediate technological research in home building to serve as a guide for research investments by government and industry. The PATH Industry Steering Committee (ISC), comprised of builders and manufacturers of building products and materials, oversees the development of all technology roadmaps.

As the primary 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 approved by the PATH ISC will be provided to private sector interests to guide their technology development and to the government to guide its investment in research and development. Through this process, new technologies and additional research work will be generated as the roadmaps are implemented.

The ISC initiated the roadmapping process during the first quarter of 2000. A group of 40 builders, materials and products suppliers, academicians, researchers, and other stakeholders identified and rank ordered technologies that hold the promise of guiding PATH's research. The ISC then assembled the technologies with the highest potential benefits into three technology portfolios as follows:

- *Information Technology to Accelerate and Streamline Home Building;*
- *Advanced Panelized Construction;* and
- *Whole House and Building Process Redesign*.

The PATH ISC recommended development of technology roadmaps for each of the three areas, with *Information Technology* initiated in November 2000, *Advanced Panelized Construction* in December 2000, and *Whole House* in March 2001.

The roadmapping reports are available on both the PATH website (www.pathnet.org) and the NAHB Research Center's ToolBase Services website (www.toolbase.org).

This report deals specifically with *Advanced Panelized Construction*.

VISION

The vision for *Advanced Panelized Construction* is to develop common building panels that perform multiple functions and integrate multiple tasks using non-specific material specifications, that deliver consistent levels or grades of performance from basic to high performance, and are easy to order, deliver, assemble, and integrate with the building process.

Ideally, the building panel achieves lower in-place cost (i.e., materials, labor, overhead) than the individual pieces and individual tasks it replaces or integrates.

The vision applies and extends to small builders, high-volume production builders, and manufactured home producers. It brings progress and contributions to each of the PATH goals via lower in-place cost, increased energy efficiency and durability, and safer means to construct the building envelope.

Home building, a critical component of the U.S. economy, represents about $230 billion, or four percent, annually of the nation's economic activity. Home building is the seventh largest U.S. industry. The U.S. home building industry remains highly fragmented and is typified by small builders managing many small trade contractors, in addition to larger production builders and manufactured housing companies. In 1999, 1.3 million single-family (including manufactured housing) and 300,000 multifamily housing starts generated more than 3.5 million jobs.

It is estimated that 790,000 homes constructed in 1999 had a basic form of component or panelized construction, predominantly roof trusses. The wide adoption and use of roof trusses have brought some significant benefits versus individually framed rafters. Roof trusses were found in approximately 60 percent of the homes in 1999, yet panelized systems represented only 0.2 percent of the expenditures in new housing. The existing market for panelized structures represents approximately 5 percent of all wall systems.

Panelized construction is a method where the building is subdivided into basic planar elements that are typically constructed under some form of mass production then shipped directly to the construction site and assembled into the finished structure. There are many advantages to panelizing structures, ranging from cost reductions possible through mass production, to ease of assembly, to lower skill sets required for field construction, to quality control and worker safety. There are also disadvantages, which include shipping, site equipment requirements, market perceptions, engineering requirements, and connection complexity. Panelized construction lends itself to evaluation of the components and their resultant assembly with respect to code, which would minimize the time and resources necessary to secure building code approval at the state and local levels. If, however, panelized construction components are not evaluated in this manner, it is likely that additional time and resources will be needed to secure their approval.

Most of the existing panelized products are traditional "wood-based" structures in the wall panel area, whereas wall panel design was born out of taking traditional wood-based site materials and processes back into a factory or controlled setting. Wall panels are the most common area of building today beginning to employ panelized components. To date, very little has been seen in the way of floor or roof panel systems. Some progress is being made in foundation panel systems, predominantly precast panels (e.g., Superior Walls).

Several wall "panelizers" are simply framing walls off-site locally with 2x dimension lumber and sheathing them before sending them to the job site for placement and installation. These panelizers have moved the framer from job site to the lumber yard or other industrial park building. Others are going a step further to add insulation or even air barriers, such as house wrap, to the panel.

Wausau Homes (of Wausau, Wis.) and others have built factories and have begun to employ various manufacturing practices to panelized construction, selling them to smaller builders. Large national builders, such as Toll Brothers, build many of their own components in central locations and then ship them to sites. Manufactured housing companies like Fleetwood or Champion build walls complete with finishes, and then assemble them inside a factory.

Most of these companies are still working from custom plans or narrowly limited plans and making each panel for specific job prints. Custom shop drawings and custom set-ups for each batch of wall panels are required.

Incremental thinking and engineering refinements have led to better versions and what is commonly known as the present "state" of wall panels—Structural Insulated Panel Systems (SIPS). SIPS are made of foam sandwiched between sheets of oriented strand board (OSB) or similar sheet good. SIPS have begun to emerge as a viable alternative to stick framing walls on the job site, or even producing stick framed walls at some off-site location. They can reduce onsite labor requirements and the amount of material needed, while improving the energy efficiency of the wall assembly. They fabricate simply (i.e., cutting openings for doors, windows), ship flat, and assemble in a comparatively simple manner using traditional carpentry techniques. Many SIPS manufacturers also prepare documentation verifying code compliance and secure evaluation of those documents by organizations such as the National Evaluation Service (NES). These evaluation reports are then used to support code compliance for each building where SIPS are used to reduce the time and complexity that would otherwise be associated with the approval process.

Enhancing today's products is a promising opportunity for market development in the panelized sector, but it is not the only route to growth.

One important factor impeding the market penetration of panelized systems for residential construction is the lack of well-developed, generally accepted performance standards and product specifications that, when followed, will satisfy stated code and other requirements. Individual manufacturers have focused on development, refinement, and protection of their own proprietary designs, and are marketing those as complete packages in addition to securing the necessary code approvals for them. This approach can be economically beneficial from a manufacturer's standpoint, but it is not conducive to rapid industry adoption and use.

The complexity in the current environment is evident from a review of model code evaluation reports. These reports can be retrieved online from sources such as the NES (www.nateval.org) or the BOCA Evaluation Service (www.boca-es.org). Individual manufacturers pay a fee for an evaluation report. Such a report verifies that calculations, tests, and other documentation the manufacturer or their consultants have prepared on the products they produce or license support conformance to model code requirements and any limitations on the use of the product. These reports provide state and local code officials with evidence that the product or system has been tested, reviewed, and found to be an acceptable alternative method of construction to those specified in the codes. Such reports also provide the builder, specifier, and other user of the product with a ready-made submittal for review by the code official and minimize the need for the product manufacturer to prepare custom documentation each time the product is to be used. Evaluation reports also include conditions of use for the product or system, which qualify the report and highlight some important limitations imposed by the codes on panel products.

For example, the conditions of use that permit applications for buildings using essentially any SIP system must be accompanied with signed, sealed, structural calculations from a registered architect or engineer. Panels with openings (such as for windows and doors) typically are not within the scope of the report, requiring additional building-specific analysis on every job. Connection details between panelized components often are excluded specifically from the scope of the report.

There is no such thing as a standardized, generic, "deemed-to-comply" panel variant that can be used without incurring the added cost of case-by-case engineering, unlike the way conventional wood framing, concrete, and, more recently, steel framing are allowed to be constructed. This is because there is a lack of prescriptive code provisions and standards to govern the application of such panels in a building, such that their application for a particular use must be verified through such engineering. By the same token, it is difficult for a builder to know whether it is possible to "mix and match" different types of panels from different sources and be assured they will work together (or even fit together) as intended in the finished building.

As is the case for acceptability of most new products, acceptability for panelized systems is varied by region. One universal term that makes any adoption faster is profitability. If systems can be developed and demonstrated to be more profitable while giving enhanced adaptability, flexibility, reliability, and durability benefits, the adoption rate will be exponential.

The origins of plywood or OSB development were really about combining multiple functions into a single standardized product (i.e., sheets) that could be used in floors, roofs, walls, and foundations. Many manufacturers make plywood or OSB according to prescribed standards, grades, and specifications. Other minor evolutions (i.e., roof truss processes and engineering now migrating into floor trusses and web trusses) show us that the thinking in one part of the building envelope can lend itself to other parts of the building.

While continuing efforts to maximize and incrementally evolve SIPs, minimal energy or effort has been put into starting from a blank sheet and designing flexible, standardized, multiple-use panels that achieve multiple functions consistently across walls, floors, roof decks, or all the planar (i.e., horizontal, vertical, or angled) surfaces of a building envelope.

Many of the challenges for achieving advances in panelized construction are similar to those noted in other roadmapping papers (i.e., regulatory, education and training, and industry fragmentation). The group also identified several reasons why panelized construction does not hold a greater market share today:

- Lack of flexibility once panels are made, despite their high flexibility in the design stage (e.g., how an out-of-square foundation complicates panel erection);
- Variable economic advantages depending on cost of labor in specific market areas;
- Difficulty moving inspections to the factory, as field inspections of connections would still be necessary;
- Low acceptance of raceway wiring, which would simplify closed panel systems;
- Sensitivity to damage during transportation and handling;
- Limited availability of panelized systems in retail locations where builders and their customers purchase building products;
- Lack of education and training on the installation of panelized systems;
- Builder, architect, engineer, and specifier reluctance to use panelized systems;
- End market (customer) skepticism; and
- Lack of training for code officials who evaluate the benefits of panelized systems.

Standardization of dimensions to facilitate interchangeability was discussed as a way to increase the acceptance of panelized products. On one hand, standardization leads to interchangeability among components so that a builder is less reliant on proprietary systems. The analogy for compatibility standards can be found by looking at nuts and bolts. Recognized standards for dimensions and thread pitch geometry allow bolts from one manufacturer to be used with corresponding nuts from another manufacturer. Standardized tensile strength grades allow buyers to specify the level of performance required in their applications, regardless of who manufactures the connectors. This approach has proven far superior to a system where proprietary nut-and-bolt combinations must always be used together.

On the other hand, standardization is not a panacea for the panel sector. As individual products become more technically advanced or complex, they may not fit into the standardized approach, at least not until the standards "catch up." Until a large part of the market achieves better standardization, any wholesale shift toward panelized systems remains unlikely.

Some manufacturers recognize this type of need and develop standards on their own. More often, however, it is large buyers who demand some degree of standardization across alternative sources of supply, leaving manufacturers to compete on service or advanced product features within a standardized framework. Standardization in the panelized sector may have lagged due to the lack of large single buyers or an organized community of buyers.

Other challenges and barriers reflect differences in applicable code requirements resulting in part from geographic or climatic variations, the reluctance of producers to see today's products evolve into commodities where price competition is strong, and the reliance of many producers on franchise-type arrangements with semi-custom production rather than third-party distribution networks and mass marketing.

Analytical predictions do not correlate well with the performance demonstrated in the built environment, so we are forced to test proposed panelized components and their interconnections directly against standard prescriptive designs. This testing is expensive and time consuming, and it limits the application of proposed systems to conform to existing designs and structures.

ROADMAP

OVERVIEW

Three elements, described below, were identified as those needed to achieve the vision for *Advanced Panelized Construction*. Participants in the roadmapping process originally identified specific technologies that could be viewed as starting points for subsequent steps in the process, but they ultimately decided to create a vision and various strategies that could make that vision a reality. Participants also identified the types of activities that could be carried out under each strategy.

The overall roadmap strategies needed to achieve the vision for *Advanced Panelized Construction* can be categorized in numerous ways. One categorization relates to the state of development of panel products. For example, the advanced building panel design element is focused on developing "new" technology that can meet the vision. This could include entirely new products or materials, or major modifications of existing materials. This strategy tends toward revolutionary change and implies a longer timeframe for product development.

The other two strategies, although they should eventually apply to existing and future products, tend to offer the most benefit for existing products and materials. There is somewhat of an underlying assumption with these two elements that panels will be more widely accepted if there are improvements in the design and infrastructure system.

Each of the strategies presented in this report will be the subject of continued working sessions to further refine the Roadmap for industry and government R&D planning. The next round of roadmapping for *Advanced Panelized Construction* will most likely address more of the specific technologies that can be developed to help the industry meet the PATH goals.

The three strategies for achieving the vision for *Advanced Panelized Construction*, and the corresponding benefits of each, follow.

1. Design, engineer, and develop adaptable, standardized, multiple-use panels that achieve multiple functions for walls, floors, or roof surfaces of a building envelope.

   Benefits

   ✔ (Building panels developed as floor and roof panels) Will reduce the amount of time workers spend in situations where most injuries due to falls occur.

2. Develop performance requirements at various levels and engineering methods to analyze, design, and specify panel systems, including connection and interface protocols and standards for ease of use.

   Benefits

   ✔ Will yield durability and energy efficiency.

   ✔ Will increase the potential for uniform measurement and performance ratings or levels for the entire building envelope.

3. Create a more effective and efficient production, delivery, and site assembly process for panelized building systems.

   Benefits

   ✔ Will use less labor, at lower wages, using a broader pool of labor.

   ✔ Will require less onsite storage than is required for lumber today.

   ✔ Will lower costs by reducing theft and vandalism.

   ✔ Will reduce costs by shortening the construction cycle (and the chance of weather delays).

   ✔ Will generate less scrap and waste.

   ✔ Will improve the quality and durability over site-piece construction.

The three overall roadmap elements needed to achieve the vision for *Advanced Panelized Construction* are discussed in the pages that follow.

1 DEVELOP ADVANCED BUILDING PANEL DESIGN

The Advanced Panelized Construction working group identified the primary objective for this Roadmap as to design, engineer, and develop adaptable, standardized, multiple-use panels that achieve multiple functions for walls, floors, or roof surfaces of a building envelope. The working group concluded that in-place costs (materials and labor) for panel systems should be lower than the in-place costs of the combined materials and labor that the panels replace.

This strategy will likely require the use and integration of multiple materials according to the function needed, but it may also be possible to develop a homogenous material. Materials and processes may involve looking beyond the traditional building industry for technology and ideas.

The Roadmap for implementing this strategy contains the steps shown in Figure 1 and is summarized below.

1.1 Develop In-Place Cost Analysis Tool

The first step is to develop a cost-in-place analysis tool for existing panel products to establish a baseline. This tool will provide the basis for determining in-place cost for any new development in panel design.

1.2 Identify Panel Function

The next part of the strategy is to identify the various and respective functions needed in wall, floor, roof, and foundation panel systems. Then find the common functions and attributes, and the distinctive functions and attributes. Also, determine the relationship and interface attributes between each.

1.3 Initiate Materials Research

Once the functions are identified, it will be necessary to initiate materials research that begins to identify materials or composites of materials that are candidates for fulfilling specific attributes or functions outlined in the function identification strategy. This will involve brainstorming and developing ideas and concepts that can feed longer term research of material composites.

1.4 Explore Efficient Design Concepts

The final phase of this strategy is to link with whole house projects and with panel performance standards and specifications projects, to explore efficient design concepts that could adapt to multiple material uses but common design attributes. This would include linking with assembly and connections projects from the *Whole House and Building Process Redesign* roadmapping activities and logistics work.

The working group identified the following possible project ideas:

- Roof panel systems with high insulation levels and finished exterior surfaces;
- Lower cost roof panel systems capable of achieving wider spans and incorporating photovoltaics as the roof surface;

- Higher insulation wall panels that are designed to take the utility installation out of the critical path of construction;
- Wall panels that take materials and trades out of wall manufacturing and assembly in order to speed up cycle time; and
- Floor panels that provide structure and sheathing, and possibly finished floor surface and that allow utilities to easily pass through.

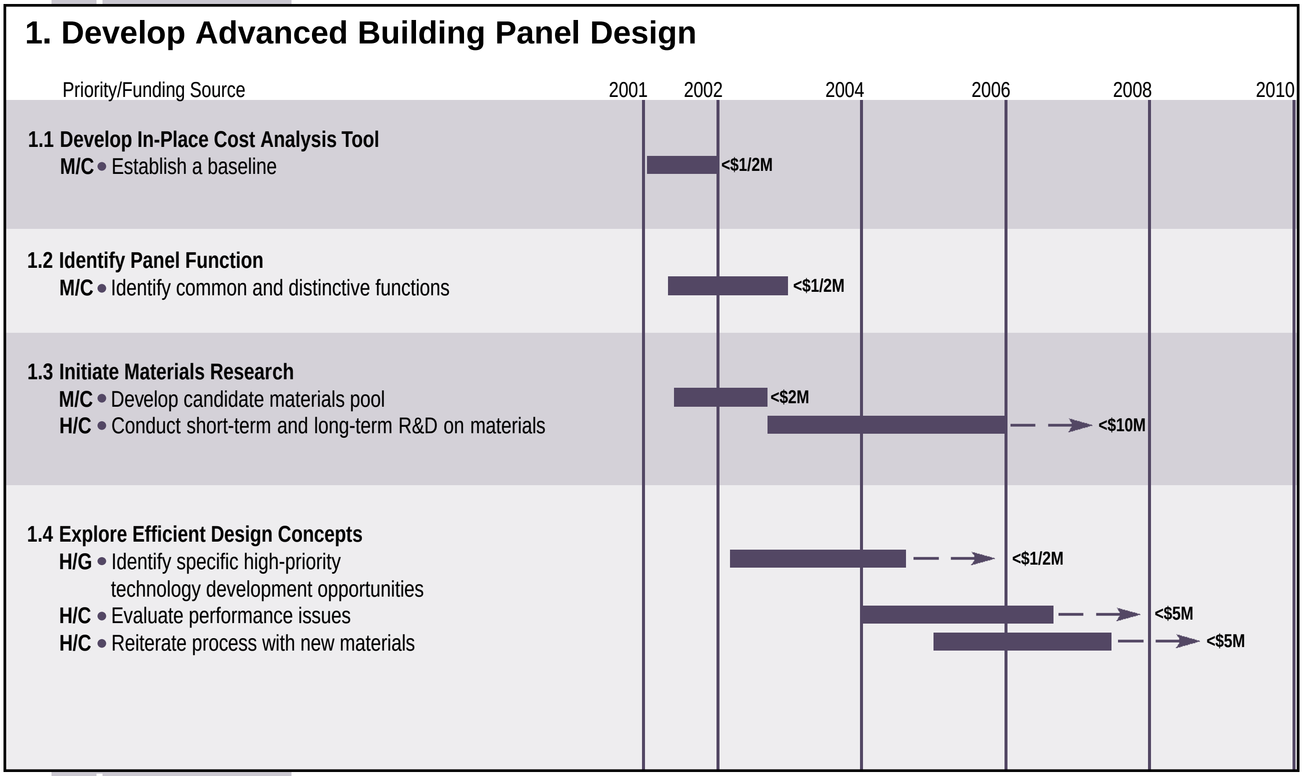

Figure 1

Key: Priority: L, M, H = Low, Medium, High
Funding Sources: G,P,C = Government (public), Private Industry, Combination
Funding amounts are approximations.

2 ESTABLISH COMMON STANDARDS, SPECIFICATIONS, AND INTERFACES

The objectives for this strategy are to develop performance requirements at various levels and engineering methods to analyze, design, and specify panel systems, including connection and interface protocols and standards for ease of use. This strategy will also address code and regulatory acceptance issues.

The group's emphasis here was focused on improving the "support" system for panel products (i.e., tools that make it easier to more efficiently design, approve, and use panel products). 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 for implementing the working group's strategy calls for R&D in five distinct areas. These areas are shown in Figure 2 and summarized below.

2.1 Define Expected Performance Requirements

If new panelized technology is to be developed and brought to market economically, it is imperative that it competes at the same level as prescriptively constructed structures. This will only be possible if the research that is ongoing and has been completed by many individual researchers is brought together in a formal manner. Bringing the main researchers and companies with a vested interest together in a government and industry sponsored conference specifically concentrating on residential connection issues will most likely facilitate this. The information gained from this type of information transfer will need to be focused and gaps filled in by an ongoing research program.

2.2 Perform Connections Testing and Analysis

Once the current state of research is known, the testing and analytical gaps will be filled in using targeted, focused research. This research will help determine the system effects that occur in current prescriptive methods that are not accounted for in current analysis methods. This stage also will require that panel-specific connections be developed, tested, standardized, and proven.

2.3 Conduct Whole System Testing

Final proof of any systematic approach to performance-based design is to accurately predict the behavior of entire systems. This proof and information needed for model development is only derivable through whole house type testing. Several recent tests will provide much of the needed information for model development, but verification will need to be conducted on separate designed structures to demonstrate full compliance and weaknesses of predictive analysis.

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 is built by the industry, with the assistance of the government, and resides in the public domain. Then, commercial entities can develop market-specific front and back ends to the programs tailored to specific applications.

2.5 Perform Panel Testing and Analysis

The model developed under the strategy above will be based on the rigid panel flexible connector concepts and will require panel level testing and analysis tools to accurately predict the behavior of individual panels. This will require panel-specific testing and evaluation.

2.6 Encourage Standards Development

Standards for panels, including connections, sizes, performance, and applications, 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 assemblers. Development of standards will require the following actions:

- Create the organizational framework for standards development;
- Define the problem and/or opportunities and document the current situation;
- Draft or compile the standards and seek committee consensus; and
- Disseminate and promote the use of the standards.

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 consensus process as by technical performance or construction issues.

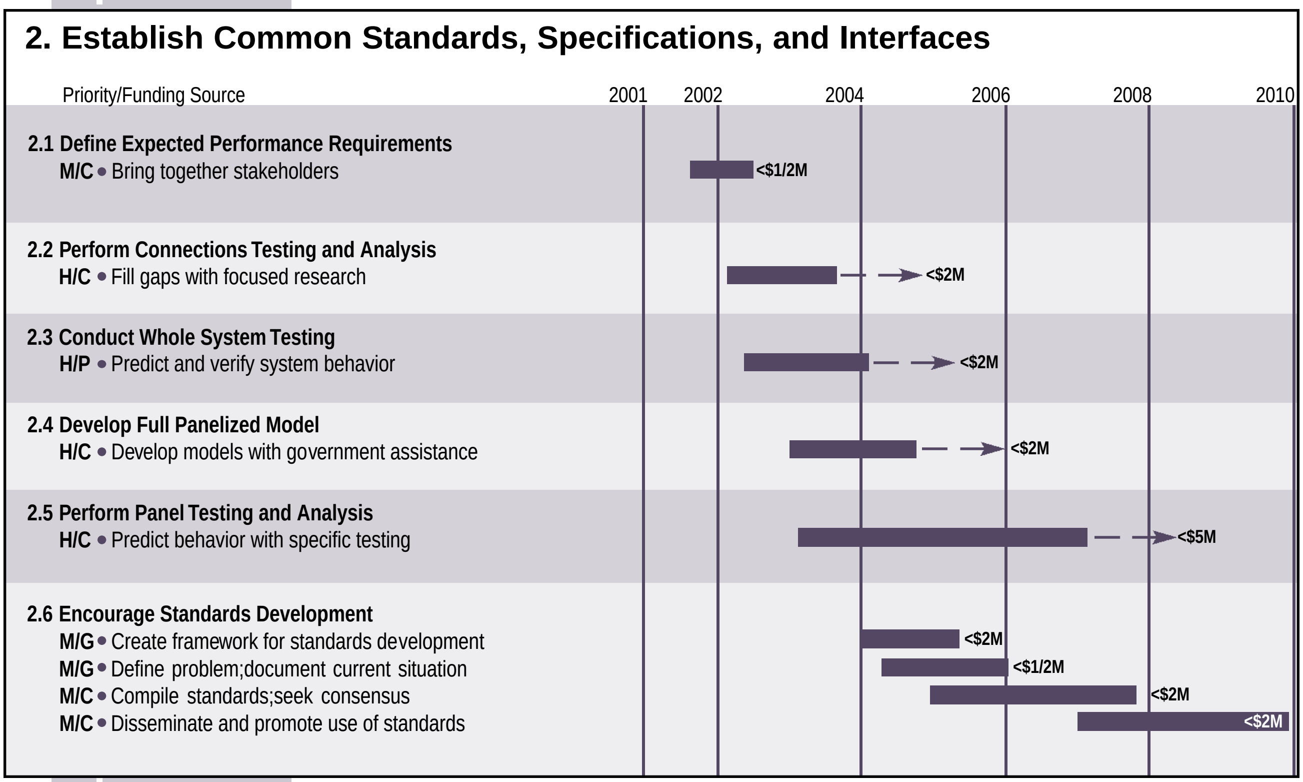

Figure 2

Key: Priority: L, M, H = Low, Medium, High
Funding Sources: G,P,C = Government (public), Private Industry, Combination
Funding amounts are approximations.

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 previously covered. Achievement of this objective depends on advances in each of the following areas (shown in Figure 3).

3.1 Develop a Center of Excellence

A central resource for showcasing breakthroughs in production, delivery, and site assembly for panelized building systems is needed. 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 will serve as a resource for builders, product manufacturers, and trade contractors involved in panelized home building.

3.2 Develop a Demonstration Project

New techniques for designing and manufacturing building panels can be showcased in demonstration projects around the country involving builders and panelized producers. Emphasis will be placed on the industrial engineering evaluation of labor efficiencies and overall installation costs.

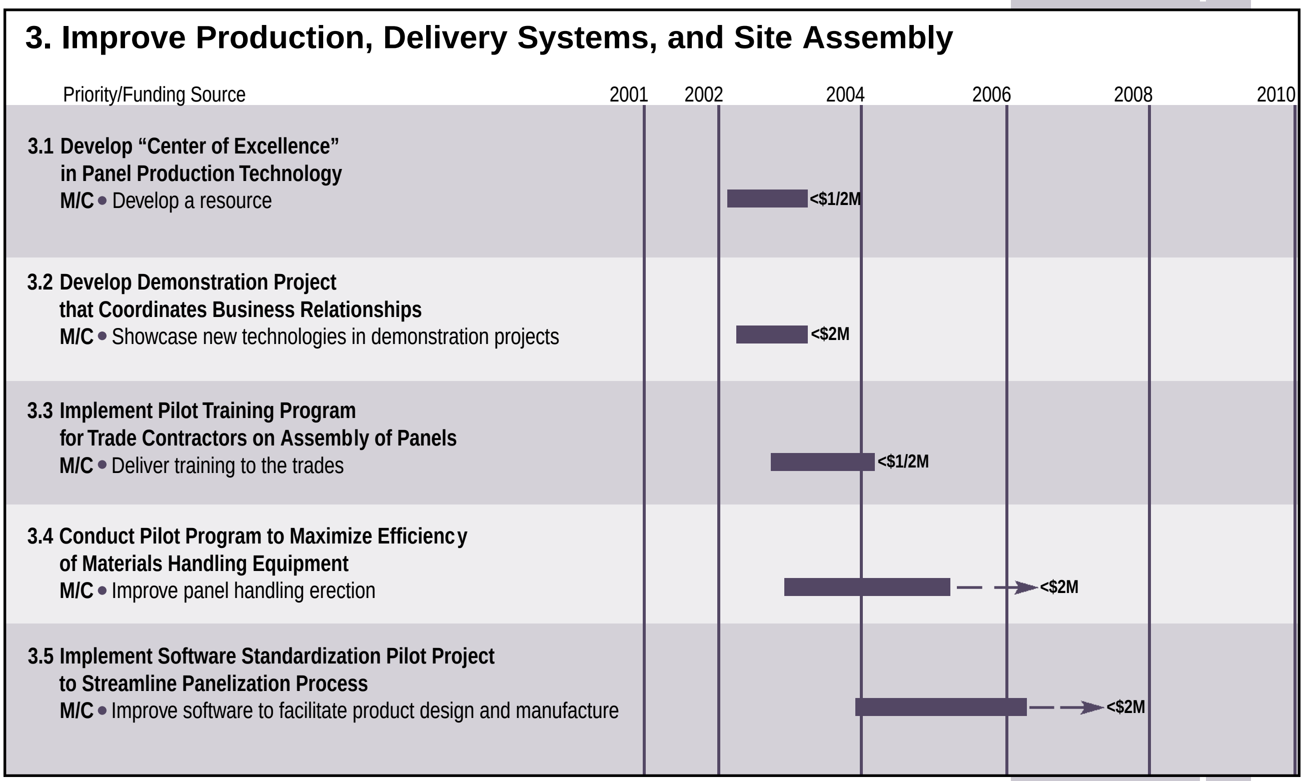

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Figure 3

3.3 Implement a Training Program

As new building panel designs, production processes, and installation techniques gain acceptance, the building trades need training to understand how to maximize the efficiency of onsite production.

3.4 Maximize the Efficiency of Handling Equipment

Use of cranes for panel installation adds significantly to overall cost. Techniques for improving the efficiency of panel handling and erection onsite could lead to lower overall production costs.

3.5 Evaluate Standardized Software Systems

New software for designing panelized systems and managing the overall production process must be evaluated to determine how effectively it facilitates product design, manufacture, and erection.

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