PATH TECHNOLOGY ROADMAPPING

PANELIZED SYSTEMS IN RESIDENTIAL CONSTRUCTION

BACKGROUND PAPER

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1. INTRODUCTION

This paper addresses panelized systems in residential construction and has been prepared for participants in a technology brainstorming session organized by the NAHB Research Center in conjunction with the "Partnership for Advancing Technology in Housing" (PATH). PATH is a public-private partnership that was created to improve new and existing American homes in several important ways between now and the year 2010.

PATH Program Goals

- *reduce the monthly cost of new housing by 20 percent or more*
- *cut the environmental impact and energy use of new housing by 50 percent or more and reduce energy use in at least 15 million existing homes by 30 percent or more*
- *improve durability and reduce maintenance costs by 50 percent, and*
- *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 residential construction work illnesses and injuries.*

The objective of PATH technology roadmapping is to identify potential technologies that can, in combination, allow the building industry to achieve the PATH goals by 2010 and to define specific, time-phased research and development activities required to implement these technologies. The PATH Roadmaps are intended to help coordinate and leverage private sector and public sector R&D for maximum benefits. The completed roadmaps will:

- ✓ Provide a common, shared vision among the public and private sectors of how the technology, if effectively implemented, will benefit the industry;
- ✓ Serve as a guide for public and private sector investment in R&D;
- ✓ Provide direction to public sector, private sector, and academia on needed research and development; and,
- ✓ Facilitate or encourage joint private/public sector activities that will reduce or eliminate barriers to achieving the vision -- e.g. development of connection and panel standards to speed construction.

More information about PATH, including its technology outreach and technology roadmapping activities, appears in Appendix A.

Roadmapping work began in March 2000 with a two-day "brainstorming" session where a cross-section of industry experts identified and evaluated 40 "Technology Options" as candidates for roadmap development. Six specific options, appearing in Appendix B, addressing panelized or panelized type systems were consolidated into an Advanced Panelized-Type Systems "Portfolio" that was designated as a high priority area for roadmap development. This high priority reflected the potential contribution of panelized technology in helping the industry to achieve the PATH goals. The Advanced Panelized-Type Systems Roadmapping activity, to be initiated on December 13th, focuses on the potential application of panelized systems to the home building process.

The charge of this roadmapping exercise is to determine:

1.) To what extent can panelized systems help meet the goals of PATH?
2.) What is the shared vision of the industry for panelized systems?
3.) Where are the problems that should be worked on to achieve this vision?
4.) What are potential intermediary steps?

The balance of this paper presents a vision of what can be achieved with panelized systems, along with a description of the current market realities for panelized construction and barriers that need to be overcome in order to accelerate market acceptance of panelized systems. The paper also addresses alternative approaches that could contribute to achieving the path goals through panelized-type systems. It also presents an overview of the various panelized options that currently comprise the Advanced Panelized-Type Systems Portfolio.

2. BACKGROUND

Panelized systems in residential construction are pre-manufactured components, elements, or systems that are site assembled into the finished home. It is estimated that 790,000 homes constructed last year had some form of panelized construction, most commonly roof trusses. The top 42 panelizers had gross sales of roughly $450 million dollars last year. While this appears to be a large number, it is minor in comparison to the estimated $250 billion dollars spent on new residential construction last year. Panelized systems only represent approximately 0.2% of total expenditures for new residential housing.

In 1999 trusses represented 63.4% of total roof area in residential construction, yet only 5.2% of the linear feet of residential walls were panelized.[1] With all of the promise panelized systems offer, why are these numbers so low?

Panelized construction can bring the benefits of mass production into the highly customized residential market through the pre-production of components and systems. While not generally considered as panelized systems, virtually all windows and doors installed today are *panelized*; they are built off-site in controlled environments, packaged, shipped, and offered to builders and buyers as commodity products. Builders rarely construct doors and windows on-site even though it was once the only method used. Acceptance of these components was due in large part to the standardization of the connection details that allowed simple, economical, and uniform installation. We now have a thriving pre-manufactured window market where manufacturers compete on price, quality, options, material, size, shape, and style. This commodity approach increases the market acceptance as well as increases the total market size. Today's homes have more windows than homes at the turn of the century largely due to the improvements in manufacturing, assembly, and installation. The benefits of having a commodity-type product are far reaching, allowing the concepts of capitalism to continually push the beneficial evolution of change.

[1] Annual Builder Practices Survey, NAHB Research Center, © October 2000.

While individual components have seen the largest market acceptance, the impacts required to meet the PATH goals are too large to be attained without a broad-based, system-wide approach. This is where panelized systems offer the greatest impact. They can leverage the known benefits of mass production to provide easily transportable components to builders economically and on schedule. Panelized construction also generates less scrap and waste – both on the job site and in fabrication. Once the panels are on site they can be quickly and easily assembled into homes with minimal worker risk and environmental disturbance. The quality and uniformity of mass-produced panels and good well-designed connection techniques will translate into increased disaster resistance and durability of homes. Panelized construction offers other advantages: ease of assembly, factory controlled tolerances, and delivered directly to a job site. Since the panels are delivered to the job site they themselves can be viewed as a delivery system speeding material and technology acceptance into the market place.

The challenges facing panelized construction are both technical and market driven. Acceptance in today's market is often driven by installed cost to the builder, not life cycle costs which could justify value-added features from panelization. On the technical side, the industry faces issues relating transportation economics, change order flexibility, and labor training to mention a few. In addition, most panels are shipped as "open" panels so that inspectors may view the installation of plumbing and mechanical systems. This requirement limits innovative or "closed" panel fully integrated wall and floor systems.

Since the first panelized home was built in the United States in 1624, panelized structures have been limited to niche markets. They have been tried in differing configurations, materials, and level of completeness to differing levels of success. Historically, the shortcoming have related to market acceptance, shipping limitations, erection tools, connection details, regulatory restrictions, and lack of technology to rapidly deliver the level of customization needed in the residential marketplace. The tools are now generally available to be able to overcome past limitations and bring the power of mass production to the residential marketplace through the panelization delivery system.

3. POTENTIAL VISION FOR PANELIZED SYSTEMS

Since one of the charges for this roadmapping exercise is to form a vision for the future of panelized systems, let's examine one potential vision. This potential vision is offered as a springboard for the roadmapping session. Various components of this vision are discussed later in the paper. This vision is couched in a letter from a hypothetical residential contractor to his association and is not intended to place bounds on the roadmapping effort. Rather, it is intended to open the door to our collective creativity while attempting to initiate some plausible and practical direction for the roadmapping effort.

The year is 2010. Here follows a letter being sent by a characteristic residential contractor to his panelizers' association.

December 25, 2010

North American Panel Producers Association
Washington, DC

Dear Sir or Madam:

We have been a successful family residential contractor for the past 35 years and have never had happier customers or more business than right now. The customer satisfaction is mainly due to the vastly better houses we are delivering faster than I ever thought possible. The main reason for these significant improvements is the panelized construction we switched to a few years ago. They allow us to expedite the projects with any level of changes the customer asks for, and for a cost that allows us to compete in the competitive entry-level market while still realizing our margins. Basically, as a residential builder we face many roles such as, the salesman, the designer, the supervisor, the project manager, the business manager, and the chief financial officer. Switching to panelized construction has helped us meet the demands of these many roles.

The house we will start and finish this week is a modest move-up home in an in-fill location. The footprint is tailored to the site, roughly 52' by 36'. Due to the in-fill location we will once again have no staging area. This is not a problem, since the materials will be delivered from the panelizing plant on schedule and the assembly is uniform enough that my crew is comfortable meeting the necessary production rates. The foundation will be delivered and installed by lunch. After lunch the floor panels will be delivered and installed. By break we will be finishing the walls and starting on the roof panels. By quitting time we will have installed the roof panels and be able to lock our tools in the house without fear of weather, theft, or vandalism using the same keys I will give the homeowner on Friday.

Selling the homebuyers on panelized systems is easy, especially with the variety of materials available. The panel manufacturers have tailored their productions to allow me to sell the right materials for the right locations, durable concrete and high tech materials for the savvy buyer concerned with value and wood based panels for the traditional buyers. In either case, both the home buyer and I have a wide variety of foundation, floor, wall, and roof systems that are virtually interchangeable thanks to the standardized connections. The buyers are always bewildered with the amount of easily customizable options they have to choose from and ask me to help them through the sea of choices. These choices not only allow me to sell more easily I also get the benefit of building a stronger relationship with my customers early on in the process that carries through the entire project.

Since most customers see their home as unique as themselves they want them customized. The problem is that most people have a hard time envisioning what the final house will truly look like before it is built. With the virtual walkthroughs that are supplied by my panel suppliers of the basic layouts my clients can see the modifications that fit their ideas and pocket books. This allows them to target the things that effect them the most while allowing them to keep the cost within their budgets. Once they have decided on their homes the panels are fully detailed and reviewed before construction to minimize mishaps. The level of design that goes into these panels is more than a conventional contractor could afford and the buyers love it.

My crews have never been happier. In fact my carpenters no longer refer to themselves as carpenters, they now say they are residential assembly engineers. Since the panels come complete with finishes, and embedded mechanicals they really do get to put the entire home together and this gives them a sense of pride. The skills have evolved and now my guys are more plug, bolt, and connection oriented than they are hammer swingers. The interesting thing is the assembly is actually so simple my current crew is rarely required to frame. This reduced level of skill allows me more flexibility in hiring for my three person crews.

The fit and finish of these panels is far better than my dads' experienced crews could produce thirty years ago and much faster. But, in their defense, they had to contend with weather, inconsistent materials, site cleanliness, and theft. My crews today have only a couple of days they have to contend with the elements then they are stitching up the home and getting it ready for the home buyer.

The economics of these panel systems are excellent. They allow me to meet my margin requirements and still offer the homebuyer costs that are actually better than mobile and modular houses, which also carry stigmas. I know that I have an unfair advantage since all of my materials come pre-assembled on just a couple of trucks and I am not as controlled by shipping widths since the house is assembled on site. The value the customer feels is unquestionable and the number of people who can afford my houses ensures that I will never run out of customers.

In summary, because of the panelized construction that I have embraced I know that I am meeting the needs of my customers, my business, and my community.

Sincerely

This envisioned letter would serve as an example of the success of both PATH and the PATH roadmapping efforts. The goals of improving the affordability, durability, energy efficiency and environmental performance, disaster resistance and worker safety record of U.S. housing have been met with assistance of a better material delivery system, panelized construction.

The main elements encompassed in this hypothetical letter are:

- Reduced labor time and skills requirement.
- Componentized panel systems.
- Simplified supply chain integrated directly with builder sales.
- Reduced construction cycle time.
- Leverage benefits of factory construction.
- Less opportunity for theft and vandalism on the construction site.
- Better utilization of raw materials.
- Less material waste on construction site.
- Better estimates of delivery dates.
- Lower assembly costs.
- Known costs lowering contractors' contingency fees.
- Minimized on site staging areas.
- Better management of delivered quality systems.
- Increased durability.
- Component integration within panel assembly.
- Evolved construction practices.
- Integration of finish materials into panels.
- Reduced skills required for assembly.
- Safer construction.

4. DEFINING ALTERNATIVE APPROACHES TO ACHIEVING THE VISION

For this envisioned letter to come to fruition, much hard work will need to be applied toward the development of products and systems that resolve the technical and market issues that have limited the acceptance of panelized systems. There are a variety of material options (e.g. SIPS, precast concrete panels, insulated concrete forms, steel, composites, engineered, and traditional wood based panel systems) currently under development.

The National Association of Home Builders passed a resolution in 1999 calling for the development of a range of "economically viable" alternative materials. Builders want to be able to switch easily between one material and another. This suggests that a range of material options may better assist builders in achieving housing affordability for their customers.

Successful development and introduction of next generation panelized systems would address the following issues:

- Delivery systems
- Construction Process

- Marketing Methods
- Regulatory Issues

Each of these topics is discussed in more depth below. They may help frame the discussions in the Roadmapping process.

A. *DELIVERY SYSTEMS*

The delivery system is broadly defined as the processes and activities that would transpire from the time a contractor and buyer place an order until the completed panels are delivered to the building site. Some of the main activities and issues involved in this time frame are listed below. This is just a proposed list and should not be viewed as inclusive.

- Fabrication location (on or off-site)
- Ordering/option selection
- Panel design
- Panel fabrication
- Transportation
- Industry organization
- Connection details
- Panel liability
- Enterprise resource planning.

B. *CONSTRUCTION PROCESS*

The construction process is broadly defined as the process and activities that would occur on site once the panels are delivered to the site. Some of the main activities and issues involved would be:

- Assembly techniques
- Connection details
- On site equipment requirements
- Required assembler training
- Production rates
- Assembly problems

C. *MARKETING METHODS*

Panelized systems will not be successful without widespread utilization. The importance of contractor and customer acceptance is such a key to success that it must be an integral component of the roadmapping effort. Some of the main areas that must transpire for a homebuyer or builder to be knowledgeable enough to consider panelized construction when buying or selling would be:

- Local completed projects
- Centralized education effort
- Contractor training
- Trade publications
- Trade associations

D. REGULATORY AND MISCELLANEOUS ISSUES

To what extent do codes and local regulatory processes impede the introduction of advanced building materials and systems? Can approval and inspection processes accommodate off-site fully utility integrated closed panel systems? To help navigate through the regulatory waters there are areas to investigate and possibly use as leverage for acceptance. A few of the topics for discussion could be:

- Codes and Standards
- Inspections
- Inpectability
- Guidelines for fabrication
- Use of alternative and or proprietary materials and components
- Product liability
- Land use issues

5. CURRENT PROPOSED ADVANCED PANELIZED SYSTEMS PORTFOLIO

A series of related concepts for advanced panelized-type systems were developed during the broader initial March PATH Technology Roadmapping sessions. While most options focused on specific applications for walls and roofs, the technology option dealing with integrated wall, floor and roof systems received the most favorable evaluations of the set. Although the emphasis was on factory production, the need to develop economical on-site or near-site production methods to add flexibility and address transportation issues also was clearly recognized. There was considerable overlap among the proposals. Several proposals called for integrated exterior and interior finishes as well as adding functionality or enhancing performance with integral insulation or distribution of utilities. Some focused on adaptation of systems used in commercial applications or in other countries, while others would require significantly more original work for development.

The six specific options already proposed for the Panelized System Portfolio are plotted in Figure 1 according to the time required to achieve commercialization and the relative risk of bringing these products to market. In this figure it is shown that relatively mature systems such as precast wall panels offer short development periods and very low risks, while more futuristic goals such as combined systems such as roof sandwich panels will take a longer time period to develop and offer more risk. It is important to remember that development risk is so closely related to the end user benefits that they are virtually synonymous.

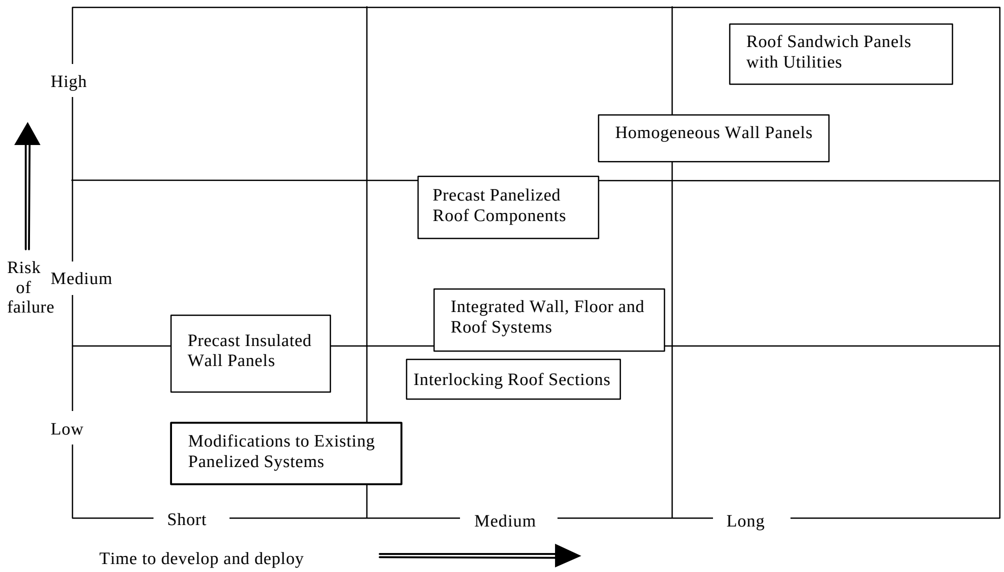


Figure 1, Risk Time Development Relationship

These six options as presented in Appendix B should be evaluated, rejected, accepted, or refined as desired by the roadmapping group. They are presented as examples of the pieces or technology that can be focused on as intermediate steps. They are not the only options available. The portfolio of technologies envisioned by this focused panelized system group should contain options that are high and low risk and short and long term much like a financial investment portfolio. The aim should be to characterize a set of technology development options with a mix of risk and returns on investment.

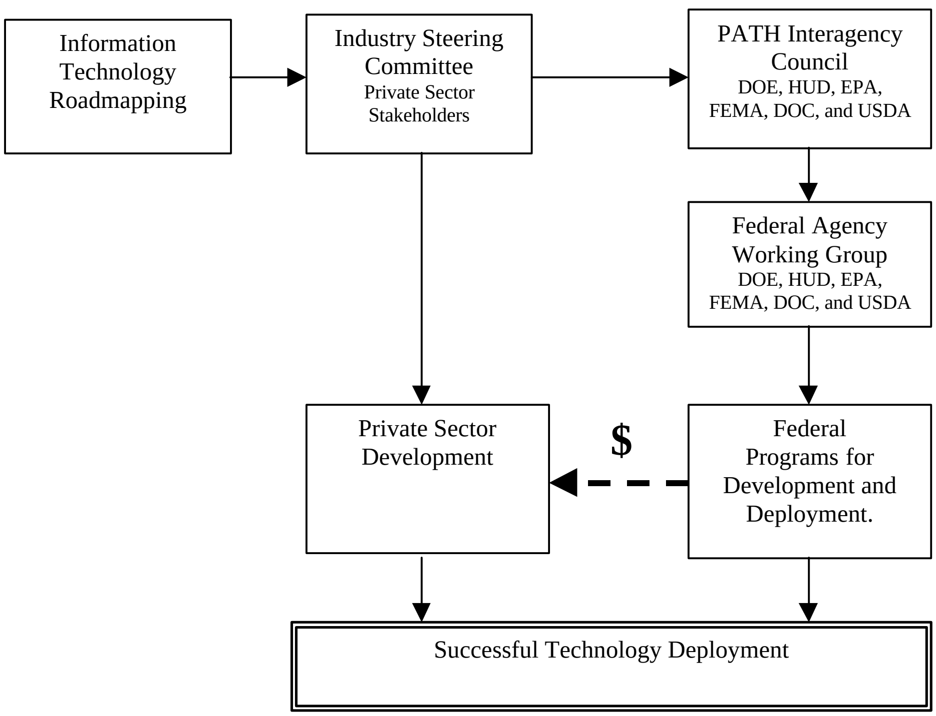
Through initially expanding our perspectives to explore a range of possible futures, the Technology Roadmapping group will consider specific actions that will help the industry to achieve the PATH goals. Individual companies may discover partnering opportunities with complimentary product interests on specific projects.

APPENDIX A

PATH Organization, Technology Outreach and Technology Roadmapping

Work is underway on several fronts in pursuit of the PATH goals. Extensive technology outreach activities are ongoing, both over the Internet and in field evaluations or demonstrations around the U.S. At the same time, PATH has a Technology Roadmapping Working Group, which has been laying groundwork for the development and introduction of beneficial new products over the life of the program. The diagram below shows how the technology roadmap information flows. The roadmapping information - time-phased strategies and projects - is approved by the Industry Steering Committee which is comprised of private sector members.

The approved roadmaps are then provided to the public sector via the PATH Interagency Council, which consists of the Assistant Secretaries of participating agencies. High priority items may eventually result in R&D or other types of programs that would accelerate the technologies. The roadmaps are also made available to the private sector, where companies might decide to separately or cooperatively develop products related to or derived from the technology. The end result will drive R&D funding by both the private and public sector.



In addition, four other PATH Working Groups have been organized to focus on the various institutional forces that affect technology adoption and utilization, including (1) finance, (2) labor and quality issues, (3) barriers and insurance, and (4) consumer education. Activities of these PATH Working Groups are also under the general oversight of the Industry Steering Committee are summarized below:

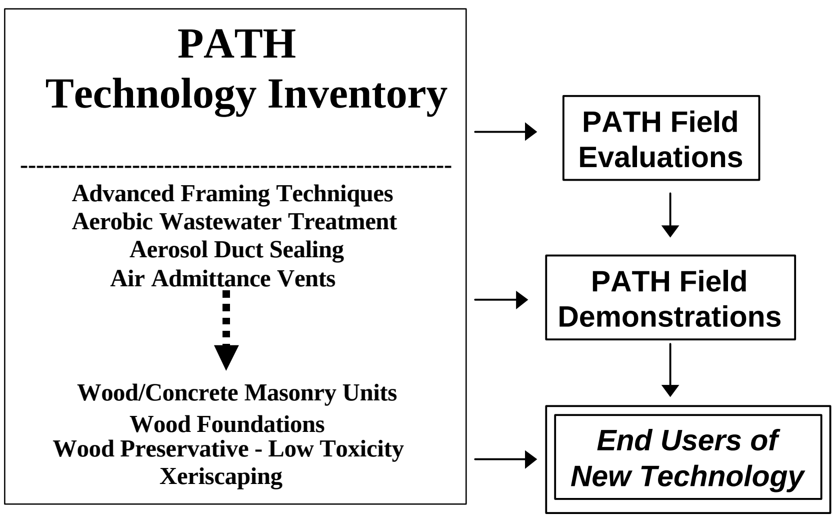
Barriers and Insurance Working Group. This group is investigating ways to help control exposure to liability and translate improved building performance into lower insurance premiums as a consumer incentive.

Consumer Education Working Group. This group is looking at ways to stimulate consumer demand and create market "pull" for PATH technologies.

Labor and Quality Working Group. This group is working to promote quality improvement methods and provide training that will address persistent labor shortages in the construction market. It could potentially play a role by identifying strategies for training construction labor to use information technology and maximizing the quality improvement potential of ERP.

Finance Working Group. This group is working to enhance "energy efficient mortgages" and define similar products offering expanded access to financing or reducing the cost of originating mortgages and other loans.

PATH Technology Outreach. An extensive Technology Inventory with information about new, emerging or underutilized housing technologies was developed early in the program and placed on the Internet at "http://www.nahbrc.org/toolbase/xtech.html." Visitors will find searchable information about the nature and status of more than 150 technologies for housing. Several of these technologies are being more closely studied and reported on as part of PATH Field Evaluations. Others are being used and documented on a larger scale in PATH Demonstration Projects.



Notably lacking from the PATH Technology Inventory are information technologies. The fact that information technologies do not appear in the list is no doubt partly because the technical evaluation team was not looking for such technologies, but may also be symptomatic of the small amount of emphasis the industry has to date placed upon information technologies.

PATH Technology Roadmapping. PATH initiated a process of Technology Roadmapping to complement the technology outreach and help accelerate the development and introduction of new technologies that can achieve progress towards the PATH goals. Roadmapping can be viewed as intended to ensure a future supply of new items for inclusion in the Technology Inventory, and for PATH Field Evaluations and Demonstrations, as shown below. Specific areas

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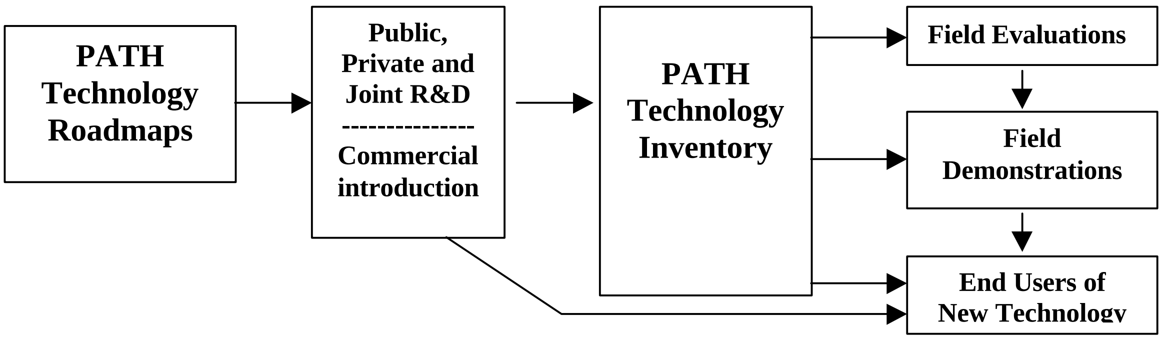

for roadmapping will be selected by the Industry Steering Committee, which will review and approve the results.

The roadmapping process began with a two-day brainstorming session in March 2000, where a diverse group of 35 experts reviewed all the PATH goals, then identified and documented a total of 40 "technology options" as candidates for further study. The titles of these options give some idea of their scope and content.

TECHNOLOGY OPTIONS IDENTIFIED DURING MARCH, 2000 PATH BRAINSTORMING

Advanced Roof Coverings
Augmented Reality
Automated Tools
Connected Home
Cooling with Night Air
Distributed Generation - Fuel Cells
Distributed Generation - PV Solar Cells
Electronic Control Technology for HVAC
Enclosed Attic Space
*Enterprise Resource Planning for Home Construction
Flexible, Adaptable Space
Foundation Stave System
Frost-Protected Shallow Foundations
Helical (screw) Footings
Homogeneous Wall Panels
Improving Safety in Roof Construction
Indoor Air Quality
*Information Technology for the Approval Process
Insulating Concrete Forms
Integrated Wall, Floor and Roof Systems
Interlocking Roof Sections
Less-Finished Interiors
Mechanical System Disentangling
Microtechnology
Modular/Whole House Systems
*Non-Commercial Information Portal
Precast Insulated Wall Panels
Precast Panelized Roof Components
Prefabricated Ducts
Radiant Heating
Roof Sandwich Panels with Utilities
Self-Fitting Membrane Interiors
*Software Integration/Standards
Sound Isolation
Targeted Heating and Cooling
*Virtual Inspections
Water Recycling and Reuse
Whole House Process Redesign
Wireless Communications
Zero Negative Emissions

*The technology options marked with an asterisk are assigned to the Information Technology roadmapping team.

One-page write-ups of all 40 options in the list can be viewed on-line through the Public Access area at "http://roadmap.nahbrc.org." The brainstorming was followed by an evaluation process in which benefits, risks, market potential and other factors were assessed for each technology option. Based on the results of the participant evaluations, the following three "portfolios" were selected for initial roadmap development:

1. *Information Technology to Accelerate and Streamline Home Building*
2. *Advanced, Panelized-Type Systems*
3. *Whole-House and Building Process Redesign*

Each of these portfolios includes one or more Technology Options that received very high ratings along with other closely related items. Roadmapping task groups being organized under each of these areas will operate concurrently this fall and into the year 2001.

APPENDIX B

PROPOSED ADVANCED PANELIZED SYSTEMS PORTFOLIO CONTENT DESCRIPTIONS

PRECAST INSULATED WALL PANELS

Technology Description

Description: Precast concrete wall panels for basement and crawlspace foundations can reduce construction time compared to masonry and cast-in-place foundations, and improve quality while remaining cost-competitive. These precast wall panels are usually constructed of high-strength (5000 psi), steel-reinforced concrete, with vertical ribs (studs) at 24-inches on center, connected to top and bottom integral concrete beams. The exterior face consists of a 1 to 2-inch thick fiber reinforced concrete shell. Panels are insulated between the ribs with a layer of 2-inch expanded polystyrene, which also provides a moisture barrier. For interior finishing with drywall, either 1 x 2 preservative-treated wood nailing strips or insulated light gage steel ribs are used. Horizontal holes formed in the ribs allow passage of plumbing and electrical wiring. Wall openings are lined with wood blocking for attachment of window and door frames. Completed wall panels are transported from the factory to the site, and placed by crane on compacted and level gravel footing. A polyurethane adhesive/sealant is applied in all panel joints to prevent water infiltration, and panels are bolted together using steel hardware.

Current Status: This is a well established technology currently used throughout the United States. Superior Walls is one company currently providing foundation wall panels for residential construction. Because of the weight of current products, research and development is needed to produce durable, strong, and affordable lightweight aerated or foam concrete panels.

Benefits

Affordability:	No poured concrete footing is required to support wall panels, thus reducing onsite costs. On-site construction time and therefore labor costs are lower than conventional masonry block foundation walls. However, costs are dependent on shipping distances from the factory and availability of cranes for erection. Consumers can easily finish interior surface at a later date
Energy/Environment:	Insulated wall panels provide a good thermal barrier, and a dry, warm and livable basement.
Durability:	Precast concrete is durable and weather resistant.
Safety:	Foundation walls can be designed to resist earth and water pressures, and forces from natural hazards, such as high winds and earthquakes.

Technology Development Risks and Barriers

- Concrete panels are very heavy, requiring cranes for erection, and the weight adds to shipping costs. Research and development to provide lighter weight panels is necessary.
- Location of openings is done at the factory, and ERP and information technology are needed to provide "mass customization."

Other Risks and Barriers

- Bracing at footing and first floor levels is required prior to any backfill over 3-foot in height placed against the wall.

- There still are regulatory issues and builder reluctance that may need to be resolved in some areas. However, these foundations are recognized by building codes, and accepted under homeowner warranty programs.
- There also may be distribution, transportation, and capacity limitations in many regions.

Estimated Time to Develop and Deploy

The systems are already being used. However additional research and development to reduce weight and implementation of information technology will help the speed diffusion.

Interlocking Roof Sections

Technology Description
Description: Develop roof sections, including structural members and coverings, that interlock for quick field assembly.

Current Status: Closely related to current panel technologies; some interlocking systems are reported to exist.

Benefits

Affordability:	Potential for accelerated cycle-time, modest cost reduction and expanded interior space with free-spanning panels compared to conventional truss systems.
Energy/Environment:	Little or no effect except perhaps where high-performing insulation is used in a cathedral-type application over a conditioned space.
Durability:	Similar to current practice with truss or rafter framing, except quality control of sheathing attachment could improve high-wind performance.
Safety:	Quicker roof assembly and pre-shingling would reduce worker exposures to falls associated with truss erection, roof-deck installation and roof covering.

Technology Development Risks and Barriers

Some issues include connections to walls, provision of a load path, ensuring diaphragm action, accommodation of other than the simplest roof designs (e.g., hips, valleys, turned gables), long-term prevention of leakage at panel joints, treatment of field penetrations for vent stacks or installation of dormers, potential need for heavy equipment to lift and position panels, and provision of venting when the sections enclose conditioned space.

Other Risks and Barriers

Legal restrictions and high cost of transportation of very wide or long products over the highways is an issue unless production occurs on-site or close by.

Estimated Time to Develop and Deploy

Estimated Development Cost

Integrated Wall, Floor and Roof Systems

Technology Description

Description: This is an open or closed wall, floor, roof system that can be put together in a factory or in a structured, on-site process. This system can incorporate several functional systems including: thermal inertia, r-factor, electrical (lighting) distribution, cooling, heating, solar collector, water, sanitary sewer, acoustics, surface aesthetics, and human contact with the environment. The current systems include precast (one to multiple layers), tilt-up (one to multiple layers), SIPS, ICF, engineered wood, etc. Material choices include: wood, expanded polystyrene, polyurethane, concrete, hydrated concrete and others.

Also include in this concept a wall panel process that prefinishing wall panels off-site and delivering to the house JIT. The process would allow the finish to be customized to each buyer/house and delivered to the site to eliminate several of the trade integration issues currently experienced on the job site.

A specific technology showing good potential is precast or composite panels with carbon fiber reinforcement. Such panels are low cost and lightweight. When used in combination with post and beam construction, they provide extremely affordable housing solutions in certain climates. Similar panels when combined with insulation and interior finish promise to be affordable solutions in any climate.

With the proper R&D, most of those familiar with the product feel that the carbon could be developed to act as both the reinforcement and radiant heat element when used in the inside wythe (room side of the sandwich insulated panel). A European company has already developed a very lightweight cellulose filled "precast" that can be cut, drilled, sanded, etc. with standard tools. With this on the inside combined with a sandwich insulation core and a precast structural outer wythe the panel may be structurally capable as a "stand-alone" building component - no post and beams, etc.

Current Status: Unfinished or partially finished panels such as SIPs and precast, tilt-up are being used, although not yet widely. The use of totally finished panels, custom made by "mass customization" in the factory and delivered to the job site is not widely used, if at all.

Benefits

Affordability:	High, depending on the market and region and number of systems integrated. Panels reduce redundancies and part counts while shorter contractor cycle through concurrent activities negating on-site sequence delays and interface failure.
Energy/Environment:	High, depending on the thermal inertia and r-factor.
Durability:	Excellent, less movement of materials creates tighter buildings that allow less air and water infiltration thereby increasing the material natural service lives.
Safety:	Excellent, single lift of each panel reduces unstructured labor doing high work on site or off-site labor is more managed and will provide production quality improvement.

Technology Development Risks and Barriers

- Research is needed to find or develop the appropriate materials.
- Education in building science and systems integration is weak.
- The technological problems are found in the economical structural attachment.

Other Risks and Barriers

- Momentum, history, hard-headedness.
- There is bias by architects, real-estate agents, etc., about panelized construction.
- Custom building is perceived as a stick-framing process only.
- Low-level of consumer awareness.
- Transportation cost of panels.
- Panelization has been around for a long time, but is not widely accepted.

Estimated Time to Develop and Deploy

This is an integration of many trades, materials and concepts and will require a multifaceted research and implementation process. The wide scale solution and implementation will take 2 to 10 years.

Estimated Development Cost

PRECAST PANELIZED ROOF COMPONENTS

Technology Description

Description: Precast concrete roof panels have been used for years in the U.S. for commercial and multi-story residential apartment and motel structures. The most common system used consists of hollow-core precast and prestressed plank for spans of 20 to 30 feet, supported on concrete masonry unit (cmu) bearing walls. However, a system developed in Europe has an exposed top surface form-molded to match shingle or tile roofing. The underside has integrated bar joists cast into the concrete with wood purlin strips for attachment of ceiling material. Foam or insulation batts can be factory installed and drywall ceilings are field installed.

Current Status: The system was developed in Europe and may be proprietary. Potential production in the U.S. or importation of the system is unknown. Status of any testing for compliance with U.S. standards and building code compliance is also unknown.

Benefits:

Affordability:	Affordability for detached or low-rise single family is questionable, and needs to be assessed.
Energy/Environment:	Insulation properties should reduce energy costs.
Durability:	Concrete is a very durable product.
Safety:	Design of concrete roof plank system would provide natural hazard resistance, and roof planks could support heavy snow loads.

Technology Development Risks and Barriers

- Compliance with U.S. standards and building codes, and testing for durability are the major barriers to accepting a European system.
- Establishing a manufacturing facility in the U.S or importing the product could be time consuming and costly.
- Concrete is durable, but somewhat permeable. An exposed roof surface could be affected by the environment, such as by ultraviolet exposure and freeze-thaw conditions.
- Affordability may be the biggest issue and requires analysis.

Other Risks and Barriers

- Barriers may include shipping distances to job sites, weight of the product, and customization for U.S. dwelling designs.
- Connections to wall panels and erection details for traditional hip and gable roof designs may also add to the cost.

Estimated Time to Develop and Deploy

Homogeneous Wall Panels

Technology Description

Description: Automated manufacturing techniques are used to mass-produce wall panels. A combination of computerized, continuous forming machines coupled with new or non-traditional raw materials and automated cutting and sizing equipment will produce these panels quickly, accurately, and with minimal labor constraints.

The panels can be extruded, continuously laminated, formed on a mat and pressed, or poured into a form. Anticipated raw materials include fiberglass, graphite, high-carbon fiber, wood and wood waste, agricultural fiber, cement, clay, steel, polyisocyanurate or other foams, plastic, and ceramics.

Once the raw panel is formed, exact fenestration and perimeter dimensions are created using automated sizing technology such as CNC machine centers, boring machines, and saws. Laser and optical visioning technology is envisioned for proper sizing and machining of these panels.

Current Status: Currently, industries using these materials and techniques for component manufacture include the automobile industry in the stamping of steel, the plastic and wood industry molds resin and wood fiber, the wood industry presses wood fiber into composites and processes solid wood and wood composite material using CNC equipment, and the aerospace industry employs graphite, carbon, and ceramics into panels for various uses.

Benefits

Affordability:	Will improve significantly because panels can be easily manufactured. Allows automation and reduces labor in the plant and at the jobsite. Precision dimensioning speeds installation.
Energy/Environment:	Highly energy efficient materials, correctly installed in the plant should provide excellent energy characteristics. In-plant and jobsite waste should be very low.
Durability:	More consistent material properties and precision assembly should make the finished product inherently highly durable.
Safety:	Safety will be improved on the jobsite and in the factory.

Technology Development Risks and Barriers

Research and development will be required to identify materials, develop designs, develop manufacturing capability. If it is a new material, extensive performance evaluation will be required.

Other Risks and Barriers

- Transportation of large panels is required
- High capital cost in plant and equipment.
- High labor cost due to skilled employees
- Acceptance by builders, trades, code officials.
- Ability to remodel or rehab. panelized structures

Estimated Time to Develop and Deploy

8-10 years – while panels and panelized systems are known and used, the building community is conservative by nature and has experienced problems from hastily introduced products, i.e. fire retardant plywood, Inner Seal siding, EIFS. Development time will probably be much faster than time required for employing the technology.

Estimated Development Cost

High

Roof Sandwich Panels with Utilities

Technology Description

Description: An integrated structural roof panel product with embedded photovoltaic circuitry, hydronic piping, waterproof exterior surface/roof covering, insulation, and textured interior surface.

Current Status: Currently most roofs are assembled in place, with structural members, sheathing, building felt, shingles, insulation, venting and interior surfaces built on-site by multiple trades.

Benefits

Affordability:	Moderate benefits in the form of reduced cycle time, simplified mechanical installation with hydronic piping installed off-site, and easy opportunity to finish attic space.
Energy/Environment:	PV circuitry would have clear benefits if it could be incorporated without driving cost to unacceptable levels, although this is a long-term prospect at best. Some types of insulation used in panel products outperform mineral fiber materials on an inch-for-inch basis, so assembly R-value could be improved over typical cathedral ceilings built without oversized framing or trusses.
Durability:	Shingle blow-offs could be eliminated by eliminating shingles, and the lifetime of this assembly could easily reach 50 years. Factory quality control in fastener installation could improve roof diaphragm action in high winds.
Safety:	Minimizes worker exposure to the hazards of constructing roofs in-place.

Technology Development Risks and Barriers

Structural design issues vary by location but would need to be addressed. Extremely durable gaskets or joint treatments between adjacent panels and at the roof ridge are required. It is not clear how to produce the panels on-site or close by without sacrificing potential economies of scale and quality control. A flexible approach to production is needed for the system to work with the complex rooflines found in many new homes. An interior surface that withstands some flex during transportation and installation without cracking or requiring extensive refinishing is necessary.

Other Risks and Barriers

Various code issues arise concerning roof assembly ventilation and non-standard roof covering systems. Problems in the distribution chain if producers or middlemen need to stock many variations of the basic panel. Logistical issues with transportation of very long or wide panels limit opportunities for centralized production and scale economies. There is limited value of hydronic piping in markets where central air conditioning is standard.

Estimated Time to Develop and Deploy

3 years (for all but the PV elements)

Estimated Development Cost