

# **The Road to Peak Performance Homes: Top Innovations from Building America Transforming American Housing**

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## **ABSTRACT**

Most industries invest nearly 4 percent of annual revenue into research and development. The housing and remodeling industries invest a small fraction of one percent. When innovations finally appear, the National Association of Home Builders reports it takes almost 25 years to be adopted by the housing industry. Meanwhile, housing in the U.S. accounts for 22 percent of total energy consumption. The U.S. Department of Energy's (DOE's) Building America program addresses both this critical innovation gap and the huge energy saving opportunity by delivering high-performance home solutions for new construction and retrofit and accelerating the market transformation process. The results have had profound impacts increasing energy efficiency and affordability, while improving comfort, air quality, and durability in U.S. housing. This includes knowledge of how to build homes 30 to 50 percent more efficient than minimum code and how to perform whole house retrofits that can reduce energy consumption by 30 percent or more. What are these major innovations? Unfortunately, they have been hidden within hundreds of detailed research reports and studies. It's time to stop hiding these innovations in the DOE library. In 2012, Building America is creating a 'Hall of Fame' for past innovations and will make a major announcement each subsequent year, promoting the latest innovations. This paper highlights these top innovations contributed by Building America research over the past decade-and-a-half and highlights new strategies to accelerate their adoption in the market place. World-class research can make a significant difference and that story needs to be effectively told.

## **Just Like Homes, Good Government Should Be Integrated 'As-a-System'**

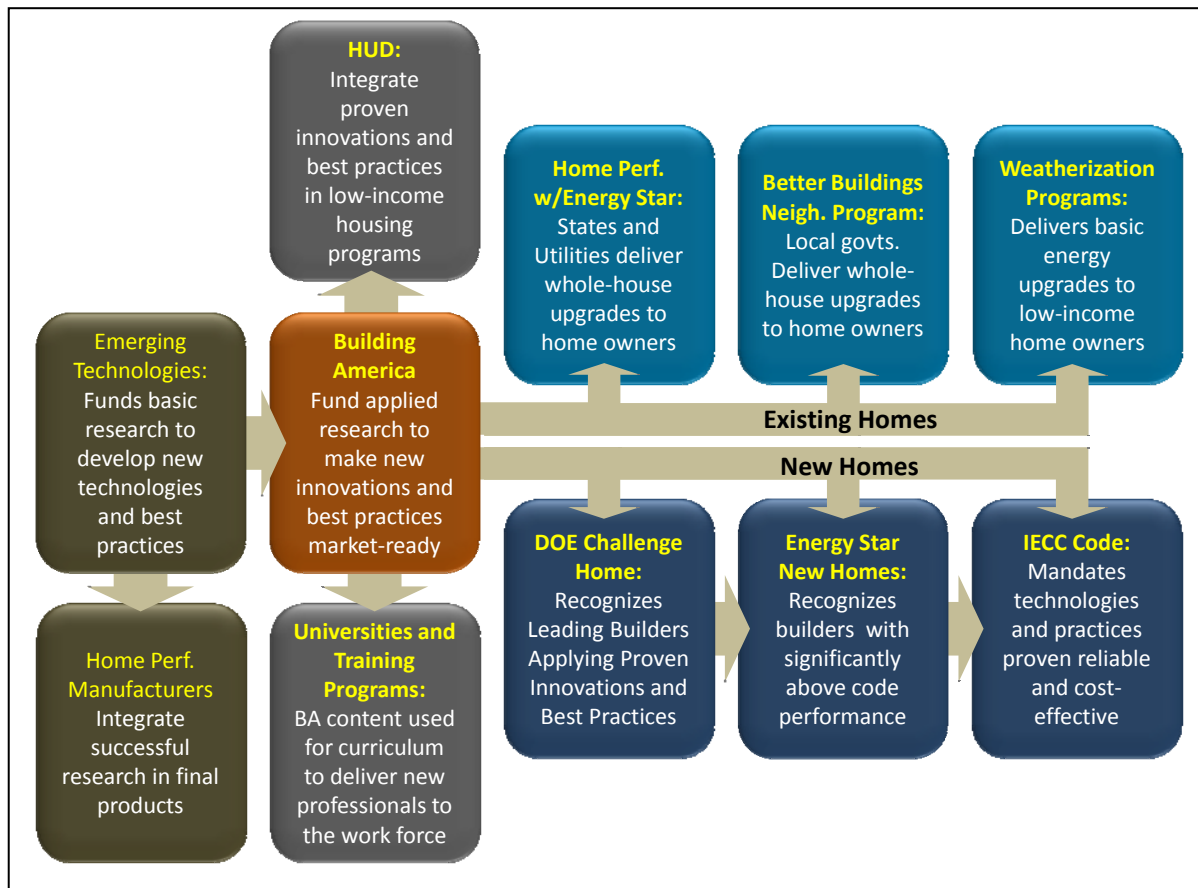
The house-as-a-system concept recognizes the importance of integrating critical systems and components for optimal home performance. Similarly, good government needs to address the interrelationships among a broad array of programs that can produce and deliver critical innovations to the market. With that concept in mind, Building America is part of a portfolio of residential programs at DOE's Building Technologies Program (BTP) that work together with industry as an effective integrated technology development system. This is accomplished with strategic hand-offs that allow home performance innovations and best practices to work through the entire market transformation process from applied research to full market adoption and/or inclusion in codes and standards (see Figure 1). This process can be summarized as follows:

- BTP's Emerging Technologies program funds applied research to accelerate development of new technologies and then hands them off to the building and remodeling industries directly and through the Building America program.
- Building America builds upon new technology developments from the Emerging Technologies program and then addresses key research gaps that can help overcome remaining barriers to full market adoption of high-performance new and existing homes.

- On the new homes side, Building America feeds market-ready innovations directly to the DOE Challenge Home program, which recognizes leading edge builders applying proven technologies and best practices.
- Where the resulting DOE Challenge Home specifications prove market ready, they can then pass on to the U.S. Environmental Protection Agency’s (EPA’s) ENERGY STAR for Homes Program and ultimately to the building codes (e.g., the International Energy Conservation Code – IECC).
- Building America also provides direct support to ENERGY STAR for Homes, resolving technical issues and removing important barriers in the codes and standards process.
- On the existing homes side, Building America supports DOE programs including the Better Buildings Neighborhood Program, Home Performance with ENERGY STAR and the DOE Weatherization Assistance Program.
- Building America provides additional support assisting HUD programs for low income housing, integrating building science into college curriculum for the next generation of professionals, and training the existing housing industry work force.

Thus, Building America is at the hub of an effective system for development and implementation of innovations and best practices for new and existing homes.

**Figure 1. U.S. DOE Residential Programs Hand-Offs and Market Transformation**



Source: Sam Rashkin, U.S. Department of Energy 2012

## Top Innovations: The Building America Story

The nation's housing industry is extremely fragmented. According to one count, there are almost 100,000 home builders (CB 2007). Similarly there are nearly 90,000 home remodeling contractors and an even larger number of individual trade contractors for heating and cooling, insulating and air sealing, and window replacement (CB 2008). Whereas typical industries invest nearly 4 percent of revenue into research and development (BAH 2010), it is estimated that the housing and remodeling industries invest a fraction of one percent<sup>1</sup>. Moreover, the nation's residential sector accounts for over 22 percent of all energy consumed in the country with tremendous opportunities for greater efficiency (EIA 2012). Building America was initiated by DOE in 1995 as a national research program to address the disparate and poorly funded research efforts of the housing and remodeling industries. The program funds integrated research into market-ready technology solutions through collaborative teams partnered with building and remodeling industry leaders. Initially the focus was on new construction, but starting in 2010, the program has allocated more than half of its funding to retrofit projects.

After a decade-and-a-half, what has been the impact of the investment in Building America research? DOE staff addressed this question by reviewing existing program publications and working with participating national laboratories and Building America teams to identify specific innovations resulting from Building America projects that have had the most profound impact in transforming the housing and retrofit industries to high-performance homes. Once a master list of innovations was compiled, it was prioritized and sorted to uncover a basic framework underlying the research results. Here's the Building America story that resulted from this effort:

- ***New building science solutions*** have been developed to address critical knowledge gaps and market barriers preventing large scale adoption of proven technologies and techniques for delivering high-performance (i.e., affordable, comfortable, healthy, and durable) new and existing homes;
- ***House-as-a-system approaches*** have been developed and demonstrated, providing cost effective whole-house solutions for new and existing high-performance homes;
- ***Innovative business solutions*** have been adopted by participating builders and contractors showing how high-performance homes are directly linked to critical business metrics;
- ***Effective guidance and tools*** have enabled new innovations and best practices to be easily applied and more accurately researched; and
- ***Infrastructure development*** has helped prepare current and future generations of professionals to deliver high-performance new and existing homes and targeted barriers have been removed from codes and standards.

These five major categories of innovations and their sub-categories are highlighted in Figure 2, and described next in further detail.

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<sup>1</sup> The authors are not aware of any documented estimates of industry funded R&D, and typical financial statements of publically traded homebuilders do not report any R&D expenses. Therefore, the authors estimate that housing industry R&D percent is quite low (a fraction of a percent), based on decades of experience observing the industry and querying experts.

## Top Innovations ‘Hall of Fame’

DOE plans to promote these past Building America Top Innovations to help accelerate their market adoption. After reviewing the entire history of innovation in the program, over 50 of the most significant projects have been nominated for inclusion in what is being called the Top Innovations ‘Hall of Fame’. Each subsequent year, a few completed new projects will be selected and announced as that year’s Top Innovations, and the prior year Top Innovation projects will then be added to the ‘Hall of Fame’.

At the time of writing this paper, the final selection process for the initial Top Innovations ‘Hall of Fame’ was still underway. The following descriptions give examples of innovations being considered under each major- and sub-category. Most examples come from a Building America document that highlights results from the first ten years of the program, including technical details, contributing researchers, and industry partners for each major innovation (DOE 2006).

**Figure 2. Building America Top Innovations by Category**

1. Building Science Solutions	2. House-as-a- System Solutions	3. Business Solutions	4. Effective Guidance and Tools	5. Infrastructure Development
Advanced Technologies and Practices	New Homes w/Whole-House Packages	High-Performance Homes Don't Cost More	High-Performance Home Solutions	Educating Next Generation Professionals
Assured Moisture Protection	Existing Homes w/ Whole-House Packages	High-Performance Homes Are Better Business	High-Performance Home Metrics	Educating Housing Industry Professionals
Assured Health and Safety	High-Perf. Homes with Ultra-Low Peak Loads	Support Whole-House Programs	Research Tools	Informing Code/Standards Process

Source: Sam Rashkin, U.S. Department of Energy 2012

### Building Science Solutions: Advanced Technologies and Practices

**Advanced framing systems.** Extensive knowledge on advanced framing techniques is currently available to builders to help minimize thermal bridging in insulated wall assemblies while also reducing material costs, labor costs, call-backs, and waste disposal. Building America was instrumental in developing and documenting solutions for advanced framing and then proving their effectiveness in production homes.

**High-R walls.** As the housing industry progresses towards net-zero-ready performance, wall enclosures will demand cost-effective, durable solutions for assemblies with very high R-values

(30-40ft<sup>2</sup>h<sup>0</sup>F/Btu and above). Several Building America teams have worked with production builders on these assemblies delivering valuable insights on practical ways to construct durable and effective high-R walls. These assemblies can be very cost-effective, especially in cold climate new construction, with the resulting thermal loads so low that simpler, lower-cost HVAC systems become possible.

**Unvented attics.** Building America research in the first phase of the program helped determine that locating HVAC equipment and ducts inside conditioned space was one of the most cost-effective energy saving measures. However, a variety of practical limitations made this more challenging for production builders, including floor space, noise, and simplicity of construction concerns. Building America developed two different types of solutions to these problems: 1) address builder constraints through improved designs, allowing installation of the HVAC equipment and ducts inside the conditioned living space, or 2) expand the conditioned-space boundary outside the space where the HVAC components are installed (i.e., the attic). One very successful Building America solution employed this second option by insulating and air sealing the roof slope rather than the ceiling (attic floor). This eliminates the thermal control challenges associated with the myriad of holes, cracks, and openings at the attic ceiling interface. By developing proven methods such as unvented attics, installing duct systems inside the conditioned space has gained significant use across the nation.

**Simplified duct distribution.** As thermal enclosures substantially improved, duct distribution systems no longer needed to reach extremities to compensate for leaky construction, poorly insulated walls, and inefficient windows. Building America developed guidance and practices for compact duct layouts including solutions for sound and vibration dampening and then proved their effectiveness with a diverse group of production builders.

**Tankless gas water heater performance.** As instantaneous hot water heating technologies make major inroads in the hot water heating market, there is greater urgency to understand their actual performance and installation issues. Building America research uncovered that energy savings are not linear with hot water use (e.g., as usage increases, the amount of savings decreases). This better understanding of actual performance helped improve the accuracy in estimating energy savings with replacement of storage type water heaters and provides a basis for developing an improved federal test standard for tankless water heaters.

### **Building Science Solutions: Assured Moisture Protection**

**Basement insulation with moisture control.** For a variety of cost and ease-of-construction issues, most basements in new homes in recent years have been insulated on the interior. The addition of interior insulation in basements, along with other components (e.g., vapor barriers, wood framing, drywall, paint, etc.), have led to significant changes in the way heat and moisture move through basement wall assemblies. These changes are often for the worse because interior insulation makes inside basement wall surfaces colder, increasing opportunities for condensation. Furthermore, vapor barriers installed on interior basement walls decrease the ability for basement wall assemblies to dry, resulting in increased incidence of mold, rot, and odor problems in both new and existing homes. Building America research has provided code-compliant (i.e., fire rating) interior insulation strategies that permit moisture from the soil and curing concrete to move through and out of the concrete and the interior insulation. This innovation is critical for

high-performance homes because it enhances energy performance goals, while controlling moisture, mold, and odor problems.

**Moisture control in high-r assemblies.** As thermal insulation levels are increased in high-performance homes, the rate of drying for thermal enclosure assemblies decreases. Traditional rain control has been shown to be ineffective in highly insulated and airtight building assemblies. Rigorous testing with test huts has led to the development of rainwater control recommendations for insulating sheathings, non-insulated sheathings, building papers, house wraps, and other water resistant barriers. In addition, data from instrumented test walls in key climate zones were used to determine boundary conditions for hygrothermal modeling. This modeling was then used to develop climate specific recommendations for vapor control with the use of insulated sheathings. These have been submitted by DOE in the 2008 ICC code development cycle.

### **Building Science Solutions: Assured Health and Safety**

**Simple residential ventilation systems.** The transition to high-performance homes demands cost-effective solutions for whole-house ventilation. Building America research has developed a series of simple, low-cost ventilation strategies for different climates that can consistently comply with the latest ASHRAE 62.2 standard. This includes a simple air handler integrated ventilation controller for supply-only ventilation and field testing to verify simple exhaust-only systems can be effective in specific applications.

### **House-As-a-System Solutions: New Homes with Whole-House Solutions**

**Net zero energy home demonstrations.** Building America teams have worked with a variety of production builders on ultra-low energy homes ready for net-zero performance as well as full net-zero homes including renewable energy systems. These whole-house demonstration projects have provided critical field experience, monitoring data, and customer behavior information that will serve further efforts by the housing industry to provide net-zero homes.

### **House-As-a-System Solutions: Existing Homes with Whole-House Solutions**

**Affordable approaches to existing building rehabilitation.** Building America partnered with Habitat for Humanity to develop innovative, yet affordable, system-engineering research strategies for retrofit housing. This led to a set of rehab guidelines that helped construction managers incorporate high-performance improvements and learn from actual projects that demonstrated real-world applications.

## House-As-a-System Solutions: High-Performance Homes with Ultra-Low Peak Loads

**Premier gardens community.** In April 2004, Premier Homes opened the first standard ‘zero energy’ community in the Sacramento Region. Impressive 50 percent savings were experienced in both total energy consumption and peak demand. Moreover, the research results demonstrated that westerly facing solar electric systems accounted for marginal cost savings of 32 percent compared to east facing systems and 5.4 percent compared to south facing systems. These findings were used by the local utility and state energy office in the design of subsequent solar programs that took into account solar orientation. Thus, this innovation was instrumental in demonstrating net-zero energy homes can substantially address utilities’ need to reduce peak-demand. This is critical because utility programs are often a major contributor to successful market transformation objectives

## Business Solutions: High-Performance Homes Don’t Cost More

**Building America cost performance trade-offs.** Demonstrating zero- or low-cost “break points” or cost trade-offs is one of the most important factors driving successful deployment of Building America technologies with production builders. They involve construction strategies or levels of energy efficiency that allow a specific building component to be downsized or deleted. In other words, installing an energy efficient feature often allows for savings on one or more other components. For example, well-insulated and air-tight homes with advanced windows results in substantially reduced heating and cooling loads that saves cost on much smaller HVAC equipment (e.g., downsized equipment). Creating a conditioned attic by insulating the sloped roof and gables forgoes the need for roof vents, attic eave wind baffles, insulated attic hatches, ICAT recessed lighting fixtures, and air barriers at openings and kneewalls (e.g., deleted components). Examples of actual trade-offs from real projects are shown in Figure 3. Positive (+) values show increased installed costs; negative (-) values show savings.

**Figure 3: Building America Cost Trade-offs**

Example Cost Summary: Building America Metrics		Example Cost Summary: Building America Metrics	
Hot Dry Climate		Severe Cold	
Unvented Roof	+ \$750	Advanced Framing	- \$250
NOT Installing Roof Vents	- \$500	High-Performance Windows	+ \$250
High-Performance Windows	+ \$300	Controlled Ventilation System	+ \$150
Controlled Ventilation System	+ \$150	Power Vented Gas Water Heater	+ \$300
Downsize Air Conditioner 2 Tons	-\$1,000	Simplified Duct Distribution	-\$ 250
Sealed Combustion Furnace	+ \$400	Downsize Air Conditioner 1 Ton	- \$350
<b>TOTAL PREMIUM</b>	<b>+ \$100</b>	<b>TOTAL PREMIUM</b>	<b>- \$150</b>

Source: DOE 2006

## **Business Solutions: High-Performance Homes are Better Business**

**Energy bill guarantee programs.** Building America technical assistance effectively supported development of energy bill guarantee programs that would enable builders to back-up low energy cost claims to prospective homebuyers. This was possible by providing critical performance targets used to develop criteria for builder participation. This project provided a critical link between high-performance homes and the ability to offer a compelling consumer value proposition (e.g., peace-of-mind that low energy bills are assured).

## **Business Solutions: Support Whole-House Programs**

**ENERGY STAR for Homes support.** ENERGY STAR for Homes is a voluntary labeling program that was launched in 1996 to builders nationwide. The initial program threshold was based on a minimum HERS score. There was one problem. There was virtually no HERS industry. Building America was able to provide critical verification support that enabled ENERGY STAR for Homes to sustain itself during this early period.<sup>2</sup> As ENERGY STAR for Homes continued to develop, Building America developments provided technical underpinnings for specification changes. Today, Building America continues to provide assistance resolving ENERGY STAR for Homes technical issues. This is an excellent example of two government programs working synergistically to deliver market transformation.

## **Effective Guidance and Tools -High-Performance Home Solutions**

**Building America best practice series.** The vast lessons learned on advanced technologies and best practices from Building America are documented in a series of climate-specific guides. These guides have been instrumental in providing building science solutions that can be applied by builders and contractors including over 20,000 downloads per year from the Building America web site<sup>3</sup>.

## **Effective Guidance and Tools: High-Performance Metrics**

**National residential efficiency measures database.** Building America research has produced a public database that characterizes the performance and costs of common residential energy efficiency measures. This addressed a key gap in content for high-performance homes that has enabled a wide range of software programs to evaluate cost-effective retrofit measures for improving the energy efficiency of residential buildings.

## **Effective Guidance and Tools: Research Tools**

**Energy analysis software for optimization of energy saving solutions packages.** As part of the Building America program, NREL has developed a home performance modeling tool called BEopt that can simulate the energy performance of new or existing homes, efficiently analyze and prioritize various combinations of energy saving measures, and make recommendations for optimal performance. It includes a robust DOE2/EnergyPlus analysis engine fully linked to a

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<sup>2</sup> Observation of author (Sam Rashkin) while serving as National Director of ENERGY STAR for Homes.

<sup>3</sup> This is a conservative estimate based on over 9,000 views of Building America publications from March to May 2011 (one quarter).



cost/measure database to drive the optimization analysis. This tool allows all research under the Building America program to be benchmarked with a consistent tool. In addition, BEopt has developed significant improvements for whole-house simulations that lead to improvement of other software tools, including popular private sector home energy rating system (HERS) tools.

### **Infrastructure Development: Educating the Next Generation of Professionals**

**College building science curriculum.** Building America advanced technologies and best practices have been effectively integrated into university and college curricula for building science. Example curricula are featured on the Building America web site providing easy access to proven content for training the next generation of housing industry professionals (DOE 2012). This education infrastructure development also includes the National Consortium of Housing Research Centers with members from major universities promoting building science research and curricula in accredited architectural and engineering programs.

### **Infrastructure Development: Educating Housing Industry Professionals**

**Houses that work training.** Building America resources and content were a major contributor to this building science training program for builders and contractors. This program has reached thousands of builders and contractors with critical guidance for constructing high-performance homes. Moreover, the course content has found its way into numerous other building science training programs around the country, such as the annual EEBA Excellence in Building and ACI Home Performance conferences.

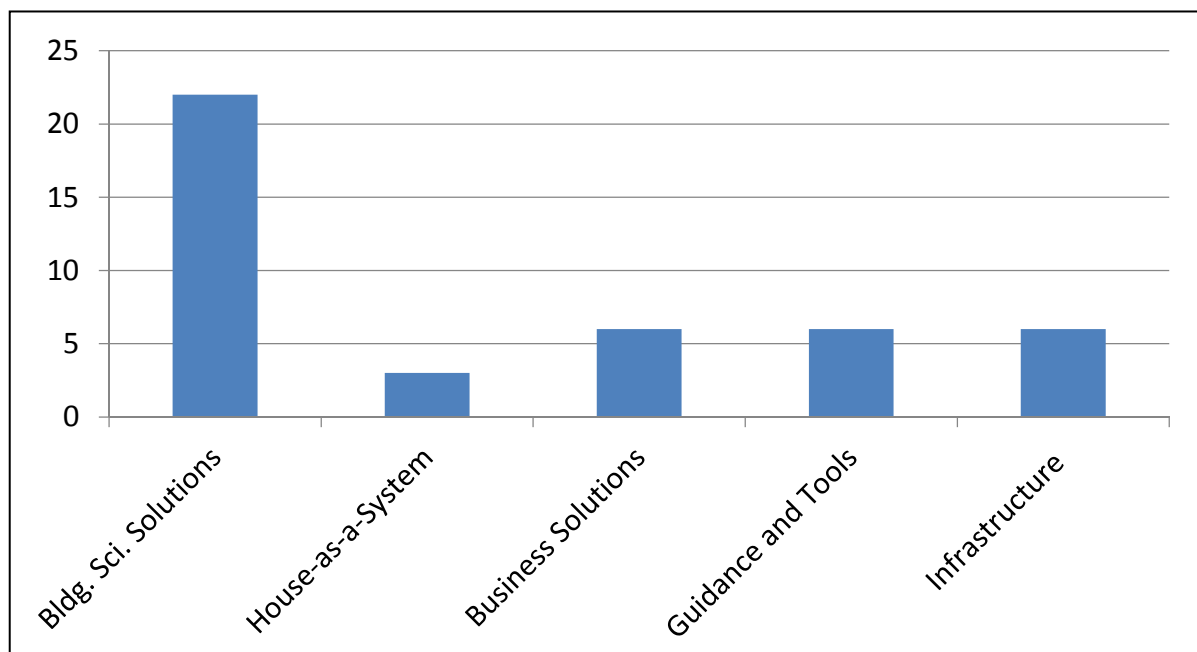
### **Infrastructure Development: Informing the Codes and Standards Process**

**Building code changes.** Work done on moisture control and high-R assemblies identified the need to alter significant building code provisions to facilitate the construction of energy efficient building enclosures. The work done with test hut construction and monitoring, computer simulation work, and field investigations and demonstrations culminated in an alteration of the 2006 IRC and IECC, deleting the outdated and problematic code requirements for interior vapor retarders and vapor barriers in one half of the nation (Zones 1 through 4). A pending code modification for Zones 5, 6, and 7 will result in allowing the construction of high-R assemblies without interior vapor retarders or vapor barriers. This will positively affect every building enclosure constructed in the nation.

## **Top Innovations Lessons Learned and Future Directions**

Based on the initial evaluation of Building America Top Innovations at DOE, the distribution of innovations across the five major categories is shown in Figure 4.

**Figure 4. Distribution of Building America Top Innovations**



Source: Sam Rashkin, U.S. Department of Energy 2012

Although there are impressive accomplishments for all Building America top innovations, this initial tracking reveals a definite skew towards developing new building science solutions, consistent historically with the number of Building America projects funded by category. There is an increasing focus with current work on whole-house and community scale demonstration projects. Additionally, a forthcoming guidance tool called the DOE Building America Solution Center is scheduled for release at the end of 2012. This new tool is expected to be a ‘game changer’ in terms of accelerating the delivery of world-class research results to all housing and contracting stakeholders much more expediently and with dramatically improved accessibility (web or mobile devices), organization, and ease-of-use. This tool will help stakeholders apply, promote, or educate on any high-performance home topic. Moreover, rather than fixed content, this tool will create a community of users with two-way communication that allows for feedback, content sharing, and continuous improvement.

Looking at these future developments along with existing Building America accomplishments suggests Building America has a strong portfolio of innovations in three of the major categories, but needs to bolster future program efforts in two others: business solutions and infrastructure development. There is a critical need for research in these areas because the housing industry needs compelling empirical results demonstrating a strong link to business objectives before embracing high-performance home innovations. Furthermore, an infrastructure of skilled high-performance home professionals and compatible codes is essential to deliver the proven innovations.

## **Conclusion**

The housing and remodeling industries are extremely disaggregated and systematically under fund research and development activities. DOE’s Building America program has helped industry overcome this limitation with a centralized world-class research program that actively engages with industry to develop energy-efficient whole house solutions. However, Building

America research results and best practice guidance need to more effectively disseminate proven innovations. Future Building America research should be held accountable to delivering vital results that serve targeted market transformation goals. On that basis, Building America program accomplishments were evaluated in detail relative to their contribution towards high-performance new and existing homes. The evaluation revealed there were five major top innovation categories that represent a comprehensive strategy for developing innovations and supporting transformation to new and existing high-performance homes. Further evaluation of the top innovations to date reveals current program developments are on target to fill critical needs, but suggests opportunities for increasing the effectiveness of Building America's market transformation goals with additional efforts targeting business solutions and infrastructure development. Thus, tracking top innovations has proven to be a vital tool for effectively communicating the return-on-investment for a major residential research program and an important reference for more effectively planning future research priorities.

## References

- [DOE] U.S. Department of Energy. 2006. "Building America System Research Results: Innovations for High Performance Homes." [http://apps1.eere.energy.gov/buildings/publications/pdfs/building\\_america/building\\_america\\_lessons\\_2006.pdf](http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/building_america_lessons_2006.pdf). Washington, D.C.: U.S. Department of Energy.
- [CB] U.S. Census Bureau. 2007. "2007 Economic Census." Washington, D.C.: U.S. Census Bureau.
- [CB] U.S. Census Bureau. 2008. "County Business Patterns Report, 2008." Washington, D.C.: U.S. Census Bureau.
- [EIA] Energy Information Agency. 2012. "Total Energy Flow, 2010." <http://www.eia.gov/totalenergy/data/annual/diagram1.cfm>. Washington, D.C.: U.S. Department of Energy.
- [DOE] U.S. Department of Energy. 2012. "Building America Resources: Building Science Education." [http://www1.eere.energy.gov/buildings/building\\_america/education.html-University](http://www1.eere.energy.gov/buildings/building_america/education.html-University). Washington, D.C.: U.S. Department of Energy.
- [BAH] Booz Allen Hamilton. 2010. "Corporate R&D Spending Declined During 2009 Downturn, Finds Booz & Company Global Innovation Study," November 3, 2010, <http://www.booz.com/global/home/press/article/48789421>. Booz Allen Hamilton.