2 Research and Development

Under our Research and Development (R&D) activities, BT will conduct a balanced portfolio of high-risk and applied research to accelerate the introduction of energy-efficient building technologies and practices.

Research is conducted in two areas: systems integration and component R&D. Systems integration research and development activities analyze building components and systems and integrate them so that the overall building performance is greater than the sum of its parts, often using the components developed by BT. In turn, research and development of individual building components (such as envelope and equipment/appliances) provides the technical basis for significant contributions to achieving net-zero energy performance in buildings.

BT's challenge is to address the opportunities with appropriate strategies, and design subprograms that give appropriate consideration to the trends in the marketplace and barriers to energy efficiency. To accomplish this, the BT will implement the following strategies:

- Use a "whole buildings" approach to energy efficiency that takes into account the complex and dynamic interactions between a building and its environment, among a building's energy systems, and between a building and its occupants. This is often referred to as building systems integration.

- Focus the R&D portfolios using Stage-Gate methodology[1] to ensure that the most promising, revolutionary technologies and techniques are being explored, and close efforts where investigations prove to be technically or economically infeasible; align the Residential and Commercial Integration subprograms to a vision of net-zero energy buildings; and appropriately exit those areas of technology research that are sufficiently mature or proved to the marketplace.

Stage-Gating provides specific evaluation points, gates, where a project is evaluated on pre-determined criteria and, approved for the next phase, rejected, or recycled to resolve issues. Each phase has must-meet and should-meet criteria. The project is required to address the should-meet criteria to receive additional funding, then it proceeds to the next phase where the project is typically held to the previous phase's should-meet criteria.

Through BT's multi-year planning and the Stage-Gate process, key priorities were developed for selection of the portfolio of activities. These priorities are (in order of importance):

1. Research and development to create systems integration solutions to enhance the technical energy efficiency of whole residential and commercial building new construction (including substantially new commercial construction) leading to marketable zero energy homes in 2020 and commercial zero energy buildings in 2025.

2. Research and development to create technical solutions to component and equipment advancement needs identified through system integration research activities conducted in priority.

3. Research and development activities of an enabling nature (including simulation software and design guides) that enhance and support the activities conducted in support of priorities 1 and 2.

4. Research and development in systems integration, components and practices that when implemented primarily improve the technical efficiency of existing homes or commercial buildings through equipment replacement or retrofit.

Through the BT portfolio analysis and multi-year planning, technical targets were developed for Research and Development activities, including both top-down and bottom-up approaches:

- The top-down approach (from the integrated whole building perspective) establishes the component-by-component cost and performance needed to get to the optimized economic and performance result.

- The bottom-up approach (from the component perspective) informs the top-down perspective by establishing the baseline (standard current practice), best current available, projected improvement, and max potential performance of components.

Reconciling the two approaches yields the identification of gaps between the top-down performance needs and the bottom-up technologies, and this process also identifies the "good enough" states for the components in the optimized whole buildings context.

The individual component subprograms of Research and Development identify a time-specific target for providing the cost-performance solutions identified in the integration activities (residential and commercial). Further, the component research subprograms identify the maximum technical potential as an exit criteria past the target associated, which satisfies the whole building need, only if a strong enough justification for going beyond the optimized need can be made. Setting component targets in excess of the identified needs is prudent given the uncertainty that every component would exactly meet the stated need, and thus higher performance component research goals would allow for trade-offs and flexibility in meeting the zero energy building (ZEB) goal.

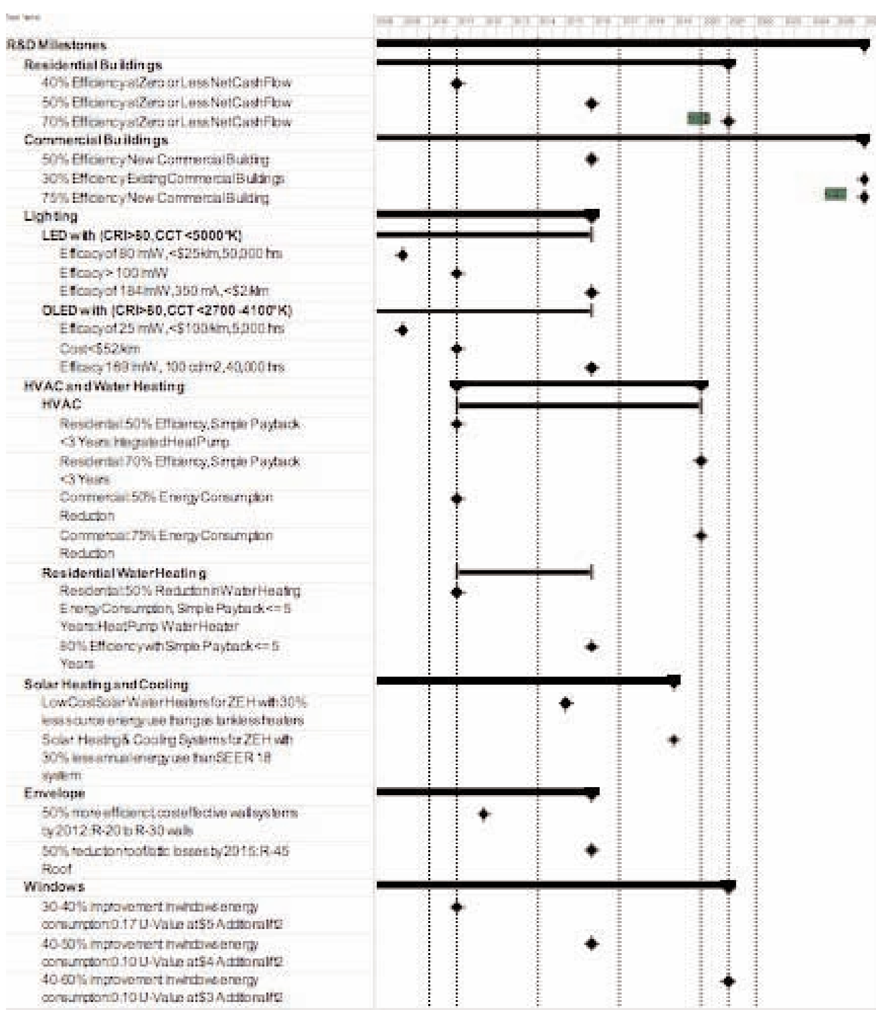
1 Adapted from Robert Cooper, "Winning at New Products, Accelerating the Process from Idea to Launch." Perseus Books Group. 3rd Edition. 2001. ISBN: 0738204633

With the long-term ZEB goal in mind, BT has developed the following key Research and Development targets to be achieved over the next five years.

- By 2010, develop technologies and design strategies that can achieve an average of 40 percent reduction in purchased energy use for new residential buildings.
- By 2010, develop five or more cost-effective design technology packages that can achieve an average of 30 percent reduction in purchased energy use for new, small commercial buildings.
- By 2012, develop Solid State Lighting laboratory devices with 125 lumens per Watt.
- By 2010, develop heating and cooling systems with the technical potential to reduce annual HVAC, dehumidification, and water heating energy consumption by 50 percent.
- By 2010, develop attic/roof systems with dynamic annual performance equal to conventional R-45.
- By 2010, develop wall systems with dynamic annual performance equal to conventional R-20.
- By 2010, Develop low-cost (target $20/ft2 in 2010), durable (measured by number of cycles to failure, per ASTM standard) prototype dynamic window with 30-40% energy consumption improvement.

These intermediate goals over the next five years are part of BT's critical path to achieving the ZEH strategic goal by 2020 and ZEB by 2025. The following Gantt chart summarizes the major R&D milestones and decision points on the path to ZEB.

Figure 2-1 Major ZEB Milestones



As shown in this MYP, we have arrived at our technology portfolio through rigorous internal evaluations, using objective investment criteria, as well as examining key opportunities offered by our external partners, including industry, universities, and other government agencies (see Chapter 5 for more detail). By bringing together relevant stakeholders, the BT has been able to build the critical mass necessary to address many of the barriers to increasing the energy efficiency of buildings and equipment. The path to ZEB outlined here will show continuous demonstrated success, focusing on incremental steps (such as 30 percent then 50 percent for homes) and a series of technical targets.

The following sections describe the results of this planning as well as the priority activity areas for BT Research and Development to meet the ZEB goal.

2.1 Residential Integration

The Residential Integration (RI) subprogram, primarily Building America activity, focuses on improving the efficiency of the approximately 1.5 million new homes built each year.[2] These improvements are accomplished through research, development, demonstrations, and technology transfer of system-based strategies. The system-based strategies improve whole house source energy efficiency through integrating technologies to achieve reductions in all residential energy uses, including space heating and cooling, ventilation, water heating, lighting, and home appliances. These activities support efforts to develop strategies to integrate solar energy applications and other renewable technologies into buildings, and increase energy efficiency to achieve net-zero energy homes (ZEH). Working with various partners, Building America will achieve ZEH by 2020 for six climate zones by increasing energy efficiency, with intermediate efficiency goals, and incorporating renewable energy technologies. Outputs from the subprogram include technology package research reports, which represent research results achieving a particular level of performance. These reports, as well as other research reports, form the basis for Best Practices manuals tailored to specific climate regions. Table 2-1 summarizes the subprogram's history, including past accomplishments and future direction.

Table 2-1 Residential Integration Summary

Start date	1995
Target market(s)	New, single-family residential buildings
Accomplishments to date	• Developed the Building America Benchmark Definition • Developed protocols for validating whole house energy tools • Documented research and publishing Houses That Work, Builder Guides, and Best Practices manuals • Increased the number of ENERGY STAR® Homes • Completed 15% whole house Best Practices • Developed Building America benchmark for whole house energy use • Completed 4 climates at 30% energy savings compared to Building America benchmark • Completed 40,371 Building America houses • Developed advanced duct systems for factory built housing • Completed Nightcool
Current activities	2008 activities: Developing integrated cost-effective, whole building strategies to enable new, single-family residential buildings to use 40% less total energy than the Building America Benchmark in the Mixed-Humid climate. Also working towards 40% reductions in Marine and Cold climates in 2009.
Future directions	Continuing to develop the strategies for new, single-family residential buildings to use 40-100 percent less energy than the Building America Benchmark in the Marine, Hot-Humid, Hot-Dry/Mixed-Dry, Mixed-Humid, and Cold climate regions
Projected end date(s)	2020
Expected technology commercialization dates	See Table 2-4 Residential Integration Efficiency Performance Targets by Climate Regionls

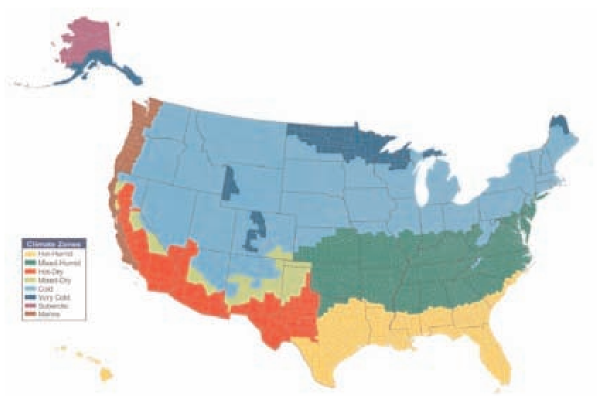
2 National Association of Home Builders, *Annual Housing Starts (1978-2006)*, 2006. http://www.nahbregistration.com/generic.aspx?sectionID=130&genericContentID=554

There are currently thirty-six states working with Building America on 40,371 total projects, resulting in over 989 Billion BTUs saved.[3] In addition to the state programs, Building America has projects involving 318 builder partners.[4] Building America directly benefited 648 houses in 2007 and a total of 40,371 houses over the 10 year program duration. The ENERGY STAR® new homes program has also directly benefited from Building America research and continues to utilize and promote the research results. Due to the program's outreach efforts at professional and builder conferences as well as with trade press media, the number of homes indirectly built with Building America best practices is far greater, up to the hundreds of thousands.

Table 2-2 Total Research Houses by Climate Region[6]

Climate Region	Number of Houses
Hot-Dry	23,661
Hot-Humid	4,024
Mixed-Dry	1,524
Mixed-Humid	921
Cold	5,073
Very Cold	14
Subarctic	1
Marine	1,641

Figure 2-2 Building America Climate Regions[5]



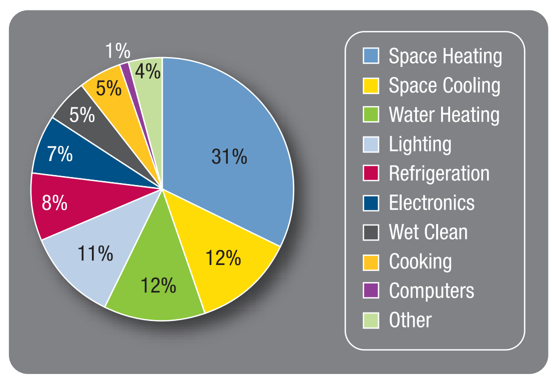
Unlike other building types, residential buildings include a limited number of different end uses with many similarities in a particular climate region. Therefore system solutions can be replicated on a regional basis. Figure 2-2 shows the climate regions defined by Building America and Table 2-2 lists the number of research houses by region.

Building America currently focuses on six of the eight climate regions: Marine, Hot-Humid, Hot-Dry/Mixed-Dry, Mixed-Humid, and Cold. Very Cold and Subarctic were addressed in the past, but due to a lack of growth, they are currently omitted from development. The majority of the prototype home activity is in the Hot-Dry and Cold regions due to the relative number of housing starts in these climates.

2.1.1 Residential Integration Support of Program Strategic Goals

In 2005 the US consumed 100.2 quads and the buildings sector represented 40% of the total energy consumed. Within the buildings sector, residences used the majority of the energy, representing 55% of the total energy consumed and accounting for 21.8 Quads in 2005.[7] The largest end uses of energy in a home are space heating and cooling, water heating, and lighting as shown in Figure 2-3.

Figure 2-3 2005 Residential Buildings Primary Energy Use[8]



3 http://www.eere.energy.gov/buildings/building_america/cfm/project_locations.cfm, accessed Sept. 26, 2007.

4 NREL, Bob Hendron. Email Communication.

5 Anderson, Ren, et all, Analysis of System Strategies Targeting Near-Term Building America Energy-Performance Goals for New Single-Family Homes, November 2004, National Renewable Energy Laboratory. Report No. TP-550-36920.

6 Source: NREL 2007

7 BED

8 BED

The Residential Integration subprogram goal is to develop integrated energy efficiency and onsite renewable power solutions that will be evaluated on a production basis in subdivisions to reduce whole-house energy use in new homes by an average[9] of 50% by 2015 and 70% by 2020 compared to the Building America Benchmark[10] at neutral cash flow.[11] These efficiency solutions will help to achieve the strategic goal of ZEH by 2020 when combined with on-site renewable energy generation.

2.1.2 Residential Integration Support of Program Performance Goals

Building America developed the following performance goals for each phase of the systems approach. The performance targets show the energy savings from improvements in efficiency that will be reached on the path to net-zero energy homes in 2020, under the base research schedule. It is feasible to accelerate achievement of these goals by three to four years if additional resources are available.

Table 2-3 Residential Integration Efficiency Performance Goals[12]

		Year				
Characteristics	Units	2008	2010	2015	2019	2020
Average Energy savings	%	30	40	50	60	70
Home Owner Cost	$	Neutral Cash Flow				

9 The distinction between the average savings and the range of savings is important because it is not cost-effective (or even possible without wasteful over engineering) to design a net-zero energy home for every possible potential occupant. Because the range of possible occupant behavior is large, the average savings target in 2020 is 95%. This average will include a significant number of homes that achieve 100% savings, ensuring that the goal of net-zero energy homes is met.

10 Building America Research Benchmark Definition, 2006, National Renewable Energy Laboratory.
http://www.eere.energy.gov/buildings/building_america/pdfs/40968.pdf

The Building America Research Benchmark Definition consists of the 2000 IECC envelope requirements plus, HVAC, lighting, appliances and plug load energy levels derived from best available research studies and energy use data for 1990's housing stock.

11 Net cash flow is the monthly mortgage payment for energy options minus the monthly utility bill cost savings. "Neutral" means that monthly utility bill cost savings are equal to the monthly mortgage payment for energy options. In other words, the increase in a 30-year mortgage payment is offset by the energy savings.

12 Year of completion of annual Joule targets in six climate regions. Energy savings are measured relative to the BA Research Benchmark. This schedule assumes that funding for the systems research activities will remain at FY 2008 levels.

13 The current Building America target year for completion is 2020. Climate zone target dates for the 70 percent level are dependent upon progress at lower target (energy savings) levels and will be determined in a future planning cycle; some climate zones may be completed before 2020.

14 Berson, David, et al, America's Home Forecast: The Next Decade for Housing and Mortgage Finance, 2004, Homeownership Alliance. http://www.homeownershipalliance.com/documents/americas_home_forecast_005.pdf

Building America has also specified the following interim performance targets for each climate region, which also serve as the annual Joule milestones for the subprogram.

Table 2-4 Residential IntegrationEfficiency Performance Targets by Climate Region

Target (Energy savings)	Marine	Hot-Humid	Hot-Dry/ Mixed-Dry	Mixed-Humid	Cold
40%	2009	2010	-	2008	2009
50%	2011	2015	2012	2013	2014
70%[13]	2020	2020	2020	2020	2020

The performance targets are incremental percentages to manage research risks, closely track progress, and allow early identification and targeting of barriers to achieving the strategic goal. Hence, the Building America systems research strategy increases the performance targets leading toward long-term strategic goals based on the successful development of system solutions at the previous performance level. These goals are adjusted and reviewed on an annual basis relative to current year technical progress and barriers.

2.1.3 Residential Integration Market Challenges and Barriers

Building America targets single-family homes because they are the most significant residential sector from an energy use and growth in energy use perspective. Technologies developed for single-family homes can often be applied to multi-family and existing homes.

The residential sector is the largest user of energy for buildings, and single-family homes currently consume approximately 80% of the energy used for residential buildings. New homes are significant contributors to the growth of peak electric demands during the cooling season because of the high market penetration of air conditioners. Not only do single-family homes account for four-fifths of the residential energy use, but over the next decade the single-family home sector is projected to grow and account for over 70% of new housing units.[14] The remainder includes both multi-family and manufactured homes.

Construction of new homes requires the combined efforts of a numerous suppliers and contractors whose efforts are coordinated by a large number of builders. Because of the high costs of failure, the residential construction industry is highly risk-intolerant and first-cost sensitive.

The key market barriers to development of advanced residential energy systems are the large number of market players, the relatively low level of investment in R&D relative to other sectors of the economy, and the strict requirements for market acceptance based on achievement of low incremental costs and high reliability. The market barriers to meeting the strategic goal and performance goals are summarized in Table 2-5.

Table 2-4 Residential Integration Market Chellenges and Barriers

Barrier	Title	Description
A	Identification of cost neutral system solution	Evaluation and validation of most cost-effective options needed to achieve target energy savings
B	Integration of advanced component	Identification of performance gaps and advanced component cost and performance requirements
C	Acceptance of new building practices by industry leaders	Evaluation of new system options on a cost shared basis with lead builders, manufacturers and contractors is required for acceptance
D	Acceptance of new building practices by industry leaders	Identification of issues where additional performance information is required by local and national code officials to facilitate broad use of advanced systems require
E	Quality management tools and practice	Development of quality management practices in order to gain market acceptance of high performance homes

2.1.4 Residential Integration Technical (Non-Market) Challenges/Barriers

The key technical barriers are the large number of technical performance requirements that must be met before a new system can be implemented on a production basis. These technical performance requirements are driven by regional differences in building energy loads and construction techniques. For example, systems that work well in cold climates may not be applicable in hot climates. The technical barriers to meeting the strategic and performance goals are described in Table 2-6.

Table 2-6 Residential Integration Technical Challenges/Barriers

Barrier	Title	Description
F	Self-drying high R wall assemblies	Identification of flashing and drainage plane details required to block wind-driven rain and smart vapor barriers to permit drying in both directions Development of integrated framing, insulation, air barrier, and vapor barrier details required to construct durable high-R walls
G	Advanced foundations subsystems, tools, and practices	Development of advanced durable, energy efficient foundation systems needed to address moisture, termites, durability, and energy efficiency issues
H	High performance hot water systems for cold climates	Reduction of distribution losses, recovery of waste heat, integration of tankless hot water systems, and integration of simple, durable, low cost solar hot water systems are required for cold climates
I	Miscellaneous electric loads	Improvement of miscellaneous electric end-uses' energy efficiency and reduction of standby losses
J	Supplemental dehumidification systems for Humid climates	Development of efficient, reliable, low cost supplemental dehumidification systems for hot humid climates that are capable of maintaining internal RH below 50% during periods when the demand for sensible cooling is low
K	Efficient low capacity space conditioning systems	Development of cost effective and efficient space conditioning systems with capacities 50% less than current systems, including integration with night cooling, and evaporative cooling options, as well as development of efficient/low cost ground coil systems
L	Air distribution study	Evaluation of systems that can provide uniform mixing of air with low-tonnage HVAC in heating and cooling climates while minimizing duct thermal and pressure losses
M	Supplemental ventilation strategies	Development of reliable energy-efficient ventilation systems for very high performance homes
N	High performance windows for Cold climates	Development of a window with an overall performance of R-10 or better
O	Modeling for ground source heat pumps	Modeling of thermal load profiles in soil conditions for ground source heat pump design and energy analysis
P	Electric and thermal storage	Feasibility testing for peak heating reductions using electric and thermal storage
Q	Desiccant cooling	Development of energy-efficient advanced direct expansion systems to improve latent load fraction

2.1.5 Residential Integration Approach/Strategies for Overcoming Challenges and Barriers

Building America conducts a systems research approach for single-family homes in six climate regions to meet the stated goal of developing integrated energy efficiency and onsite/renewable power solutions to reduce whole-house energy use in new homes by an average of 50% by 2013, with the ultimate goal of ZEH by 2020.[15] In order for energy-efficient solutions to be viable candidates over conventional solutions, they must cost-effectively increase overall product value and quality, while reducing energy use. Building America's systems research approach provides opportunities for cost and performance trade-offs that improve whole building performance and value, while minimizing increases in overall building cost. Alternately, a component research approach would not account for system interactions, creating integration barriers and additional risk in meeting energy savings goals cost-effectively.

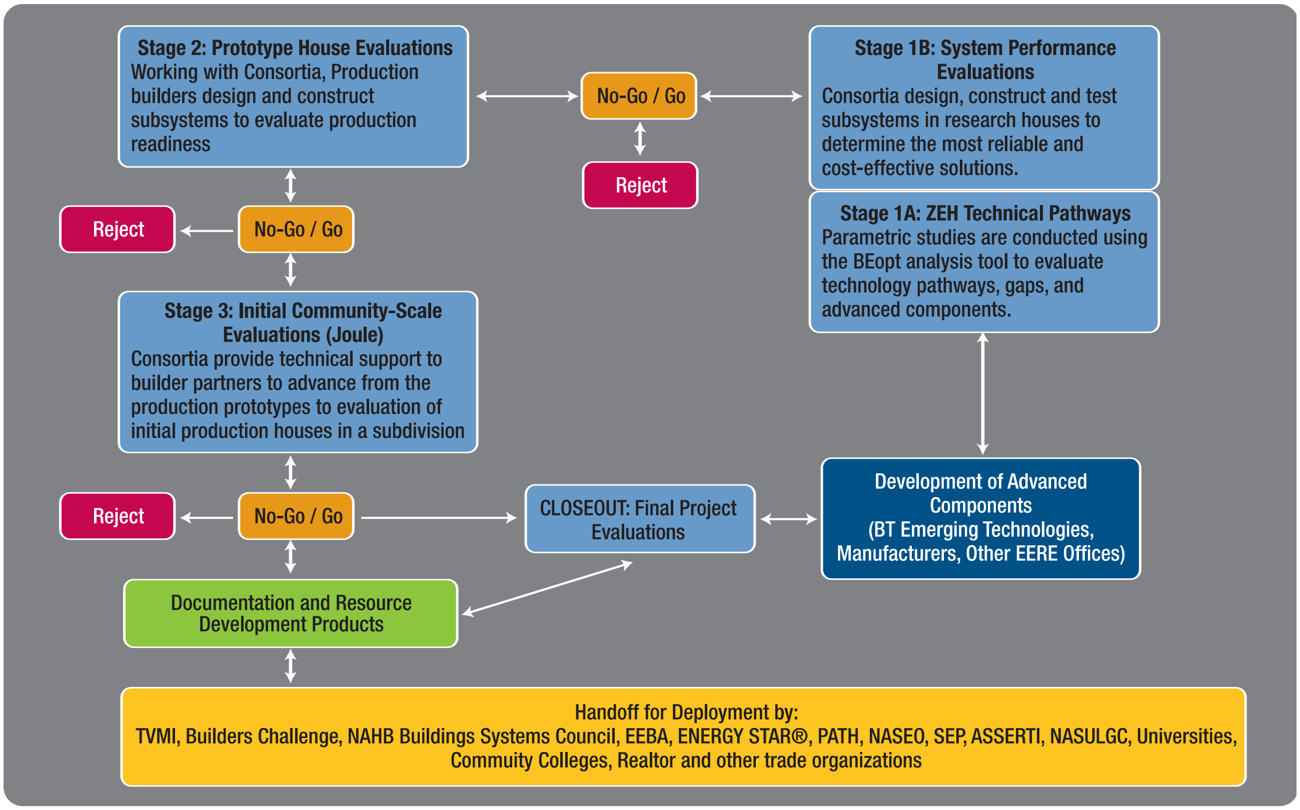
Building America performs systems research by combining operations research and systems engineering in the Stage-Gate process. The first step utilizes operations research techniques to identify the technology pathways that will achieve the target energy savings in each climate region for the lowest installed cost. From these results, the optimal efficiency targets can be identified and technologies can be developed that will meet the energy savings needs cost-effectively in all climate regions. The second step in the systems research is to implement the optimal technology pathways through systems engineering in prototype homes. The step identifies challenges and barriers unanticipated by the optimization. The combination of operations research and systems engineering ensures that the solutions created will meet the energy savings and cost goals, and can be used on a production basis.

The systems research described above is applied in three stages (with a final closeout stage) for each climate zone and a stage gate planning process is used to review the project status after each stage is completed (Figure 2-4). Building America acts as a national residential energy systems test bed where homes with different system options are evaluated, designed, built and tested during the three stages. To accelerate progress towards multi-year goals, research is conducted in parallel at different performance levels, facilitating rapid use of new system solutions at all performance levels. System performance evaluations, prototype houses, and evaluations in community scale housing validate the reliability, cost-effectiveness, and marketability of the energy systems, when integrated in production housing. After completion of the initial community evaluations in Stage 3, a low level of technical support may be provided as needed to ensure successful implementation of systems research results.

The stages and closeout activities are linked to quickly resolve issues as they are identified. These research stages currently take about 3 to 4 years per climate region, but for more advanced energy efficiency levels (at and above 40% savings), the process is expected to take additional iterations of whole house testing before implementation in production ready homes. At and above the 50% level, the systems research stages will probably take 4 to 6 years to complete for each climate region.

15 2011 target assumes level funding for Building America systems research activities.

Figure 2-4 Residential Systems Research Stage-Gates



The systems research approach is best suited to meet the stated goals because the three stages allow for the early identification of performance gaps and allow for realloca-tion of resources to other high-priority areas when required. Building America identifies and resolves the arriers through the series of design and test studies at each stage of development. By identifying inefficiencies early, Building America has created a streamlined process for introducing higher energy efficiency to prototype housing by Stage 2.

The Residential Integration strategies to overcome market and technical barriers and challenges are described in Table 2-7.

2.1.6 Identification of Component Development Needs

The stage gate approach requires early identification of future system needs to allow for sufficient lead time nec-essary for developing and evaluating new options to meet those needs. Prior to starting Stage 1B systems evalua-tions, components must be developed and then evaluated to determine if they can fill gaps between current sys-tems' performance and future whole house performance goals. These components are developed in collaboration with industry partners, BT, and other EERE offices. The component research requires significant lead time in some cases and focuses on communication of system integration needs and requirements to component devel-opers. Building America's role is providing inputs to com-ponent developers that help identify residential system integration needs, requirements and gaps based on annu-al residential cost/performance studies using the BEopt analysis method.[16,17] Components that move from devel-opment to Stage 1B system evaluations must meet mini-mum requirements for energy performance, reliability, and cost-effectiveness before they are included as part of the residential integration activities in Stages 2 and 3.

16 Anderson, R., Christensen, C., Horowitz, S., Analysis of Residential Systems Targeting Least-Cost Solutions Leading to Net-Zero Energy Homes, ASHRAE Transactions, 2006.

17 Anderson, R., Christensen, C., Horowitz, S., Program Design Analysis using BEopt Building Energy Optimization Software: Defining a Technology Pathway Leading to New Homes with Zero Peak Cooling Demand, ACEEE Summer Study, 2006.

Table 2-7 Residential Integration Strategies for Overcoming Barriers/Challenges

Barrier	Title	Strategy
A	Identification of cost neutral system solutions	Develop a systematic design and performance analysis method with integrated systems to lower cost and energy use
B	Integration of advanced components	Work with lead builders and contractors to accelerate adoption of advanced technologies and systems
C	Acceptance of new building practices by industry leaders	Use an industry driven, cost shared, team-based systems research approach to involve all participants in the residential construction industry in the development of new system solutions for high performance homes; communicate research results through Best Practices and other documentation then share results with implementation partners
D	Identification of code issues limiting adoption of advanced systems	Provide research results and performance validation required to ensure broad acceptance of advanced systems by code officials
E	Quality management tools and practices	Develop trade construction documentation (trade scopes of work, specifications, checklists, etc.) and test with several builders Develop additional quality management products such as "hot spot" training packages, quality management guidelines, and an evaluation of builder quality processes and economics (analysis and methodology)
F	Self-drying high R-wall assemblies	Develop "moisture-proof" walls and evaluate alternative framing, insulation, vapor barrier and air barrier strategies
G	Advanced foundations subsystems, tools, and practices	Build and evaluate advanced durable, energy efficient foundation systems in whole house experiment
H	High performance hot water systems for cold climates	Move water heaters and hot water distribution into conditioned space, reduce piping runs using smaller pipe diameter with thicker insulation, define hot water draw profiles required to evaluate and compare the performance of alternative system designs, improve part load performance of tankless hot water heaters, and integrate low cost solar hot water systems
I	Miscellaneous electric loads	Reduce the energy used to meet plug loads by integrating best available technologies and supplement with renewable technologies
J	Supplemental dehumidification systems for Humid Climates	Work with laboratories and industry to develop and integrate supplemental dehumidification systems for hot humid climates
K	Efficient low capacity space conditioning systems	Work with national labs and industry to develop low capacity space conditioning systems
L	Air distribution study	Conduct research using modeling, laboratory testing and field testing to determine configurations that will provide satisfactory uniform mixing of the air in homes; reduce duct pressure and thermal losses
M	Supplemental ventilation strategies	Integrate delivery of outside air with home space conditioning systems, and provide technical support to ASHRAE Standard 62.2 as needed
N	High performance windows for cold climates	Work with laboratories and industry to develop an R-10 window that is no more than 25% higher in cost than current low-e window
O	Modeling for ground source heat pumps	Conduct soil monitoring to ensure optimum performance of ground source heat pumps
P	Desiccant cooling	Refine and test advanced vapor compression systems

2.1.7 Documentation and Resource Development

At the completion of Stage 3, the research results are documented in technical research reports that serve as references for students, educators, building scientists, architects, designers, and engineers. For the research results to be successfully transferred to key stakeholders in the housing industry, they must be translated into a format appropriate for dissemination to developers, builders, contractors, homeowners, realtors, insurance companies, and mortgage providers.

During and upon the completion of closeout activities, BT fosters market implementation of Building America research and building techniques, and establishes voluntary collaborations with housing and financial industries to make the nation's houses more energy-efficient and affordable. The final activities of the research process include documentation of Best Practices manuals as well as development and evaluation of resources to provide BT research findings to private and public sector implementation programs. This work supports activities that improve the energy efficiency of public and privately owned single-family housing. The subprogram coordinates presentations at technical conferences on peer reviewed and validated research results and facilitates validation, field-testing, and final project evaluations.

The Building America resource development effort creates Best Practices manuals from Stage 1-3 research results that are designed for builders, manufacturers, homeowners, realtors, educators, insurance companies, and mortgage providers. These manuals summarize best practice recommendations in illustrated text that is targeted to a specific audience, synthesizing research findings into energy-efficient processes for the building industry. To facilitate construction of affordable homes designed for non-profit organizations and small builders, BT has made floor plans and section details available through the BT website and other means.[18]

These post-Stage 3 efforts document Building America's best practices and lessons learned in over 40,000 energy-efficient new houses of all sizes, styles, and price points, constructed to date by Building America partners. Key Building America research results have also been incorporated in over 781,559 additional homes via coordination with deployment partner ENERGY STAR® New Homes Program and 700,000 additional homes via coordination with MASCO Environments for Living Program. The first Best Practices volume has documented practices for construction of energy-efficient houses at the 15% savings in all climate regions and has illustrated the results through case studies. As Building America efficiency goals increase between now and 2011, similar documentation packages will be developed for whole-house conservation and renewable energy generation levels of 40% and 50%. The current schedule for development of Best Practices is shown in Table 2-8. The documents allow a handoff of BT's building research findings to the private sector.

Table 2-8 Residential "Best Practices" Schedule

Target	Marine	Hot-Humid	Hot-Dry/ Mixed-Dry	Mixed-Humid	Cold
40% Best Practices	2009	2011	2008	2009	2010
50% & beyond Best Practices	2009	2011	2008	2009	2010

In addition, Building America provides train-the-trainer course reference materials to be used by existing training programs throughout the building industry. Building America provides these reference materials in partnership with ongoing training programs sponsored by professional organizations, universities, community colleges, vocational schools and others involved in the education and training of those associated with the design and construction of homes.

18 See www.buildingscience.com/doctypes/primer/.

2.1.8 Residential Integration Milestones and Decision Points

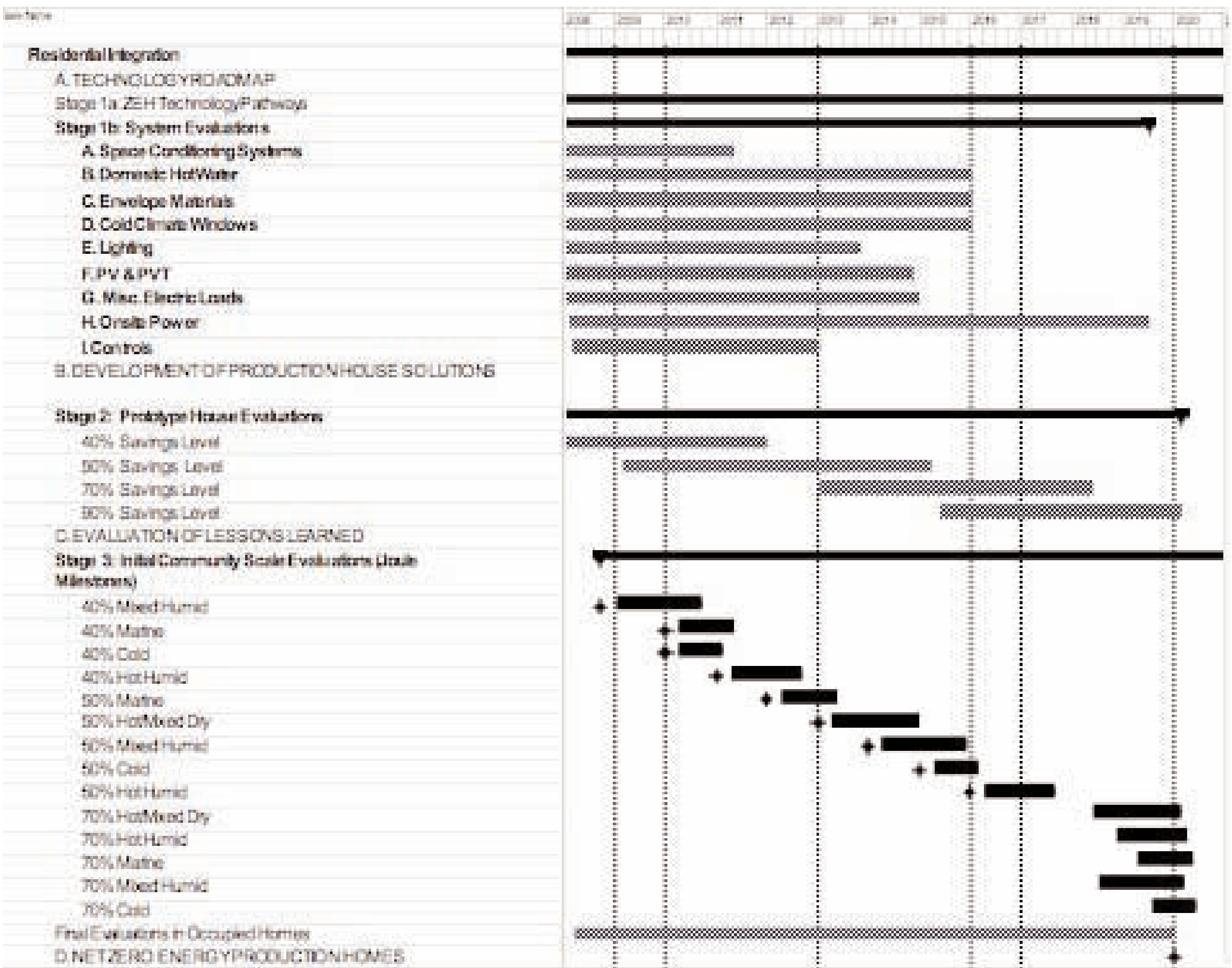
Residential Integration subprogram will undertake the tasks in the Table 2-9 to address the market and technology barriers and to meet the performance targets. The tasks are listed by stages and duration.

The Residential Integration performance targets and tasks can be translated into a schedule that incorporates the Stage-Gate process. Figure 2-5 below shows the schedule for whole house and component tasks. The end of each task is the milestone and also where the Go/No-Go decision occurs for the next stage. The completion of Stage 3 is the point where Best Practices documentation and training materials are developed and tested prior to distributing to implementation partners.

Table 2-9 Residential Integration Whole-House Tasks

Task	Title	Duration	Barriers
1	Stage 1A – ZEH technology pathways	2008-2020	A
2	Stage 1B – System performance evaluations	2008-2019	B, F-O
3	Stage 2 – Prototype house evaluations	2008-2020	B, F-O
4	Stage 3 – Initial community-scale evaluations (Joule)	2008-2020	C
5	Closeout: Final project evaluations	2008-2020	D, E

Figure 2-5 Residential Integration Gantt Chart



2.1.9 Residential Integration Unaddressed Opportunities

The Residential Integration subprogram has identified several areas of unaddressed opportunities. The current research could be expanded to address existing homes since approximately 1 – 2 million new homes are built each year, while 110 million existing homes consume the vast majority of the energy in the residential sector. Particularly attractive is existing homes whole building research, which would help the remodeling market incorporate energy efficiency techniques and solutions. Current activities could also be accelerated to achieve targeted performance goals in the climate zones earlier and thus realize the energy savings sooner. Both opportunities would allow for meeting ZEB goals in an accelerated manner.

2.2 Commercial Integration

Table 2-10 Commercial Integration Summary

Start date	1995
Target market(s)	New and existing commercial buildings
Accomplishments to date	• *Established the First of Several Planned National Energy Alliances.* Commercial Integration developed a new strategic, market-focused, approach to addressing energy use in the commercial sector. The first of these alliances, the Retailer Energy Alliance (REA), was established in February 2008. The REA is designed to aid retailers in improving their bottom lines and saving energy. Members include A&P, Best Buy, Food Lion, JC Penny, John Deere, Kohls', Macy's, The Home Depot, McDonalds, Staples, Target, Walgreens, Wal-Mart, and Whole Foods, in addition to ASHRAE and IESNA.[19] • *Technical and financial support for the three Advanced Energy Design Guides published by ASHRAE*, and also available for free download. (To date, 34,000 have been downloaded.)[20] The guides, which provide recommendations for achieving 30% energy savings over the minimum code requirements of ANSI/ASHRAE/IESNA Standard 90.1-1999, focus on Small Retail, Small Office, and K-12 School Buildings, with a fourth guide on unrefrigerated Warehouses forthcoming in Spring 2008, and fifth on Highway Lodging due in another year. • *Technical Potential of ZEB*. Commercial Integration completed fundamental analysis of the technical potential of zero-net energy commercial buildings at the National Renewable Energy Laboratory. • *Web-Accessible Database on High Performance*. Commercial Integration has supported the development of a Web-Accessible High Performance Buildings database,[21] which currently features nearly 100 projects. • *High Performance Building Field Studies*. Commercial Integration has conducted detailed case study evaluations of six recently built high performance buildings, and has summarized the "lessons learned" in a formal NREL report.[22] Lessons learned inform Commercial Integration's future research portfolio in areas, such as whole-buildings, including supporting technology option set portfolio. • *Ultra-Violet Photocatalytic Oxidation (UVPCO) for Indoor Air Applications*. LBNL has completed laboratory testing of UVPCO air cleaners for efficient removal of indoor generated airborne particles and volatile organic compounds (VOCs) in office buildings and other large buildings. • *Demand-controlled ventilation*. A review of demand controlled ventilation (DCV) performance and research needs was completed and documented in a technical report. While this study showed that current DCV sensor technologies needed adjustments, the energy saving opportunity for these systems is significant. • *Energy Efficient Portable Classrooms*. LBNL developed specifications and validated substantially improved portable classroom HVAC energy efficiency with a major manufacturer. These classrooms saved over 30% of the normal energy consumption and provided a cleaner, quieter and more comfortable indoor environment for learning. • *Commercial Building Benchmarks*. LBNL, NREL, and PNNL worked collaboratively to update a set of commercial building benchmarks for existing and new buildings. This set covers 15 building types in all the DOE climate zones. The benchmarks will be used as to help to assess progress towards goals through the National Energy Alliances, and also provide a firm baseline against which to measure progress towards net-zero energy performance. • *Building Controls Virtual Test Bed (BCVTB)*. BCVTB, developed at LBNL, makes it possible to develop, debug and validate building controls strategies and systems virtually before buildings and controls systems are completed. • *Low-Lift Cooling*. DOE completed a technical scoping study to evaluate the national energy savings potential of systems integration involving low-lift cooling in combination with other elements.
Current activities	• Establishing the National Energy Alliances and National Accounts to develop and replicate building design prototypes at 50% and beyond energy savings. • Developing design guides, decision tools, and technology option sets. Three Technical Support Documents will be completed in FY08: Warehouse and Lodging, 30% savings; General Merchandise Stores, 50% savings; and Grocery Stores, 50% savings. • Reprioritizing integrated systems research and analysis to support decision making. • Field testing, by LBNL, in an occupied building the UVPCO air cleaner with a chemisorbent added to determine the in-situ operating performance of the system and to demonstrate the benefits.
Future directions	50-70 percent whole building energy improvements, relative to Standard 90.1-2204, through better than code flexible design guides and buildings constructed through National Accounts.
Projected end date(s)	2025
Expected technology commercialization dates	2009: Wireless controls and diagnostics for rooftop HVAC 2010: Automated commissioning; Ultra-Violet Photocatalytic Oxidation (UVPCO) advanced air cleaning

19 See http://www1.eere.energy.gov/buildings/retailer/index.html for more information about the REA.

20 Email, dated 4 March 2008, from Kent Peterson, ASHRAE President.

21 http://www.eere.energy.gov/buildings/database/

22 The case studies are available at http://www.eere.energy.gov/buildings/high-performance/ research_reports.html

The goal of the Commercial Buildings Integration (CBI) subprogram is to achieve significant energy savings in new and existing commercial buildings. The subprogram includes research, development, and demonstration of whole building technologies, active engagement with significant market actors, design methods, and operational practices. Technology development efforts focus on cross-cutting, whole building technologies, such as controls and ventilation systems. These efforts support the zero energy building goal, not only by reducing building energy needs, but also by developing design methods and operating strategies which seamlessly incorporate solar and other renewable technologies into commercial buildings. DOE's National Energy Alliances and close technical support of National Accounts will be the vehicle for evaluating, testing, and ultimately implementing these approaches.

A building's key energy-related characteristics–aspect ratio, orientation, glazing fraction and core envelope–are all determined at the time of construction, and once set in metal and concrete, are not economically (and in many cases are not physically) alterable. This means that new construction represents a tremendous "once only" opportunity to apply high performance and net zero energy principles. A building can cast a relatively small and sustainable "energy shadow" if opportunities are seized with daylighting techniques, building orientation and optimized HVAC. However, if these sustainable practices are not adopted, the negative implications will last the lifetime of the building (up to 75 years). At the beginning of a project, it is essential to set aside sufficient time for design team development, goal setting, and project planning. A sustainable building can only be accomplished when everyone (the building owner, future occupants, and design team) share the same energy and environmental goals from the start. Ultimately, the building owner is responsible for setting and implementing the building's goals. It is the design team's responsibility to translate the building's goals and the project's budget into measurable benchmarks for design, construction, and operations to optimize the building's performance and characteristics.

The very long lifetimes of commercial structures, combined with extraordinary growth in commercial floorspace, explains Commercial Integration's strong focus on new construction.[23] The National Energy Alliances are further focused on those sub-sectors which are growing the fastest, and that have the largest opportunity for deep energy savings. At the same time, the large stock of existing buildings will be addressed through these Alliances. Today's existing buildings will dominate the total building stock in 2025, largely because of the longevity of commercial structures. Careful attention to operation and maintenance practices, through benchmarking and sharing best practices, as well as renovation and upgrade opportunities with Alliance members will result in significant energy savings at scale for existing buildings.

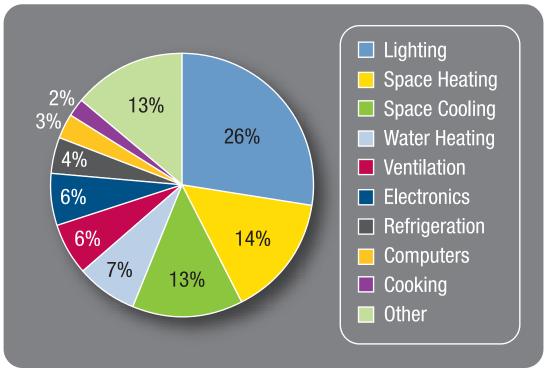
2.2.1 Commercial Integration Support of Program Strategic Goals

The Commercial Buildings Integration subprogram addresses whole-building opportunities in both new construction and existing buildings. The Nation's 4.7 million buildings have a collective footprint of about 74 billion square feet.[24] The nation spends $286 billion on new capital construction and $177 billion for building renovation.[25] Commercial buildings' energy demand, including lighting, heating, cooling, water heating, ventilation, and electronics, consume 18 percent of the Nation's total primary energy, and 35 percent of its electricity.

Commercial buildings, in the United States, consume 18 quads annually. This results in a total annual "utility bill" of about $155 Billion. The energy consumed by commercial building end-uses is shown in Figure 2-6. Lighting comprises over 25 percent of energy use and HVAC totals one third of commercial buildings' primary energy expenditures. Other loads are also significant as commercial buildings have high plug and process loads.[26]

23 BED
24 BED
25 BED
26 BED

Figure 2-6 Commercial Building Energy End Use Splits in Quads[27]



Considering construction, renovation, and energy expenditures, the U.S. invests *over half a trillion dollars per year* in the commercial built environment.[28] Commercial Integration works to reduce these energy expenditures, which supports the BT strategic goal for commercial buildings: *To create technologies and design approaches that enable net-zero energy buildings at low incremental cost by 2025.*

In order to reach ZEB by 2025, BT has implemented a new market-focused strategy based on National Energy Alliances with the private sector. These Alliances, and actively interested National Accounts within the alliance, will evaluate, test, and ultimately implement integrated whole building strategies to enable commercial buildings to use up to 75 percent less energy relative to ASHRAE Standard 90.1-2004. DOE will develop the tools and Technology Option Sets which will be evaluated and implemented by the Alliances through design, construction, and operation of commercial buildings. The balance of the buildings' energy requirements will be met by renewable energy sources to achieve a net-zero energy building.

2.2.2 Commercial Integration Support of Program Performance Goals

Commercial Integration supports BT performance goals, in new construction, with its goal of whole-building improvements of 50% by 2015 and 75% by 2025 (Table 2-11).

In addition to focusing on new construction, the Commercial Integration subprogram's new strategic approach will also increase efforts to improve the energy performance of buildings in the existing stock. BT's existing building goals are to provide the technical capability to improve energy performance 30 percent over the Commercial Buildings Energy Consumption Survey (CBECS) 2003 baselines for existing buildings by 2025.

Once Commercial Integration has determined solutions at savings targets, the subprogram will collaborate with the National Energy Alliances to implement these solutions. DOE is completing work with ASHRAE, AIA, IESNA, and the USGBC to develop advanced energy design guides at 30% for five commercial building types: Small Retail, Small Office, K-12 Schools, Warehouses, and Highway Lodging. Having proved the feasibility of 30% energy savings across a variety of building types, DOE will then exit the 30% design guide activity and focus on other areas in FY 2009.

Table 2-11 High-Performance Buildings Performance Targets

Characteristics	Units	Calendar Year		
		2008	2015	2025
New Commercial Building Energy Use – Whole Building	% Energy savings	30	50	75
Existing Commercial Building Energy Use – Whole Building	% Energy savings			30
Advanced Energy Design Guides	Guides	5	TBD	TBD

27 BED

28 BED

2.2.3 Commercial Integration Market Challenges and Barriers

The key market barriers to high performance commercial buildings have traditionally been relatively low energy prices, the inconsistency in building design verses building construction, the difficulty of verifying building operations and the lack of fees and education for high performance building design (Table 2-12).

Table 2-12 Commercial Integration Market Challenges and Barriers

Barrier	Title	Description
A	As-built versus design	When construction changes are needed (for scheduling or product availability), the solutions must be evaluated consistent with the design goals and design process flaws can lock in building designs before energy is considered.
B	Building commissioning not common practice	Building commissioning should make the building operate according to the design intent and examine the entire building system.
C	Best practices in O&M are not widely used	Current Operations and Maintenance (O&M) practice of new and existing commercial buildings is frequently poor and can increase building energy use by as much as 30 percent.
D	Unsubstantial design fees	Current low design fees do not support innovative designs and related energy analysis.
E	Minimal education on benefits of high performance buildings	Economic value proposition for high performance buildings is not well known by industry leaders.
F	Large variations due to occupant behavior	Energy use patterns are not always controlled by design; they are highly influenced by occupant behavior.

Commercial Integration (Non-Market) Challenges/Barriers

The key technical barriers are the complexity of high performance designs and building controls, the lack of a definition for high performance building and the need for building ventilation above current building codes (Table 2-13). Approaching ZEB, plug and process loads (in some buildings, such as hospitals, these are really process loads) become increasingly important, and must be addressed to attain exemplary energy performance. However, this is a research challenge; BT does not have a programmatic focus in this area.

Table 2-13 Commercial Integration Technical Challenges and Barriers

Barrier	Title	Description
G	Inherent complexity of daylighting practices	Daylighting is inherently complex and a number of elements must be carefully integrated to ensure savings.
H	Integrated building control systems have poor user interfaces	Capabilities of energy management and control systems are often neither fully utilized nor even understood by the operators due to poor user interfaces.
I	No single definition of "good" building energy performance	Standard metrics for fuel economy exist for vehicles, allowing for comparisons of energy performance and annual energy costs between models. Similar metrics for commercial buildings do not exist, so most building managers have no idea if they are operating their buildings well.
J	Indoor environmental quality (IEQ) requires more than code ventilation requirements	Recent studies suggest that human health, and performance depends on providing clean air (good IEQ) in buildings. Currently minimum ventilation standards are based on anecdotal experience because there are few studies indicating how ventilation rates affect health, performance, and learning.
K	Additional analysis techniques needed	Complex buildings require sophisticated analysis beyond average practitioners' capabilities.
L	Plug and process loads are unaddressed	Getting beyond 50% savings requires addressing plug and process loads, where there is currently little research.

2.2.4 Commercial Integration Approach/Strategies for Overcoming Challenges and Barriers

The challenges inherent in designing and operating high performance buildings and ZEBs demand a number of breakthroughs, both in technology, including software and information technology, and in the fundamental knowledge of optimizing whole building performance through integration and component operation. Systems integration and improved component technology (HVAC, lighting, windows, etc.) are required in order to achieve progressively higher levels of energy performance.[29]

Development of marketable ZEBs also requires a much richer understanding of the commercial buildings market. Commercial buildings vary widely by size, surface-to-volume ratio, construction vintage, function complexity, owner-lessor role, and energy use. Also important is a keen understanding of the market structure within market subsectors, such as the degree of market concentration in ownership of grocery stores and big box retail, as well as insight into who the key decision makers are. Understanding this market is necessary to target R&D and achieve large energy savings in commercial buildings.

Beginning in FY08, the Commercial Integration subprogram has initiated a wholly new set of strategies to overcome challenges and barriers, which are shown in Figure 27.

- *National Energy Alliances and National Accounts* are strategic alliances with businesses and organizations to achieve strong market demand-pull for new buildings with exemplary energy performance (50% and higher);

- *Building Package Research and Development* are information packages and tools developed by Commercial Integration to support realization of 50% and better buildings; and

- *Management* involves transparent management of the portfolio and development of supporting analysis and materials; development of contractor solicitations to support program activities; provision of performance requirements to the BT component subprograms.

Figure 27 Commercial Integration Strategies

National Energy Alliances and National Accounts	Building Package Research and Development	Management
• National Energy Alliances: Informal associations • National Accounts: Leaders initiating energy savings	• Design guides & technology support documents • Building decision tools • Technology option sets	• Core functions • Analysis in support of decision-making • Stage-Gate

National Energy Alliances & National Accounts

The National Alliances strategy consists of two key components. The first is the overarching alliance which combines businesses and organizations with similar building types and business sectors which results in groupings with similar energy use profiles, business case needs, and potential solution sets. The second aspect of the strategy is the use of National Accounts, which are companies within these National Energy Alliances who choose to lead efforts through implementing energy saving strategies, and then share these results with Alliance members.

National Energy Alliances

National Energy Alliances (NEA) combine businesses and organizations with similar building types (for example, “big box” one-story, high ceiling) and business sectors (for example, retail, office) and hence similar energy use profiles and potential solution sets. The members share a common goal in reducing energy consumption by significant levels in their buildings and commit to actively participate and when possible, take the lead as a National Account. The NEA strategy includes tasks which are specifically designed to improve design and operation of new and existing buildings. The Alliance will be open to broad participation (including independent associations, code bodies, and research institutions) but the benefits of participation will be fully realized by those organizations with a sustained commitment, strong involvement, and ultimately agreement to engage as a National Account. The Retail Energy Alliance was launched in February 2008 and another Alliance is planned for later in FY08.

29 Buildings “systems integration,” means the design, construction and operation of the commercial building as an integrated system so as to maximize energy performance and occupant satisfaction. Careful daylighting design – for example – involves care in the specification of building orientation, window area, the performance of windows, interior design, and the control of electric lighting systems so as to maximize the use of natural light. A systems approach, as embedded in the technology option sets will carefully integrate all these factors to optimize building energy performance, including lighting and space heating and cooling.

Using market sectors and energy impacts data from CBECS as well as ZEB potential from NREL, Commercial Integration prioritized target building sectors for NEA. The sectors are retail, office, institutional, and lodging. The initial NEA will focus on retail; however, a technical and market assessment in FY08 will shape future priorities.

The "Retail" sub-market itself is not monolithic. Commercial Integration has identified several important building types within the retail sub-market:

- Food Sales/General Merchandise (e.g., Wal-Mart, Target, or "Big-Box")
- Food Only (e.g., Whole Foods, Food Lion)
- General Merchandise Only (e.g., Home Depot, Petco)
- Food Service (e.g., McDonald, Starbucks, Olive Garden)

Working with retail building owners initially, BT will establish baseline energy consumption and undertake a series of technology procurements. The energy consumption information will be used to develop strategies for reduction and evaluate the effect of the NEA. Technology procurements by the NEA will bring down the price for energy efficient technologies.

BT will ask members with buildings that represent energy outliers to participate in a more detailed "Best Practices" study. Members will document basic data such as buildings size, location, age, energy use with fuel type, and energy service equipment (HVAC, Lighting, refrigeration). The data will be used in a baseline analysis that forms the primary measure for determining if Commercial Integration is reaching its 30 percent savings goal for existing buildings.

A second series of activities managed under the auspices of the NEAs are Technology Procurements. Alliance members will join together to "move the market" specifying equipment with energy performance characteristics which are beyond what the market might offer, or to help reduce the cost of "cutting-edge" equipment through a mass buy.

Commercial Integration will create a prioritized list from NEA input that will be used to establish several succeeding rounds of technology procurements. Further analysis will focus on the market impacts of the procurement process to determine whether the process has significantly "moved the market" by increasing the number of manufacturers who are offering equipment at the higher efficiency levels specified in the procurement.

National Accounts

The use of National Accounts is the other key aspect of the overall NEA strategy. A National Account is a company or organization that designs, builds, owns, and operates its own stock of buildings. Within each National Energy Alliance, companies or organizations (National Accounts) wishing to take a leading role in designing, constructing, analyzing, retrofitting and replicating energy efficient buildings using their current building construction schedule will be identified. Each National Account will enter into a formal Memorandum of Understanding (MOU) with DOE that specifies the roles, goals, and commitments of both DOE and the National Account.

The National Account will submit the current design drawings and specifications for analysis. A Technical Team will work with the National Account to determine an acceptable set of design and operational changes that will achieve over 30% energy use savings over the current standard. While the National Account may choose a level of efficiency consistent with operational goals, the Technical Team will analyze a full range of options up to and beyond 50% energy savings. The National Account will agree to build at least one building which will be monitored for at least three years. The National Account will pay for and install an Energy Management System and allow interoperability and communication with sensors to facilitate CBI analysis. Additionally, the National Account will conduct an analysis and retrofit of at least one of their most energy inefficient existing buildings.

In addition to design analysis, the Commercial Integration subprogram will provide the tools to develop the most energy-efficient design that meets business needs and cost targets of the National Account. The designers for the National Account will receive Building Decision tool training, which can be used to decrease the energy consumption of additional buildings. After monitoring, verifying, and reporting the energy savings, the Technical Team will support the National Account in acquiring tax or carbon credits from the energy reduction. Existing buildings may also be addressed through these energy efficiency measures.

Both Commercial Integration and the National Account will share the results of the re-design with the NEA and potentially more broadly. The data sharing, at a minimum, will include the building option sets chosen as well as the full spectrum of options analyzed and put forward for consideration (30-50 percent savings or more).

The ultimate goal is to develop prototype designs for each building type that achieve 50% or greater energy savings. It is recognized, however, that the National Account will select the design, and associated efficiency level, that meets its cost constraints and operating needs. However, the full spectrum of choices, as embodied in the Building Design Tool, from 30 to 50% energy savings, or greater, will be analyzed and documented so that other members of the Alliance have the ability to make alternative choices.

The next step will be for the Technical Assistance Team to re-simulate the "As Built" building to determine the new energy savings level. This fully documented design will then be recommended to the collective National Energy Alliance as the "Best Practice" for achieving the current energy savings level. The National Account will then adopt the new design as the standard for all future buildings.

The National Account partner will monitor and verify energy savings in the newly constructed prototype. Energy usage and incremental cost for energy efficient approaches will be reported. If the energy savings level is less than 50% in the new design prototype, which is initially expected, Commercial Integration will initiate a new design-build cycle. BT will work with the existing National Account, or other National Accounts to develop higher levels of efficiency for the next design prototype. Alternative Building Packages will be developed and analyzed and put forward for consideration.

Building Package Research and Development

Building Package R&D is the research element in Commercial Integration, developing the decision tools, guides, and underlying technology options necessary to realize 50 and 70 percent energy savings levels across a variety of building types, energy intensities and sizes. Building Package R&D features three core elements:

- *Advanced Energy Design Guides and Technical Support Documents* are information products that indicate how to achieve exemplary whole-building energy performance levels, in new construction, for specific building types.

- *Building Decision Tools* are tools enabling building designers and owners to look across sets of energy efficient technology solutions, and then to select appropriate ones for inclusion in building designs in order to achieve exemplary performance levels. These Decision Tools do not present a single solution (unlike the Guides) but instead allow for a variety of building energy efficiency solutions for achieving the desired energy target, based on user inputs, costs and constraints.

- *Technology Option Sets* are defined as specific energy efficient solutions for a specific building type or process-specific design. Technology Option Sets may include equipment, strategies, algorithms, methods, and systems. Specific examples of TOS include various approaches to delivering illumination services (and consideration of their impacts on space conditioning), approaches to ventilation and the impacts on indoor air quality, and methods for providing space conditioning services.

Advanced Energy Design Guides & Technical Support Documents

There are three distinct but related products under this element. An Advanced Energy Design Guide (AEDG) is a publication targeted at architects and other practitioners that provides specific guidance on how to achieve certain levels of high energy performance in buildings. A Technical Support Document (TSD) is a background document describing the assumptions and methodologies used to achieve particular levels of energy performance. AEDGs invariably have concomitant TSDs (to document the rationale behind the design decisions), but not all TSDs are necessarily associated with AEDGs. After the AEDGs have been released, Commercial Integration will commission market evaluations to determine the impact of these information resources with practitioners and decision makers, which will help guide future program resources.

One way to achieve "above-code" exemplary energy performance in new construction is to provide a prescriptive guide that indicates specific designs and features of a building. To this end, Commercial Integration has actively supported development of a series of AEDG. These are hardcopy publications designed to provide recommendations for achieving 30 percent energy savings over the minimum code requirements of ANSI/ASHRAE/IESNA Standard 90.1-1999. The guides have been developed in collaboration with ASHRAE, AIA, IESNA, and USGBC. Having proved the feasibility of achieving 30% energy savings levels in these buildings, Commercial Integration does not plan to support the development of any more 30% guides. However, the subprogram is considering developing further AEDGs targeting 50% energy savings and is undertaking TSDs (analysis) to support future publications. The anticipated release dates for AEDGs and other resources are listed in Table 2-14.

Table 2-14 Building Package R&D Publications Dates

	30% AEDG	50% TSDs	Decision Tools	50% AEDG
Retail	2007 (small)			
Food Sales/ General Merchandise	NA	TBD	2009	2015?
Food Only	NA	TBD		2015?
General Merchandise	NA	TBD		2015?
Food Service	NA	TBD		
Warehousing & Distribution	2008	TBD		
Office	2005 (small)	TBD		
Institutional (Schools, Hospitals)	2008 (K-12 schools, hospitals)	TBD		
Lodging	2008	TBD		

The Technical Support Documents (TSDs) describe the process and methodology for developing the guides.[30] TSDs typically describe the following:

- Charge given to the committee in developing the AEDG
- Development of prototype buildings to represent the class targeted by the AEDG
- Rationale for the measures selected
- Simulation approach used to meet the energy savings target
- Energy savings results by climate region

The FY08 50 percent TSDs do not support ASHRAE-published AEDGs, but are intended to be stand-alone reports documenting the technical feasibility of achieving a 50% reduction in whole-building energy use. These reports will demonstrate to National Accounts that exemplary energy performance is feasible today with available technology.

By early FY09, Commercial Integration, ASHRAE, and other key partners will have completed five 30 percent-savings AEDGs. The subprogram will conduct analysis to determine the impacts of AEDGs in the new construction market. To answer such questions, Commercial Integration has commissioned an evaluation of the currently available AEDGs, as well as of alternative guide products.

Decision Tool for Evaluating Technology Packages

Commercial Integration will develop Building Decision Tools to support building prototype redesign for National Accounts, which integrate across the TOS to help select solutions appropriate to the building type and the owners/designer performance target. The tools will present a continuum of efficiency levels from 30 to 50 percent and beyond. While a National Account may select a particular level of performance for prototype design and construction (see National Accounts below), other Alliance members can use this tool to pick alternative energy efficiency performance levels based on their design needs, costs, and other constraints.

30 For example, PNNL has developed TSDs for both the small-retail and small office AEDGs which are available from the PNNL publications website at http://www.pnl.gov/main/publications/external/technical_reports/PNNL-16031.pdf and http://www.pnl.gov/main/publications/external/technical_reports/PNNL-16250.pdf

Beginning in FY08, Commercial Integration is introducing a new strategy to develop simplified decision tools that enable design practitioners to evaluate quickly and efficiently the energy saving contributions of various technology "packages." These tools will be less intensive than EnergyPlus simulations but more complex than prescriptive, single-solution (and hard-copy) AEDGs. By using EnergyPlus as the background calculation engine, the tools will essentially present pre-packaged results tailored for a specific building type and location and will feature a selection of technology packages. The user will then be able to quickly evaluate the various pathways for a specific energy savings target. The decision tool is much simpler to use than performing many multiple building simulations; yet it still has the capability to explore various pathways.

In line with Commercial Integration priorities, as reflected in the preliminary ranking of NEA launches by building type, the subprogram will first develop a decision tool for Retail buildings, specifically General Merchandise stores and Food-Only Grocery stores, with a 50% energy savings target.

Technology Option Sets

Commercial Integration will be developing or adopting Technology Option Sets (TOS) for consideration by Alliance members. These TOSs will address specific energy efficient solutions (such as illumination) for a specific building type or process-specific design. TOSs provide multiple pathways for designers and builders to achieve advanced energy savings with the flexibility to mix and match energy-efficient technologies. The Commercial Lighting Initiative (CLI) managed in the Technology Validation and Market Introduction (TVMI) sub-program is an example of a TOS that is being developed for the retail "Big-Box" market.

As of FY08, Commercial Integration will include all of its "technology" research and development work under this element. The core objective of this element is to develop technology option sets that directly support the 50% to 70% whole-building energy savings targets in new construction, and where applicable, the 30-50% targets in existing buildings. Technology options or research endeavors that are not integrally related to realization of these goals will no longer be supported.

Within this category, Commercial Integration will manage its work across two elements. The first element will produce a prioritized list of TOS that the subprogram can then execute as part of its Annual Operating Plan. The second element will align the current research portfolio directly to support those priorities.

Prioritized List of Technology Option Sets

The purpose of this annual activity is to produce a rank-ordered list of technology option sets, and then fund top priorities as part of the Annual Operating Plan solicitation to national laboratories and contractors. Commercial Integration will systematically list all possible TOSs applicable to its priority building markets, namely Retail, Office, Institutional and Lodging. This listing will favor inclusion and comprehensiveness over any detailed description of TOS; the purpose is to identify as many candidates as is practicable. Then, the subprogram will actively seek input from the NEAs, National Accounts, and others external to the subprogram. Commercial Integration will synthesize this input, draw insights from relevant analyses and studies[31] and proceed to rank-order the candidates using the following criteria:

- Contribution to new construction and existing building savings targets;
- Likelihood of future adoption by Retail Alliance partners in their buildings;
- Amount of research in the area conducted by others; and
- Appropriateness of the BT research role.

After identifying top-priorities, Commercial Integration will issue a call for proposals in these select areas annually to reflect changing technology and market conditions, and to reflect the status of the national energy alliance cycle.[32] This process differs greatly from the subprogram's past practice in calling for TOS because Commercial Integration is first determining priorities, and then requiring national laboratories to propose projects in these priority areas.

31 Including NREL's Assessment of Opportunities

32 A list of TOS for hospitals will be different than for General Merchandise, so the TOSs reflect NEA priorities.

Align Current R&D Portfolio with TOS Priorities

Commercial Integration will align the existing portfolio of Integrated Systems Research so that it directly targets the TOS prioritizations described above. Integrated Systems Research includes daylighting, integrated building controls, commissioning and O&M, and ventilation to support good Indoor Environmental Quality (IEQ). The desired outcome from the prioritization will be a prototype TOS that can be tested and validated in real buildings in target building markets. This process of "rationalizing" the current portfolio of research within an operational TOS context will occur in FY08, with Stage-Gating, for the four Integrated Systems Research elements. In the case of IEQ/V, Commercial Integration will draw upon the forthcoming NREL report on ventilation to inform the discussion.

With the alignment complete, the subprogram's activities in IEQ/V and daylighting will be "migrated" to a resolute TOS focus by FY09 and its activities in controls and commissioning to similar TOS focus by mid FY10, at the latest. Future areas of research needed to progress beyond 50% are MELs reduction, refrigeration, lighting, thermal insulation, very high SEER/EER AC, high R windows, and daylighting/passive solar.

Stage–Gate

Commercial Integration uses the Stage-Gate methodology to manage decision-making in the following areas: technology procurement, NEA prioritization decision tools, and others. The Stage-Gate decision for continuation of the technology procurement effort will be made after three rounds. As this is a new approach, Commercial Integration, with the REA, will conduct an evaluation at the end of one year of operation by the end of Q1 FY09.

In Q2 of the applicable years, just prior to the launch of new alliances, the subprogram will conduct technical and market analysis to determine two aspects of the NEA.The first is to confirm Commercial Integration's priority order for National Energy Alliances, by building type (or sub sector). Second, the subprogram will update its understanding on the feasibility of achieving 50% savings in the selected building type or sub sector. The purpose of this analytical update is to establish BT's "corporate" knowledge of the sub sector and guide discussions with Alliance members.

In FY08, the decision tool for technology packages will be refined to produce a prototype tool by Q1, followed immediately by a Stage-Gate Decision. This shall determine: whether the prototype looks to be a truly promising line of inquiry and deserves further support; whether it is useful (or might prove useful) to Retail Energy Alliance members; and, most critically, whether the process should be repeated for additional building types.

Assuming the resulting gate decision is a "Go," Commercial Integration will produce a "public release" version of the tool in Q2 of FY09, Stage-Gate that release in the next quarter,[33] release a revision to the public the following quarter and commence work on a decision tool for offices in Q1 of FY09, and then commission subsequent tools for other building types.

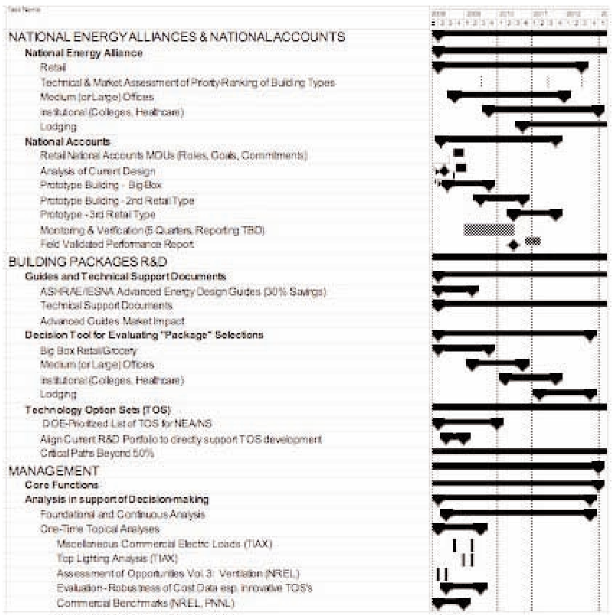
2.2.5 Commercial Integration Milestones and Decision Points

Figure 2-8 identifies Commercial Integration key activities in high performance buildings and integrated systems research. The subprogram will conduct the following assessments to help guide the new program design:

- Technical & Market Assessment of Priority-Ranking of Building Types
- Advanced Energy Design Guides Market Impact
- Technology Pathway Guidance to BT Emerging Technology Sub-Programs on Performance Levels Required for 50% & 70% targets
- Identification of Knowledge Gaps
- One-time topical analysis: MELs, Top Lighting Analysis, Assessment of Opportunities Vol. 3: Ventilation, Evaluation - Robustness of Cost Data (innovative TOS's), and Commercial Benchmarks

33 The decisions are: fund the next public release version of the Retail Decision Tool? And, should decision tools for other types by commenced? Decision criteria shall include: determination of whether or not users find the "public release" version useful; determination of the features required to make the next version of greater (or any) value; apparent "market demand" by national accounts for other such tools.

Figure 2-8 Commercial Integration Gantt Chart



2.2.6 Commercial Integration Unaddressed Opportunities

There are several unfunded activities, listed below:

- **Opportunity to launch and manage many energy alliances quickly**. The most important "unaddressed opportunity" will be the slow rate at which National Energy Alliances can be developed and launched, as well as the degree of technical support provided. Energy Alliance development, and National Account engagement is proportional to the resources appropriated. Many market sectors will have to remain unaddressed as Commercial Integration will only be able to develop and launch a select number of alliances, staged over time. With greater resources the rate of "launch" can be greatly accelerated and the level of DOE technical support provided to the alliance members will be significantly greater. This, in turn, translates directly into the speed with which DOE can affect buildings' energy performance – especially of new buildings.

- **Plug Loads**. Another important unaddressed opportunity is commercial plug loads. DOE currently has no program in this area – an area whose importance becomes more manifest as higher performance buildings are attempted. This is articulated in recent analysis by NREL.[34]

- **CBECS Sample Size**. EIA's CBECS is a foundational resource for characterizing commercial buildings, but the sample size means that data parsing, by region, type and vintage quickly leads to statistically unreliable estimates of particular data queries. This can seriously hinder BT's understanding of selected market segments. With more resources, BT could enhance the data collection of targeted market segments by increasing the number of survey respondents.

- **Energy Management and Control Strategies**. With the exception of the ongoing work on the BVCTB and the completed work on demand-controlled ventilation, Commercial Integration is doing little in the area of building controls. In several studies over the last few years, the BT role in the area of building sensors and controls has been established as one of developing controls methodologies and strategies that provide optimum building operation but not sensors or equipment.

34 S. Pless, P. Torcellini, and N. Long. 2007. Technical Support Document: Development of the Advanced Energy Design Guide for K-12 Schools—30% Energy Savings. NREL/TP-550-42114. NREL, Golden CO. http://www.nrel.gov/docs/fy07osti/42114.pdf

2.3 Lighting

Table 2-15 Solid-State Lighting Summary

Start date	2001
Target market(s)	Commercial and residential specialty, task and directional lighting applications (e.g., MR16, PAR38) and from 2015-2025, all sectors, general
Accomplishments to date	• September 2007: Cree, Inc. developed an LED array prototype that delivers 95 lm/W at 350 mA. • September 2007: GE Global Research set a new record for solution-processed white OLED devices, demonstrating a performance greater than 14% peak W/W (overall power conversion efficiency). Further improvements will enable the demonstration of a 45 lm/W illumination-quality OLED that proves near-term technology viability as an incandescent replacement for certain applications. • September 2007: Universal Display Corporation (UDC) fabricated a 6-square-inch OLED panel that produces 100 lumens of light at an efficacy of 31 lm/W and a brightness of 3,000 nits, relatively brighter than todays fluorescent lamps. • June 2007: Eastman Kodak developed a new device architecture for white OLED devices that demonstrates an extraction efficiency of 46%, a tremendous improvement over previous devices. • September 2006: Cree, Inc. released new EZBright™ power chip for general lighting applications. The new blue power chip delivers up to 370mW at 350mA drive current, and up to 800mW at 1A. • July 2006: Cree demonstrated a cool white LED array prototype with luminous efficacy of 79 lm/W, exceeding the DOE FY06 Joule target. Cree's prototype uses an array of several high-power, large-area chips to produce sufficient light for practical application in the general illumination market. • August 2006: As a result of the improved light extraction, Universal Display Corporation (UDC) achieved a new record external quantum efficiency of 30% for a white OLED device. Operating at 850 nits, this white OLED was able to obtain efficacy values of 30 lm/W with a CRI of 70. • 2006: Scientists at Pacific Northwest National Laboratory (PNNL) have created a blue OLED device with external quantum efficiency of 11% at 800 nits, previously exceeding their record blue EQE of 5%. This breakthrough will enable an entire new class of improved efficiency OLED devices appropriate for SSL. • 2006: University of California, Santa Barbara (UCSB), achieved a record brightness of 25,000 nits in a solution fabricated blue-green OLED capable of operation at increased current densities. This achievement is the highest ever reported for this approach at producing a blue emitting device.
Current activities	*LEDs* Core Technology & Product Development: 1. Large-area substrates, buffer layers, and wafer research 2. High-efficiency materials 3. Device approaches, structures, and systems 4. Design and development of modeling & diagnostic tools 5. Encapsulants and packaging materials 6. Research into low-cost, high efficiency reactor designs and manufacturing methods 7. Electronics development 8. Implementing strategies for improved light extraction and manipulation *OLEDs* Core Technology Product Development: 1. Improved OLED materials 2. Improved contact materials and surface modification techniques 3. Strategies for improved light extraction and manipulation 4. Approaches to OLED structures between the electrodes 5. Cost reduction techniques and tools 6. Develop architectures that improve device robustness increase lifetime and increase efficiency Lighting Commercialization: 7. Development of ENERGY STAR SSL Specifications 8. Design competitions for SSL 9. Market transformation, consumer and business awareness, and technology procurement programs 10. Technical information resources – Test Procedures

Table 2-15 Solid-State Lighting Summary (continued)

Future directions	• Continue to drive development of more energy-efficient, white-light SSL sources through research in both inorganic and organic technologies by working both in the core technology and product development arenas • Initial emphasis on core technology to accelerate development of more robust, energy-efficient SSL devices; later, emphasize product development activities, to improve manufacturing capabilities, reduce costs and encourage market penetration • Hold annual meetings with the SSL community to solicit input on the prioritization of the Lighting R&D portfolio
Projected end date(s)	The projected end-date is 2025 when the program achieves 50% reduction in electricity use of SSL luminaries compared to 2005.
Expected technology commercialization dates	*LEDs* 2008: General illumination commercial product with efficacy of 80 lm/W, an OEM price of $25/klm (lamp only), and a life of 50,000 hrs with a CRI greater than 80 and a CCT less than 5,000°K. 2010: Cool white device at greater than 140 lm/W and warm white greater than 90 lm/W. 2012: Luminaire at least 120 lm/W emitting ~1,000 lumens 2015: Commercial product available at less then $2/klm. *OLEDs* 2008: Niche product with an efficacy of 25 lm/W, an OEM price of $100/klm (lamp only), and a life of 5,000 hrs. CRI should be greater than 80 and the CCT should be between 3,000-4,000°K. 2010: Product cost of less than $70/klm. 2015: Product greater than 100 lm/W and a life of 40,000 hrs.

DOE initiated its work in solid-state lighting (SSL) research and development in 2000. In this short time frame, DOE researchers have made considerable progress working with partners such as industry leaders, research institutions, universities, trade associations, and national laboratories. The lighting subprogram focuses on Light Emitting Diodes (LED) and Organic Light Emitting Diodes (OLED), measuring performance in terms of color rendering index (CRI), correlated color temperature (CCT) and product lifetime.

For solid-state lighting technologies, another performance target focuses on the energy efficiency rating of the device. The unit of performance commonly used when discussing light sources and systems is lumens of light produced per Watt of energy consumed. The technical term for this metric is 'efficacy' measured in lumens per Watt (lm/W). Several lighting products, including fluorescent lamps and incandescent reflector lamps, are regulated using an efficacy target.

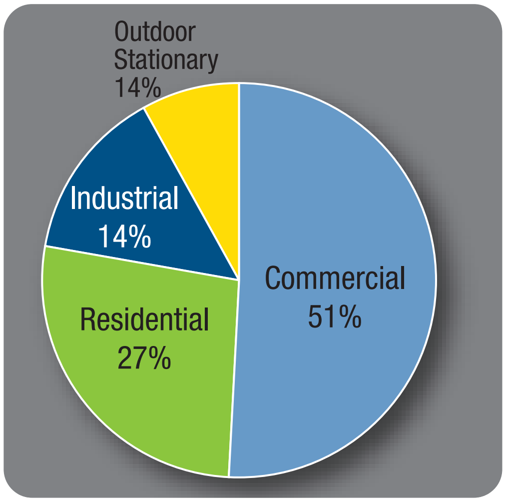
2.3.1 Lighting Support of Program Strategic Goals

Energy consumption for lighting in buildings in the U.S. is approximately 7 quads, or about 18 percent of the total energy consumed by the building sector.[35] Nationally, total energy use in commercial and residential buildings was approximately 39.7 quads, of which electricity use was approximately 28.6 quads.[36] Thus, in these residential and commercial building sectors, lighting constituted approximately 18 percent of total building energy consumption, or approximately 24 percent of total building electricity use. On a national basis, Figure 2-9 provides a break-down by building sector of the energy consumption for lighting homes, offices and other metered applications around the country. The figure shows that just over 4 quads were consumed in 2001 in the commercial sector, the largest energy user for lighting. As lighting contributes to a building's internal heat generation and subsequent air-conditioning loads at peak times, BT has targeted to develop more efficient lighting technologies specifically in the commercial sector.

35 BED

36 BED

Figure 2-9 National Lighting Energy Consumption by Sector[37]

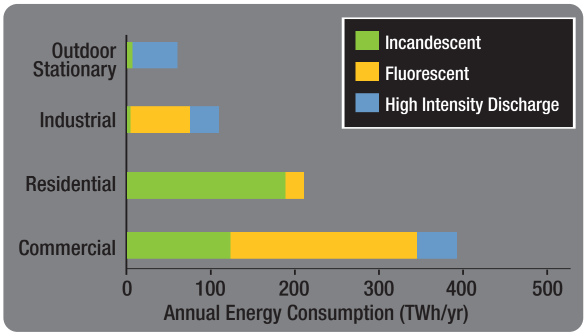


Lighting constitutes approximately 11 percent of residential building energy consumption and 26 percent of commercial building energy consumption. This electricity consumption figure does not include the additional loads due to the heat generated by lighting, which is estimated to be up to 40 percent in a typical "stock" building. Further technology and cost improvements and market acceptance of SSL technologies will dramatically reduce lighting energy consumption, and thereby the total energy consumption, of residential and commercial buildings by 2025.[38]

Figure 2 10 illustrates the breakdown by sector of national energy consumption for lighting in units of site electricity consumption (terawatt-hours/year), disaggregated by source type. These units represent the electrical energy consumed on-site for lighting throughout the United States. The figure shows that fluorescent sources in the commercial sector are the single largest lighting energy-consuming segment in the U.S., slightly greater than incandescent lamps in the residential sector. However, across all sectors, incandescent is the leading electricity consumer in the U.S. consuming 321 terawatt-hours per year (TWh/yr) in 2001. Fluorescent lighting is a close second with approximately 313 TWh/yr and HID is third with approximately 130 TWh/yr.[39]

This comparison examines the replacement not of incandescent technologies (although these are in use in 2005), but of more efficient fluorescent sources, which were identified as the largest single user of electricity for lighting in commercial buildings. Linear fluorescent lamps operating in a system (including ballast and fixture losses) can offer efficacies as high as 83 lumens per Watt luminaire efficacy. Compact fluorescent lamps, a derivative of this technology, are less efficient (approximately 60 lumens per Watt source efficacy); however, they still offer a four-fold improvement over incandescent at 14 lumens per Watt.

Figure 2-10 National Lighting Site Electricity Consumption by Sector & Source[40]



The goal of BT lighting research and development is to increase end-use efficiency in buildings by aggressively researching new and evolving lighting technologies. Working in close collaboration with partners, DOE aims to develop technologies that have the potential to significantly reduce energy consumption for lighting.

37 EERE: Lighting Research and Development. http://www.eere.energy.gov/buildings/tech/lighting/

38 BED

39 U.S. Lighting Market Characterization Volume I: National Lighting Inventory and Energy Consumption Estimate. Prepared by Navigant Consulting, Inc. for the Department of Energy. Washington D.C. September 2002.

40 http://www.eere.energy.gov/buildings/tech/lighting/

2.3.2 Lighting Support of Program Performance Goals

In order to develop technologies with the technical potential to reduce energy consumption by 50 percent over 2005 technologies, SSL will need to increase its efficacy to more than 160 lumens per Watt. Typical fluorescent luminaries today operate at approximately 80 lumens per Watt, and incandescent systems (depending on the fixture) can range from 5 to 25 lumens per Watt. Thus, the strategy of improving the efficacy of SSL will result in considerable life-cycle cost benefit to consumers, once the technology is available and commercialized. A projection of the performance of SSL devices was created in consultation with the NGLIA Technical Committee, a team of solid-state lighting experts, assuming a "reasonable" level of funding by both government and private industry; it anticipates that SSL will exceed 160 lumens per Watt (SSL device). Although the overall Lighting subprogram may be expected to continue until 2025 in order to achieve technologies capable of full market penetration, forecasts in this section only project performance to 2015.

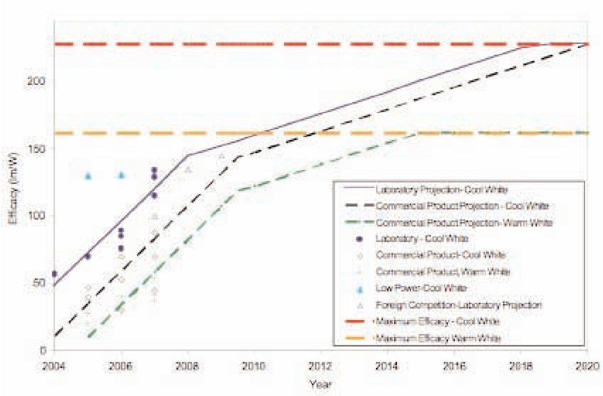
Light Emitting Diodes

The following performance goals are *exclusive* of the driver and fixture. Thus, the goals do not entirely capture the objectives of the Lighting subprogram which relate to luminaire efficiency or cost. Reaching these ultimate objectives will take longer than may be inferred from these graphs of device performance, but it is not anticipated that it will be difficult to achieve acceptable driver performance (although there are some challenges). On the other hand, innovative fixtures for LEDs can have a significant impact on overall efficiency, and the challenge in this area is to accommodate aesthetic and marketing considerations while preserving the energy saving advantages.

The price and performance of white LED devices are projected using cool white as a reference point based on currently available commercial LED products. Future improvements will ideally include warmer light at similar efficiencies, but such developments may occur later in the Lighting subprogram, beyond the forecast period. As there is typically a lag of one to two years between laboratory demonstrations and commercialization, two projection estimates are shown, one for laboratory prototype LEDs, and one for commercially available LEDs.

Figure 2-11 shows *device* efficacy improving linearly through 2015 (driver/fixture are excluded). These projections assume a prototype with a "reasonable" lamp life, and the efficacy for laboratory prototypes reaches 186 lumens per Watt in 2015. A number of actual reported results are plotted on the curve as well, although these specific examples may not meet all of the criteria specified.

Figure 2-11 White Light LED Device Efficacy Targets, Laboratory and Commercial[41]



Note:

1. Cool white efficacy projections assume CRI=70 ? 80, CCT = 4100-6500K.
2. Warm white efficacy projections assume CRI>85, CCT = 2800-3500K.
3. All projections are for high-power diodes with a 350 ma drive current at 25°C, 1mm^2 chip size, device-level specification only (driver/luminaire not included), and reasonable device life.
4. Low power diodes shown have a 20 mA drive current.
5. The maximum efficacy values for warm white (3000K and 90 CRI) and cool white (6500K and 75 CRI) are shown above as asymptotes. The target efficiency assumes a CRI of 90 and a CCT of 4100K and would lie in between these two extremes.

41 *NGLIA LED Technical Committee and the Department of Energy, Fall 2007 and Press Releases*

The performance projection is translated into point values in Table 2-16 where cost and lifetime targets are also presented. The cost estimates were developed in consultation with the NGLIA Technical Committee, and represent the average cost of 1-3 watt white-light LED devices driven at 350mA (exclusive of driver or fixture costs). The projected original equipment manufacturer (OEM) lamp price, assuming the purchase of "reasonable volumes" (i.e., several thousand) and good market acceptance, is also shown. The price decreases exponentially from approximately $25/klm in 2006 to $2/klm in 2015. Recent price reduction announcements confirm the trend in the near-term. The device life, measured to 70 percent, lumen maintenance, has increased steadily over the past few years and appears to be currently at its target of 50,000 hours. An average lamp life of 50,000 hours would allow LED devices to last approximately twice as long as conventional linear fluorescent lighting products, five times longer than compact fluorescent lamps, and fifty times longer than incandescent lamps.

Table 2-16 Summary of LED Device Performance Projections[42]

Metric	Units	2007	2010	2012	2015
Efficacy - Lab	(lm/W)	120	160	176	200
Efficacy - Commercial Cool White	(lm/W)	84	147	164	188
Efficacy - Commercial Warm White	(lm/W)	59	122	139	163
OEM Lamp Price- Product	($/klm)	25	10	5	2

Note:

1. Efficacy projections for cool white devices assume CRI=70 →80 and a CCT = 4100-6500K, while efficacy projections for warm white devices assume CRI= >85 and a CCT of 2800-3500K. All efficacy projections assume that devices are measured at 25°C.
2. All devices are assumed to have a 350 mA drive current, 1mm^2 chip size, device-level specification only (driver/fixture not included), and lifetime as stated in table.
3. Price targets assume "reasonable volumes" (several 1000s), CRI=70 → 80, Color temperature = 4100-6500K, and device-level specification only (driver/luminaire not included)
4. Device life is approximately 50,000 hrs, assuming 70% lumen maintenance, "1 Watt device," 350 mA drive current.

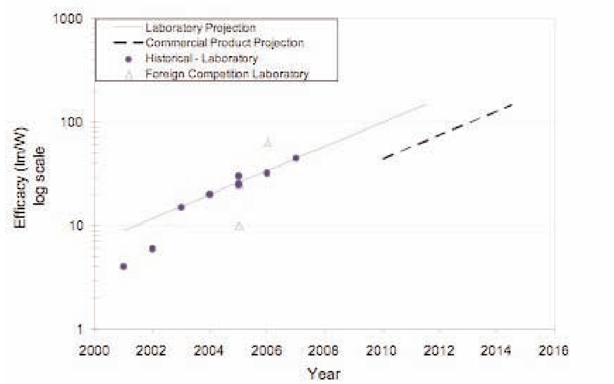
Although the subprogram is planned past 2015, it is difficult to make projections further into the future. Additional improvements are anticipated for future years, so a rough estimate of progress towards future higher CRI, lower CCT lamps (still excluding other system components) is also indicated in the figure. These projections will be revised as the Lighting R&D program progresses, and technological breakthroughs are realized.

Organic Light Emitting Diodes

In consultation with the NGLIA Technical Committee for general illumination, BT developed price and performance projections for white light OLED devices operating at a CCT of between 3000-6000 K and a CRI of 80 or higher. Two projection estimates were prepared, one for laboratory prototype OLEDs, and one for (future) commercially available OLEDs.

Figure 2-12 (plotted on a logarithmic scale) shows the efficacy for laboratory prototypes growing exponentially to exceed 150 lm/W by 2012. As there are not yet any commercial OLED lighting products, the estimated efficacies for commercial products are not meaningful until 2009 and lag approximately three years behind current laboratory products. A number of actual reported results are plotted on the curve as well, although these specific examples may not meet all of the specified criteria.

Figure 2-12 White Light OLED Device Efficacy Targets, Laboratory and Commercial (On a logarithmic scale)[43]



Note:

Efficacy projections assume CRI > 80, CCT = 2700-4100K ("near" blackbody curve (Δcxy <0.01), lifetime > 1000 hrs, luminance of 1,000 cd/m^2, total output ≥ 500 lm, and device level specification only (driver/luminaire not included)

42 NGLIA LED Technical Committee, Fall 2007

43 Projections: NGLIA OLED Technical Committee, Fall 2007, Laboratory Points: Press Releases

Today, the efficacy of OLED devices lags behind LED devices, both in the laboratory and in the market. However, when the projections of commercial LEDs and OLEDs are compared, the efficacy of OLED products is expected to experience exponential improvement, enabling it to approach that of the LED products in the latter part of the current forecast.

Point values from the projection of efficacy improvement of OLEDs are provided in Table 2-17; cost and lifetime targets are also presented. The table displays the projected OEM price of commercially available white-light OLED devices (driver and fixture not included) for a luminance of 1,000 cd/m^2. The OEM lamp price decreases exponentially from an estimated $72/klm in 2009 to $10/klm by 2015, assuming reasonable volumes of tens of thousands. The OEM lamp price, measured in $/m^2 is approximately a factor of three greater than OLED device price when measured in $/klm for the assumed luminance.

The lamp life for commercial products is measured to 70 percent lumen maintenance. Although 50% lumen maintenance is industry practice for evaluation of OLED displays, we use 70% lumen maintenance in order to compare lifetimes with other lighting products. The lifetime increases linearly to a value of approximately 40,000 hours in 2015. Lifetime projections below represent the lifetime of the device, not the entire luminaire. Because, the driver may limit the lifetime of the OLED luminaire, improving the lifetime of the driver to that of the OLED device is a goal of the SSL program.

Table 2-17 Summary of OLED Device Performance Projections[45]

Metric	Units	2007	2009	2012	201
Efficacy - Lab	(lm/W)	44	76	150	150
Efficacy - Commercial	(lm/W)	N/A	34	76	150
OEM Device Price	($/klm)	N/A	72	27	10
OEM Device Price	($/m^2)	N/A	216	80	30
Device Life-Commercial Product	(1000 hours)	N/A	11	25	40

Note:

1 Efficacy projections assume CRI = 80, CCT = 2700-4100K ("near" blackbody curve (Δcxy<0.01), luminance of 1,000 cd/m^2, total output ≥ 500 lm, and device level specification only (driver/luminaire not included)

2. OEM Price projections assume CRI = 80, luminance of 1,000 cd/m^2, total output ≥ 500 lm, and device level specification only (driver/luminaire not included)

3. Device life projections assume CRI = 80, 70% lumen maintenance, luminance of 1,000 cd/m^2, and total output ≥ 500 lm.

2.3.3 Lighting Market Challenges and Barriers

In recent years, LEDs have entered the lighting market, offering consumers performance and features exceeding those of traditional lighting technologies. While SSL sources are just starting to compete for market share in general illumination applications, recent technical advances have made LEDs cost-effective in many colored-light niche applications. LED technology is capturing these new applications because it offers a better quality, cost-effective lighting service compared to less efficient conventional light sources such as incandescent or neon. In addition to energy savings, LEDs offer longer operating life (>50,000 hours), lower operating costs, improved durability, compact size and faster on-time. However, market penetration is limited to specific applications such as traffic signs, holiday lights, commercial signage and others. As LED technology advances–reducing costs and improving efficiency– LEDs will build market share in these and other niche markets.

Table 2-18 Lighting Market (Non-Technical) Barriers

Barrier	Title	Description
A	Market Demand	Only niche markets are currently utilizing SSL technologies, but wider commercial acceptance is necessary for SSL to succeed. LED luminaires are reaching reasonable total lumen output levels although many still perceive LEDs as offering only "dim" light, a significant market barrier.
B	Technical Information and Design Selection Guidance	Buyers need product purchasing guidance to select products that perform well, and lighting designers need critical new technology application information. Objective, widely available technical information from a credible, respected source is required to help fill information gaps and clear up widespread misunderstanding of the technology, its attributes, and its limitations.
C	Objective Test Results and Industry Standards	Independent performance test results on commercially available products are needed to overcome widespread confusion on actual product performance. Industry standards and test procedures for SSL general illumination products enable basic market infrastructure, which is currently lacking.

2.3.4 Lighting Technical (Non-Market) Challenges/Barriers

There are six technical barriers which the Lighting sub-program is working to address, as shown in Table 2-19.

Table 2-19 Lighting Technical Barriers

Barrier	Title	Strategy
D	Luminous Efficacy	Although the luminous efficacy of LED luminaires has surpassed that of the incandescent lamps, improvement is still needed to compete with other conventional lighting solutions. While laboratory experiments demonstrate that OLED devices can be competitively efficacious as compared to conventional technologies, no products are yet available.
E	Quantum Efficiency	Quantum efficiency represents the capability of SSL devices to convert electrons into photons. The internal quantum efficiency assesses a material's ability to convert electron-hole pairs into photon emissions, and the external quantum efficiency measures the amount of light that leaves the semiconductor device becoming available for collection and use. Increasing both quantum efficiencies is possible through a combination of materials research, photometric modeling and other techniques.
F	Lifetime	The lifetime target for the LED device has apparently been achieved; however, it is unclear whether this same lifetime target has been achieved by the LED luminaire. Potential premature failure due to high temperature operation remains a barrier to general deployment. OLED lifetimes for both devices and luminaires still require improvement.
G	Stability	Stability and control activities address the quality and stability of the white-light emission over time, which requires improvement. Basic material properties and semiconductor physics directly impact photon wavelength, emission bandwidth and ultimately, light color.
H	Packaging and Manufacturing	The first products to enter the market will have to meet high quality standards and appeal to consumers' aesthetic. While OLEDs have been built off of display manufacturing capabilities, there has been little investment by manufacturers in the infrastructure needed to develop commercial OLED lighting products. Lack of process uniformity is an important issue for LEDs and is a barrier to reduced costs as well as a problem for uniform light quality.
I	Infrastructure	Infrastructure pertains to the installation, maintenance and supporting systems (power conversion) of SSL products. Fixtures and other unique features such as color shifting and dimming controls will require innovation as well as infrastructure development. This research activity also includes health and safety issues, information dissemination and training.
J	Cost Reduction	High first costs of lighting products extend payback periods and reduce the market penetration potential of new technologies. Lowering the cost of highly efficient SSL sources is necessary to achieve significant energy savings. Cost reduction activities concentrate on materials, methods and techniques to reduce light production costs through the aggressive development of suitable manufacturing and production technologies.

2.3.5 Lighting Approach/Strategies for Overcoming Barriers/Challenges

Currently, the Lighting subprogram focuses both on barriers associated with technical issues as well as market barriers. In order to promote SSL as an efficient lighting product, the Lighting subprogram plans to develop an ENERGY STAR designation for SSL products. Because the ENERGY STAR program has successfully increased the sale of its labeled products by educating consumers of the energy savings associated with that product, it is expected that labeling SSL products as ENERGY STAR will help overcome some of the initial market barriers.

The Lighting subprogram is also engaged in developing product testing and industry standards. Developing testing standards will help provide objective, comparative, performance information about LEDs. This information can then be used to support R&D planning, the ENERGY STAR program, and technology procurement programs that will link SSL manufacturers with high-volume buyers. The testing program will also be used to discourage low quality products, thus preventing buyer dissatisfaction. In March 2006, the Lighting subprogram hosted an LED workshop to promote cooperation among major standards organizations. Helping further coordinate the development of a cohesive set of standards will promote the entry of quality SSL products into the marketplace.

Currently, the subprogram also includes developing design competitions for lighting fixtures and systems using SSL products, coordinating with utility promotions and energy efficiency groups, promoting consumer and buyer awareness programs, and providing information resources for lighting design professionals and students. Taken together, all of these market transformation activities will help accelerate the market adoption of energy-efficient and cost-effective SSL products.

In order to overcome technical barriers, the Lighting subprogram structures its projects into a two-by-two matrix, creating four R&D areas: LED Core Technology, LED Product Development, OLED Core Technology and OLED Product Development. Within each of these areas, there are active, detailed R&D agendas which work towards the larger programmatic objective.

A summary of the strategies used to overcome barriers encountered in reaching specific SSL performance targets are listed in Table 2-20.

Table 2-20 Lighting Strategies for Overcoming Barriers/Challenges

Barrier	Title	Strategy
A	Market Demand	Develop design competitions for lighting fixtures and systems using SSL products, coordinate with utility promotions and energy efficiency groups, promote consumer and buyer awareness programs, and utilize ENERGY STAR labeling.
B	Technical Information and Design Selection Guidance	Provide technical information resources on SSL technology issues for consumers, lighting design professionals, and students.
C	Objective Test Results and Industry Standards	Test commercially available SSL products for general illumination. Encourage development of metrics, codes, and standards.
D	Luminous Efficacy	Work to concurrently meet efficacy targets and other performance criteria in a single product.
E	Quantum Efficiency	Produce and extract photons from devices with minimum heat production.
F	Lifetime	Understand degradation and failure mechanisms to extend practical lifetimes of devices to improve life cycle cost beneficial as possible. Advance scientific understanding of the role of impurities, defects, crystal structure and other factors closely related to materials systems choices.
G	Stability	Improve basic material properties and processes that impact the color and control of the light emitted from the devices.
H	Packaging and Manufacturin g	Design devices into practical packages that satisfy marketing and manufacturing goals, UV tolerance and seal out water and oxygen contamination of the products. Focus on SSL device packages that seal out moisture and oxygen, manage heat transfer, and protect optical material from UV degradation.
I	Infrastructure	Examine the marketing, sales, installation and support associated with the introduction of new solid-state light sources and fixtures.
J	Cost Reduction	Reduce the production costs to enable manufacturers to compete with existing, inefficient light sources including fluorescent.

Core Technology

Core Technology research encompasses scientific efforts that focus on comprehensive knowledge or understanding of the subject under study, with multiple possible applications or fields of use in mind. Within Core Technology research areas, scientific principles are demonstrated, technical pathways to SSL applications are identified, and price or performance advantages over previously available science/engineering are evaluated. Tasks in Core Technology fill technology gaps, provide enabling knowledge or data, and represent a significant advancement in the SSL knowledge base. Core Technology research focuses on gaining pre-competitive knowledge for future application to products by other organizations. Therefore, the findings are generally made available to the community at large.

Product Development

Product Development involves using basic and applied research (including Core Technology research) for the development of commercially viable SSL materials, devices, or systems. Activities typically include evaluation of new products through market and fiscal studies, with fully defined price, efficacy, and other performance parameters necessary for success of the proposed product. Laboratory performance testing on prototypes to evaluate product utility, market, legal, health, and safety issues as well as feedback from the owner/operator and technical data gathered from testing are used to improve prototype designs. Product Development encompasses the technical activities of product concept modeling through the development of test models and field ready prototypes. This area can also include "focused-short-term" applied research, but its relevance to a specific product must be clearly identified.

All Product Development activities are focused on one or more target applications with known cost and performance attributes from which estimates of market share and energy savings potential can be made. Along with the technical aspects of a project, market and fiscal studies are completed to ensure a successful transition from product development to commercialization. To be positioned for success, new products must exhibit cost and/or performance advantages over commercially available technologies.

The Lighting subprogram has twenty-one specific tasks to address the ten barriers (Table 2-21).

Table 2-21 Lighting Research and Development Tasks[47]

Task			Title	Duration*	Barriers
LED	Core Technology	1	High-efficiency semiconductor materials	2008-2018	B, C, D, E, H
		2	Phosphors and conversion materials	2008-2018	B, D, E, H
		3	Encapsulants and packaging materials	2008-2018	A, D,E, F H
		4	Inorganic growth and fabrication processes and manufacturing research	2008-2013	B, D, E, H
		5	Optical coupling and modeling	2008-2013	D, E, F, H
	Product Development	6	Manufactured materials	2008-2011	D, E, F
		7	LED packages and packaging materials	2008-2016	A, D, E, F, G, H
		8	Electronics development	2008-2016	F, G
		9	Thermal design	2008-2014	F, G
		10	Evaluate luminaire lifetime and performance characteristics	2008-2016	B, F
OLED	Core Technology	11	Power electronics development	2008-2016	D, E, F, J
		12	Novel materials and device architectures	2008-2016	F, G, H
		13	Novel strategies for improved light extraction	2008-2016	D, E, G
		14	Low-cost encapsulation and packaging technology	2008-2011	C, F, H, J
		15	Research on low-cost transparent electrodes	2008-2016	B, H
	Product Development	16	Investigation (theoretical and experimental) of low-cost fabrication and patterning techniques and tools	2008-2010	H, J
		17	Practical implementation of materials and device architectures	2008-2011	D, E, F, G
		18	Module and process optimization and manufacturing	2008-2015	H, J
		19	OLED encapsulation packaging for lighting applications	2008-2013	C, F, H
		20	Practical application of light extraction technology	2008-2009	A, D, E, H, J
		21	Low-cost substrates	2008-2016	G, H, J

47 For a complete list of tasks, see the Solid-State Lighting MYP, March 2008.

A stage-gate methodology,[48] tailored to the SSL subprogram, is applied to each project in the portfolio, and creates a lexicon for discussion, decisions, and planning which ensures a project meets the criteria at each gate before it advances to the next stage. By constructing this type of framework, the DOE and its contractors will properly review the R&D projects and ask the right questions to lead to successful commercialization of energy-saving products. The stage-gate system also provides management a means to terminate poorly performing projects and allocate resources to better projects.

2.3.6 Lighting Milestones and Decision Points

To provide some concrete measures of progress for the overall BT Program, the committee identified several milestones that will mark progress over the next ten years. These milestones are not exclusive of the progress graphs shown earlier. Rather, they are "highlighted" targets that reflect significant gains in performance. Where only one metric is targeted in a milestone description, it is assumed that progress on the others is proceeding, but the task priorities are chosen to emphasize the identified milestone.

Light Emitting Diodes

Product milestones for LEDs are listed in Table 2-22. The interim (FY08) LED milestone reflects a goal of producing an LED product with sufficient performance to be a good general illumination product and it could achieve significant market penetration. These goals have been met individually. In fact, some commercial products have achieved device efficacies greater than 100 lm/W.

Table 2-22 LED Product Milestones

Milestone	Year	Milestone Target
Milestone 1	FY08	80 lm/W, < $25/klm, 50,000 hrs
Milestone 2	FY10	> 140 lm/W cool white device; >90 lm/W warm white device
Milestone 3	FY12	126 lm/W luminaire that emits ~1000 lumens
Milestone 4	FY15	< $2/klm device

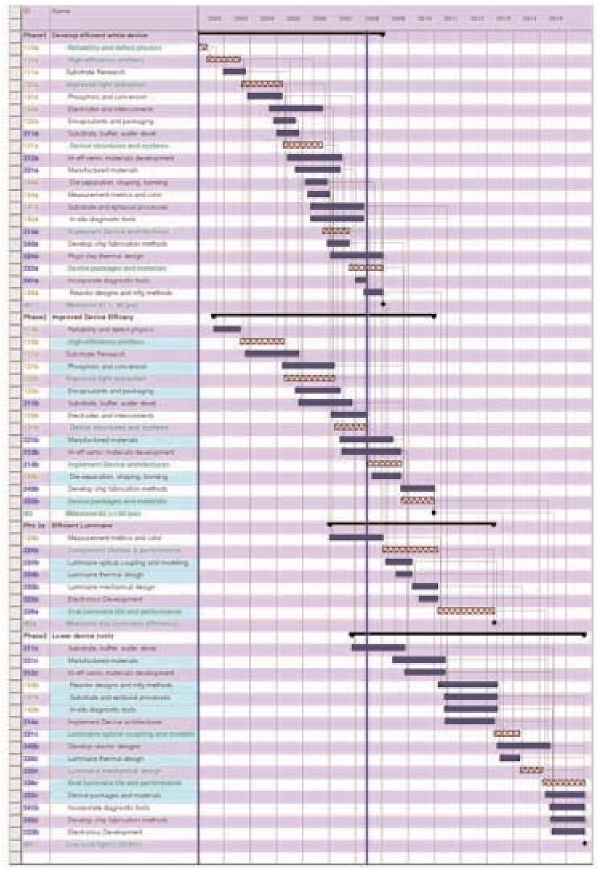
Assumption: CRI > 80, CCT < 5000K, T_j = 125°C

However, all of the milestone targets have not been met concurrently in a single product. For example, a commercial LED, which has an efficacy of 80 lm/W, is currently priced much higher than $25/klm.

FY10 and FY15 milestones represent efficacy or price targets of LEDs devices with a lifetime of 70,000 hrs. Although all milestones in FY08 were not met concurrently, it is expected that the FY10, interim goal of 140 lm/W for a commercial device will be exceeded. Other parameters will also progress, but the task priorities are set by the goal of reaching this particular mark. A new luminaire milestone has also been included in this update: By FY12, DOE expects to see a high efficiency luminaire on the market that has the equivalent lumen output of a 75W incandescent bulb and an efficiency of 126 lm/W. Finally, by FY15, costs should be below $2/klm for LED devices while also meeting other performance goals.

LED subtasks are shown in Figure 2-13 for four phases of development corresponding to the four milestones. The first phase, essentially complete, is to develop a reasonably efficient white LED device, sufficient to enter the

Figure 2-13 Planned Research Tasks – LEDs[49]



48 Robert Cooper, "Winning at New Products, Accelerating the Process from Idea to Launch." 3rd Edition. 2001.

49 NGLIA LED Technical Committee, reformatted for SSL MYP.

lighting market. Phase 2 is to further improve that efficiency in order to realize the best possible energy savings. This phase should be completed in about two years. Developing a more efficient luminaire is the thrust of Phase 3, expected to last until about 2012. Finally, the fourth phase is to significantly reduce the cost of LED lighting to the point where it is competitive across the board. This phase, currently underway, is expected to continue past 2015.

The bars on the Gantt chart indicate an estimated time period for execution of the task in question, while the connecting lines show the interdependence of tasks. The duration of the task depends to some extent on the amount of resources allocated. As a deeper understanding of each task is developed, duration estimates can be refined and varied according to the applied resources. The letters next to the task numbers (a,b,c) identify phases of the tasks. These phases are not to be confused with the overall program phases (1, 2, 3). Further task phases and program phases will be identified as the program moves past 2015 so that the full potential of solid state lighting can be realized.

Using these estimates of duration and task dependencies, one can identify critical paths to success. Those tasks on the critical path are shown with hashed bars. Tasks identified by the NGLIA/DOE team as high priority have shaded task names. For reasons noted above, the two do not necessarily coincide.

Organic Light Emitting Diodes

As with the LED program, milestones are identified and tasks are linked for OLED development. The OLED milestones have similar character to the LED milestones, but given the early state of OLEDs in lighting, the targets are somewhat more speculative (Table 2-23). They do serve the same purpose, however, which is to focus effort on specific interim goals in order to assure overall progress on the Lighting subprogram.

The FY08 OLED milestone is to produce an OLED niche product with an efficacy of 25 lm/W, an OEM price of $100/klm (device only), and a life of 5,000 hrs. CRI should be greater than 80 and the CCT should be between 3,000-4,000K. A luminance of 1000 cd/m^2 and a lumen output greater than 500 lumens should be assumed as a reference level in order to compare the accomplishments of different researchers. That is not to say that lighting products may not be designed at higher luminance or higher light output levels.

Although current laboratory devices have reached efficacies between 25 and 64 lm/W (at reasonable life, luminance, and CCT), there are currently no niche OLED products available in the marketplace for general illumination applications. According to industry experts, major manufacturers will wait for OLED laboratory prototypes to achieve higher efficacies before investing in the manufacturing infrastructure to produce OLEDs for general illumination purposes. Therefore, unless a smaller manufacturer, less averse to risk, develops a niche product, the FY08 milestone will not be met. Milestone 2 targets a commercial price of $70/klm by FY10. At this point the lifetime should be around 5,000 hours. Reaching a marketable price for an OLED lighting product, is seen as one of the critical steps to getting this technology into general use because of their large area. Although the FY08 milestone may be late in coming, cost reduction remains the focus. By FY15 the target is to get a high efficacy, 100 lm/W OLED. Cost and lifetime should show continuous improvement as well.

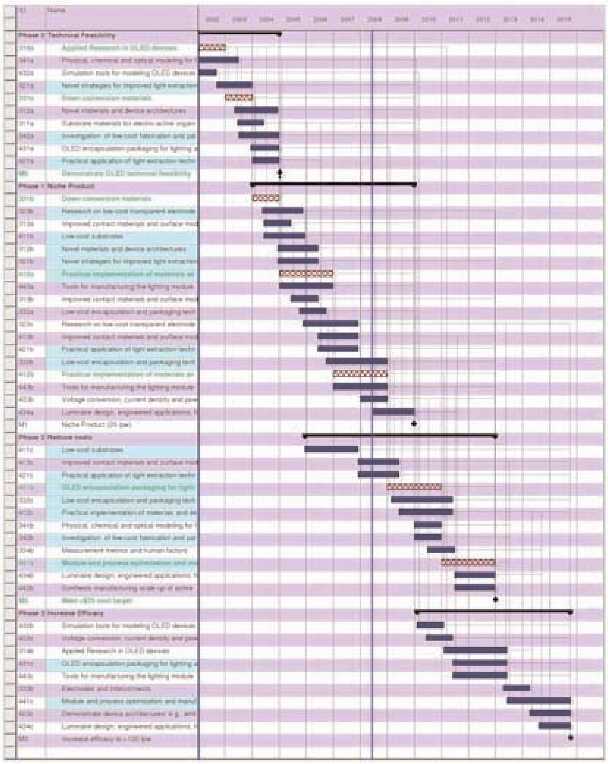
Table 2-23 OLED Product Milestones

Milestone	Year	Milestone Target
Milestone 1	FY08	25 lm/W, <$100/klm, 5,000 hrs
Milestone 2	FY10	<$70/klm
Milestone 3	FY15	>100 lm/W

Assumptions: CRI > 80, CCT < 2700-4100K, luminance = 1,000 cd/m^2, and total output ≥ 500 lumens.

Using the OLED subtask descriptions from Table 2-21, it is possible to associate those requiring significant early progress with the individual milestones. This linkage is graphically shown in the Gantt chart in Figure 2-14.

Figure 2-14 Planned Research Tasks - OLEDs[50]



2.3.7 Lighting Unaddressed Opportunities

One area of potential development is to more strongly support improved manufacturing of the products. Though outside the scope of the current program, a development in this area would represent a substantial opportunity for the industry and the country. Several potential benefits of such support are:

- Improved uniformity of processes would improve yields and lower costs.
- Improved control over manufacture would reduce color variation, an impediment to deployment.
- Advanced automation methods could reduce labor content and potentially make domestic production-"made in the USA"- a more attractive option than it is today. Currently most LED chip production has moved to Asia.
- For OLEDs, the manufacturing issue is particularly acute since the needs for displays, the apparent synergistic technology, are actually quite different from what is needed for lighting. This makes the issue of cost reduction a barrier to this technology.

While some manufacturing subtasks are prioritized for core R&D, there is not sufficient funding at this time to support advanced manufacturing development to the extent contemplated above.

Technology development of High Intensity Discharge (HID) lighting, has also been identified as an unaddressed opportunity within the Lighting subprogram. This task is an integral step in advancing conventional lighting technology. However, there is currently no funding for this task. Additionally, there is an unfunded initiative in traditional lighting.

50 NGLIA OLED Technical Committee

2.4 HVAC and Water Heating

Table 2-24 HVAC and Water Heating Summary

Start date	1980s
Target market(s)	Residential and commercial buildings
Accomplishments to date	• Initial development and ongoing improvement/ enhancement of the Heat Pump Design Model • Establishment of the total equivalent warming impact as a measure of global warming impacts of heating, refrigeration, and air-conditioning systems • First publication of laboratory measured vapor compression system performance for R-134a, R-32, R-125, and R-143a • Development and commercialization of an aerosol duct sealing technique • Creation of an ASHRAE standard for estimating efficiencies of thermal distribution systems • Development of a "drop-in" Heat Pump Water Heater (HPWH) • Development and patenting of a low-cost immersed condenser HPWH concept • Development of the Annual Cycle Energy System • Improved diagnostic techniques for duct leakage and other air flow
Current activities	1. Involve manufacturers in refining the IHP, GSHP, and HPWH 2. Support field testing and evaluation of existing equipment in Building America homes to assess their feasibility in zero-energy home environments 3. Begin design, fabrication, and initial proof-of-concept prototype testing of new HVAC system concepts optimized for the ZEH environment 4. Create conceptual designs of the most attractive integrated water heating appliance concepts, followed by the creation of prototype hardware for testing and evaluation
Future directions	• HVAC systems that meet the needs of a ZEH in various climate zones, including major reductions in energy consumption and peak demand, as well as excellent comfort control • Integrated appliances that combine space conditioning and water heating or capture waste heat for use in water heating
Projected end date(s)	2020
Expected technology commercialization dates	2010 to 2020

The primary focus of Heating, Ventilation, Air Conditioning (HVAC) and Water Heating R&D is to address the critical needs of the ZEH effort. Building America targets dramatic reductions in energy consumption in single-family homes, leading to net-zero energy homes by 2020. Cost-effective, highly efficient space conditioning and water heating systems are critical to reaching this goal. Consequently, the HVAC and Water Heating subprogram will work closely with the Residential Integration subprogram to ensure that R&D is closely aligned with the evolving needs and that those new technologies can be rapidly field-tested in homes and then transitioned to market in cooperation with Building America industry partners.

In addition, over the next several years, the equipment and performance needs of HVAC and water heating systems for commercial ZEBs will become more defined through the efforts of the Commercial Integration subprogram. In subsequent years, the HVAC and Water Heating R&D will work closely with the commercial buildings team to understand their needs, develop solutions, and test the resulting systems. Therefore, while the immediate focus of R&D is on residential ZEH targets, the subprogram anticipates devoting additional resources to commercial ZEB needs in the future.

2.4.1 HVAC and Water Heating Support of Program Strategic Goals

HVAC equipment for residential and commercial buildings consumes approximately 38.6 percent of the total energy used in buildings, a total of 15.34 Quads.[51] Electric heating and cooling are important contributors to peak electricity demand and water heating also plays a large role in energy expenditures.

In residential buildings, space heating is the dominant component of energy consumption, accounting for 30.7 percent followed by space cooling at 12.3 percent (Figure 2-15).[52] Natural gas-fired furnaces and boilers are the most common heating systems; fuel-oil based systems and hydronic systems each account for less than 16 percent of heating energy consumption.[53] Water heating constitutes the next largest element of primary residential energy consumption after space conditioning, accounting for 12.2 percent of energy consumption.[54]

51 BED

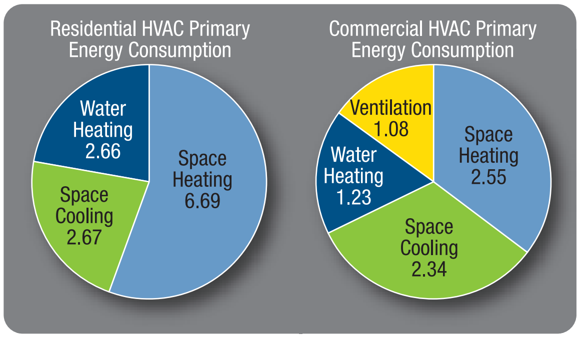
52 BED.

53 Estimated by TIAX, LLC, 2002

54 BED

In commercial buildings, HVAC is the single largest component of primary energy consumption, accounting for 33.3 percent (14.2 percent for heating, 13.1 percent for cooling, and 6.0 percent for ventilation), while water heating is substantially smaller, at 6.8 percent,[55] although it is a significant end use in some building types, such as hotels, hospitals, and restaurants.

Figure 2-15 Residential and Commercial HVAC Energy Consumption in Quads[56]



The HVAC and Water Heating R&D is fully aligned with the strategic goals of the BT program, specifically by developing technologies, products, and solutions that support the ZEB effort. To ensure R&D activities remain aligned with these strategic goals as they evolve, this subprogram will work closely with the Residential and Commercial Integration subprograms through periodic meetings, research collaboration, and participation in their program review meetings.

2.4.2 HVAC and Water Heating Support of Program Performance Goals

Dramatically improving the energy efficiency of HVAC systems and appliances is critical to achieving ZEB performance goals because they constitute a large proportion of the energy consumption in buildings. It is impractical and far too costly to design a ZEB with standard HVAC systems and appliances by attempting to generate all the required energy through on-site renewable energy. As noted in the BT program mission, the approach for a ZEB is to greatly reduce the energy needs through efficiency gains, and only then make up the remaining energy needs through on-site renewable generation. Our goal is to develop technologies with the long-term potential to meet this goal with no increase in annual mortgage plus utility costs.

Achieving the ZEH goal will require the development of space cooling and heating equipment that reduces energy consumption by 50 percent relative to the Building America 2004 Benchmark by 2010.[57] Similarly, water heating equipment that reduces energy consumption by 50 to 80 percent relative to the benchmark must also be developed. Substantial improvements in appliance energy efficiency will greatly enhance the viability of ZEH. While some tradeoffs can be made among the different systems, and the precise requirements differ depending on the climate zone, dramatic improvements in HVAC and water heating energy consumption are essential to ZEH. For design concepts such as the integrated heat pump, which combines space conditioning and water heating, the energy consumption targets will be calculated relative to Building America Benchmark totals for both functions.

Any new high efficiency water heating product must have very modest price premiums over conventional units, while offering substantial energy savings. In order to achieve the goals for ZEH by 2020 and ZEB by 2025, water heating energy consumption from non-renewable sources will need to decrease by approximately 80 percent.[58] Performance targets for HVAC systems, relative to the 2004 Building American baseline, are shown in Table 2-25. The cost target is to achieve the required performance with no increase in mortgage plus utilities costs.

Table 2-25 HVAC and Water Heating Performance Goals

		Year	
Characteristics	Units	2010	2020[59]
Residential Annual HVAC Energy Consumption Reduction versus 2004 Baseline	%	50	-
Residential Annual Water Heating Energy Consumption Reduction versus 2004 Baseline	%	50	80
Commercial Annual HVAC Energy Consumption Reduction versus 2004 Baseline	%	-	80

55 BED

56 BED

57 ZEH

58 ZEH

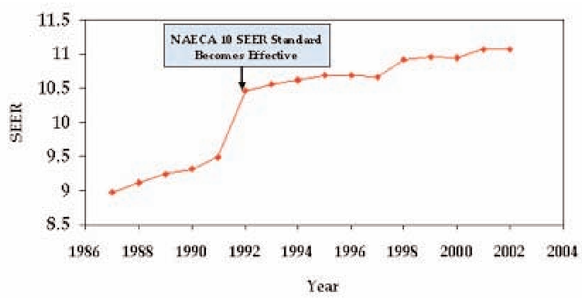
59 Year 2025 for commercial HVAC Goal

2.4.3 HVAC and Water Heating Market Challenges and Barriers

Most high efficiency residential HVAC systems are sold for reasons other than energy savings, though efficiency can be one of several factors. Such systems are typically bundled with non-energy features that are attractive to consumers, such a low noise, improved air filtration, or enhanced comfort. In the commercial HVAC sector, improved indoor air quality (IAQ), comfort, and reliability are important non-energy features. However, the majority of space conditioning equipment sold in the U.S. (approximately 70-80 percent in most years) only meets the minimum efficiency standard level mandated by DOE regulations, but does not exceed it. In recent years, the HVAC industry has seen only modest improvements in equipment efficiency, largely driven by the efficiency standards (Figure 2-16). The 13 SEER minimum efficiency standard, which took effect in January 2006, caused another large step increase in equipment efficiency. Premium HVAC systems sold in the U.S. will typically incorporate features that are valued by the customer, such as improved air filtration, reduced noise, and better fit and finish, but have little or no impact on efficiency.

High efficiency HVAC systems are commercially available today, but their market penetration is extremely limited, due primarily to their high initial costs. Such high efficiency systems have other drawbacks as well, including their large size and concerns about humidity control. New product designs and system approaches will be needed to overcome these limitations.

Figure 2-16 Shipment Weighted SEER of Unitary Air Conditioner Shipments[60]



The challenges to selling high efficiency water heating are even greater than for HVAC. Unlike white goods or even HVAC, there are few if any premium features of a water heater (e.g. comfort, aesthetics, image, enhanced functionality) that can be combined with efficiency to up-sell high efficiency products. Furthermore, most replacements are emergency sales where immediate availability is essential, and upgrading to more energy-efficient units is not feasible. Finally, the relatively low energy costs of water heating to individual consumers can make it difficult to justify a higher first cost product. Electric heat pump water heaters and condensing gas-fired water heaters offer significant energy savings over conventional products, but have very high price premiums and have therefore achieved a very limited market share. For example, of the 4 to 5 million residential electric water heaters sold annually in the U.S., only a few thousand are heat pump water heaters, whose efficiency can be more than double that of conventional units.[61]

Many aspects of the ZEH technical goal can largely be achieved for some regions of the country, and for some building types, using commercially available technology, but at an unacceptable cost. Reaching the goal with technologies that show promise of becoming affordable is critical. To achieve the economies of scale necessary to produce economical equipment, manufacturers need volumes far greater than the current ZEH market can provide. A viable ZEH strategy must address equipment that can, in the long-term at least, also be part of the broad equipment replacement and new construction market. Therefore, research should address the needs of the ZEH, but should also consider the needs of the large base of existing houses in order to provide a sufficiently large market to warrant the attention of equipment manufacturers.

60 *ARI Statistical Profile*, Air Conditioning and Refrigration Institute, October 7, 2004.

61 BED

The market barriers to meeting the HVAC strategic goal and performance goals are described in Table 2-26.

Table 2-26 HVAC and Water Heating Market Challenges and Barriers

Barrier	Title	Description
A	Affordability	The ZEH strategy requires development of much more affordable systems. Many high-efficiency HVAC and water heating products and systems are already available in the marketplace, but are far too expensive for widespread adoption. Any new technology or system developed must be cost competitive with today's technologies.
B	Market acceptance	New products need to be easily installed and maintained without necessitating substantial additional training for installers or requiring additional trades' personnel. Current products are very reliable, but HPWHs have suffered from poor reliability, leading to a poor market image. Most water heater sales are replacements where immediate availability is essential and "up-selling" is uncommon. Coupled with the commodity nature of the product, this limits the potential for advanced products.

2.4.4 HVAC and Water Heating Technical (Non-Market) Challenges/Barriers

The basic design concept for both vapor-compression HVAC systems and water heaters has changed very little in the past decades. These products look much the same today as they did 20 years ago. Because incremental improvements and minimum efficiency standards (e.g., NAECA, EPACT, ASHRAE 90.1) have captured much of the "low-hanging fruit" available for further efficiency gains, new design approaches are necessary. Therefore, achieving the ZEH goals will require smaller, more efficient systems.[62] The technical barriers to meeting the HVAC strategic and performance goals are described in Table 2-27.

Table 2-27 HVAC and Water Heating Technical Challenges/Barriers

Barrier	Title	Description
C	Achieving high-efficiency in low-capacity HVAC systems	Substantial efforts have been made to raise the efficiency of 2-5 ton heat pumps and air conditioners. As system capacity is reduced, certain losses (e.g. clearance volume flow in compressors, high-to-low pressure section leakage in reversing valves) tend to become a larger percentage of total capacity. New developments are needed to achieve high efficiency in small systems.
D	Sustained performance	Systems must be designed to sustain their initial efficiency throughout the life of the equipment or notify users when performance deteriorates so corrective action may be taken. This can be accomplished with fault detection and diagnostic (FDD) systems.
E	System efficiency	The benefits of efficient HVAC systems can be realized only if system performance is improved significantly. Therefore, near-zero-loss systems to distribute heating, cooling, and ventilation must be developed which are cost-effective and simple to install. Furthermore, providing comfort conditioning only when and where it is needed to satisfy occupants requires systems that permit efficient zoning and sensors to optimize indoor air quality and humidity while also minimizing energy consumption. Proper air distribution, which can be affected by register design and placement, is also important.
F	Ensuring comfort and indoor environmental quality	Traditional residential HVAC systems do not provide adequate humidity control under certain conditions (e.g. when sensible cooling loads are low) and do not provide sufficient fresh air ventilation which is necessary to ensure IEQ in tight homes.

2.4.5 HVAC and Water Heating Approach/Strategies for Overcoming Challenges and Barriers

Meeting the needs of the ZEH program will require new approaches to generating and distributing heating, cooling, and hot water in order to meet the particular needs of ZEH occupants. Planned activities fall broadly into two categories, one addressing HVAC systems and the other addressing water heating. Some integrated appliance concepts may incorporate both functions in a single product or system. Furthermore, as noted previously, the cost optimal solution may be very different in different climate zones.

The focus of HVAC R&D efforts will be on system energy consumption, rather than simply EER or SEER, which do not capture the impacts of the entire HVAC system. The baseline for comparison will be the Building America 2004 Benchmark. HVAC equipment will also need to be designed specifically to meet ZEH building loads, which will be quite different in magnitude and relative proportions (e.g. cooling, heating, dehumidification and domestic hot water) than those of current homes. Specifically, humidity control in a ZEH can be very challenging using conventional HVAC equipment, and forced mechanical ventilation may be required to ensure acceptable IEQ in these homes, due to their tight envelopes.

Although the energy efficiency of HVAC equipment has increased in recent years, new approaches, including radically new ideas, are required for continued improvements. The dramatic reductions in HVAC energy consumption necessary to support the ZEH goals require a systems-oriented Stage-Gate analysis approach that characterizes each element of energy consumption, identifies alternatives, and determines the most cost-effective combination of options. Therefore, the first task in this effort involved system characterizations, identification of necessary upgrades to analysis tools, and an assessment of cost and performance of alternative solutions. The following technologies are elements of possible solutions identified in cooperation with Residential Integration, but further evaluation may substantially alter these plans:

- Integrated heat pumps which combine heating, cooling, ventilation, humidity control, and water heating
- Reduction of distribution losses, recovery of waste heat, integration of tankless hot water systems, and integration of simple, durable, low cost solar hot water systems
- Stand-alone, direct expansion dehumidification systems with energy recovery ventilation and possibly hot water pre-heating
- Large surface heat exchangers for radiant floors, walls, or ceilings
- Low leakage thermal loss duct systems
- Low capacity space conditioning systems that may be integrated with night cooling or other evaporative cooling options or use ground contact
- Combined desiccant/evaporative cooling unit to supply any mix of sensible and latent loads in any climate

This effort is specifically targeted to achieving demonstration of two design concepts that have the long-term potential to reduce annual HVAC and water heating energy consumption by 50 percent in new residential buildings at neutral cost. The design concepts must also address other critical Building America needs such as humidity control, uniform comfort, and indoor air quality. Several different design approaches will be necessary for optimal performance in different climate zones and building types. If design concepts which combine space conditioning and water heating are proposed, the energy consumption and payback period targets will be calculated relative to Building America Benchmark totals for both functions.

A preliminary business case analysis of the most promising concepts was completed in FY 2006. Future activities will involve prototype development, testing and evaluation of the concepts identified. Besides the integrated heat pump concept, various approaches for high efficiency water heating exist today and have been the subject of considerable R&D in recent years. They include heat pump water heaters and solar water heating; however, both have proven cost-prohibitive despite substantial cost reduction efforts. The HVAC subprogram is not aware of any likely breakthroughs in these technologies that could dramatically reduce their costs, but remain open to the possibility that such breakthroughs may become possible due to advances in new materials, manufacturing technologies, electronics, or technology transfer from other industries or products. The subprogram continues to monitor alternative technologies and remains open to exploring these pathways if dramatic cost reductions seem likely.

The Building America program has recently refined their ZEH analysis using BEOpt, resulting in more stringent targets for cooling efficiency. Residential Integration is targeting 24 SEER systems with substantial dehumidification capabilities, so the HVAC subprogram will explore options for achieving these very challenging goals. The heating performance for this system needs to be better defined.

The HVAC and Water Heating strategies for overcoming barriers and challenges are included in Table 2-28.

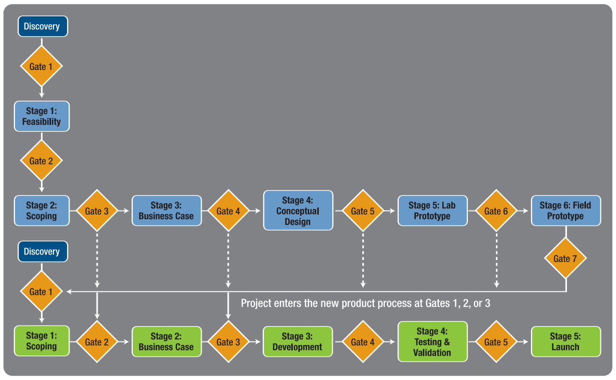
Table 2-28 HVAC and Water Heating Strategies for Overcoming Barriers/Challenges

Barrier	Title	Strategy
A	Affordability	Designs must use simple, off-the-shelf components that are mass-produced, and the concepts may not incorporate other features that raise costs without any energy benefit.
B	Market acceptance	Concepts will maintain design simplicity, use of conventional components, and ease of installation and maintenance. A market study will help address questions related to market acceptance.
C	Achieving high-efficiency in low-capacity HVAC systems	New design concepts may incorporate point-source cooling systems and small-capacity, variable-speed compressors.
D	Sustained performance	Designs will either include integrated fault detection and diagnostic (FDD) systems or should tolerate typical faults such as modest loss of refrigerant charge without significant performance deterioration.
E	System efficiency	New concepts will target part-load efficiency, reduced energy consumption through smart zone control, and approaches such as waste heat recovery that are not easily captured by the SEER metric but that can reduce energy consumption dramatically. For water heating systems, distribution system losses will also be considered.
F	Ensuring comfort and indoor environmental quality	New HVAC designs will provide integrated dehumidification capable of sufficient latent cooling under all conditions and will also provide low-cost, low-loss mechanical ventilation.

63 Adapted from Robert Cooper, "Winning at New Products, Accelerating the Process from Idea to Launch." Perseus Books Group. 3rd Edition. 2001. ISBN: 0738204633

Many different design concepts will be considered, based on stakeholder input and discussions with the Building America team. Because the subprogram cannot predict which solutions will prove most promising, a modified Stage-Gate process is used to reduce risk.[63] The BT adapted Stage-Gate methodology requires certain criteria be met before approval is gained to enter the next stage of the process. The main stages for HVAC and Water Heating include comparisons of possible alternatives, several conceptual designs, and then detailed prototype design, assembly and testing (Figure 2-17). The potential federal role in technology development involves six stages and seven gates, but depending on the nature and status of the concept, some or all of the responsibilities can flow to the private sector for product development beginning as early as Gate 3.

Figure 2-17 Stage Gate Process for DOE HVAC & Water Heating R&D Subprogram



The program starts with ideas that are successively screened by gates 1- 7 to reach feasibility, scoping, business case, conceptual design, lab prototype, and field prototype stage. From the third gate onwards, the program works diligently to encourage appropriate private sector entities to partner with the program at the earliest possible stage, so that technology and product development efforts are complementary rather than duplicative.

The HVAC & Water Heating has developed detailed descriptions for each set of gate deliverables, the criteria for passage, and the outputs, as well as for the typical activity at each funded stage. Criteria include "must-meet" criteria, which are required in order for the project to pass into the next stage, as well as "should meet" criteria, which are desirable but not mandatory.

The Stage-Gate process structures the tasks and dates for each project (Table 2-29). The designs will first be tested in a Habitat for Humanity house and then ultimately be field tested in Building America homes, which provide an excellent test bed for monitoring real world performance prior to commercialization. It is expected that several different HVAC concepts will be field tested, to address the specific needs of different climate zones.

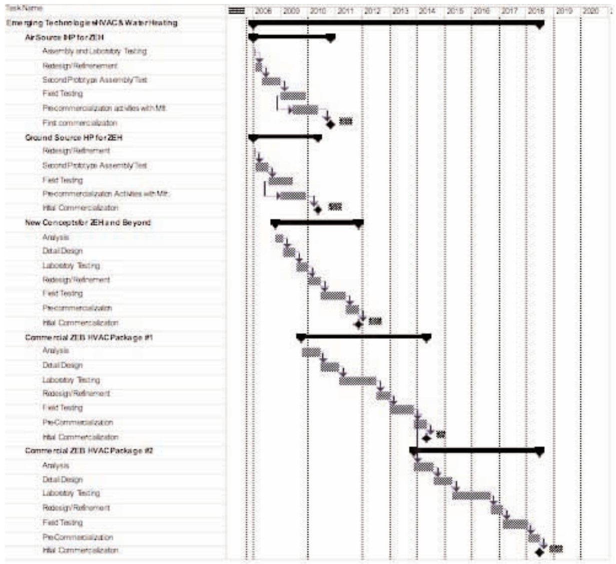
Table 2-29 HVAC and Water Heating Tasks

Task	Title	Duration	Barriers
1	Air Source Integrated Heat Pump for ZEH	2008-2010	A, B, E
2	Ground Source Heat Pump for ZEH	2008-2010	A, B, E
3	High Efficiency Water Heater	2008-2010	A, B
4	New Concepts for ZEH and Beyond	2008-2011	A, B, C, E, F
5	Commerical ZEB HVAC Package #1	2009-2013	A, B, E, F
6	Commercial ZEB HVAC Package #2	2013-2018	A, B, E, F

2.4.6 HVAC and Water Heating Milestones and Decision Points

As shown in the Gantt chart (Figure 2-18), the primary activities for the next several years relate to development and commercialization of the IHP for ZEH. New concepts for ZEH will begin to be analyzed in FY08, leading to detailed design and development of promising concepts in the coming years. The next priority will be to begin development of design concepts to support the commercial ZEB program. The schedule shows two successive efforts related to commercial ZEB concepts, based on the assumptions of roughly level funding in the next few years. If the current budget levels increase substantially, the two commercial ZEB design efforts could occur simultaneously, with additional efforts starting afterwards. An additional sub-activity, addressing needs for low-loss hot water distribution systems, may be added in subsequent years, if appropriate R&D needs are identified through ongoing field studies.

Figure 2-18 HVAC & Water Heating Gantt Chart



2.4.7 HVAC and Water Heating Unaddressed Opportunities

Low-loss domestic hot water distribution systems, large surface heat exchangers (radiant floor, wall, or ceiling), low leakage and thermal loss ducting systems, and commercial duct sealing have been identified as unaddressed opportunities within the HVAC and Water Heating subprogram.

2.5 Envelope

Table 2-30 Envelope Summary

Start date	1980
Target market(s)	New and existing residential and commercial buildings
Accomplishments to date	• Developed and demonstrated energy-savings benefits of dark colored metal, clay tile, and asphalt roofing materials and wall coatings that are highly reflective • Worked with industry to develop second and third generation of foam insulation materials that were more energy efficient and less costly • Devised manufacturing methods to dramatically reduce the cost of vacuum insulation materials • Developed methodology and tool to assess potential for moisture-related damage and the onset of mold problems in order to guide the development of failure-resistant energy-efficient envelope systems • Developed and produced consumer information and software to help homeowners select the proper type and amount of insulation, thereby promoting use of better insulation for building envelopes • Advised the Federal Trade Commission (FTC) on issues associated with their Insulation Labeling Rule • Through active participation in ASTM and ASHRAE, developed, revised, and launched over 100 standards pertaining to insulation materials and building envelopes • Assisted in the development of DOE vapor control recommendations that were submitted to the International Residential Code • Developed and tested a phenolic foam reinforced with cellulose fibers that can be used in Structural Insulated Panels (SIPs)
Current activities	1. Develop the next generation of attic/roof systems through the integration and optimization of cool colors, thermal mass, above sheathing ventilation, advanced lightweight insulation, Phase Change Materials (PCMs) and radiant barriers, including consideration of fundamental new structural components. 2. For Advanced Walls, develop best practices for PCMs. 3. Develop next generation of insulation materials that are lightweight but include thermal inertia for increased energy efficiency and peak load reduction to support ZEBs. These materials include phase change insulation, dynamic membranes, superhydrophobic materials, and insulated structural sheathing. 4. Research energy efficient and durable basement/foundation systems to quantify the effectiveness of sealing crawlspaces versus ventilating them for a large number of crawlspace building envelope and system arrangements. Determine affordable insulation strategies for full and partially insulated basements. 5. Through expert moisture analysis, define parameters for vapor barrier optimization and develop new dynamic membranes to enable the construction of significantly more efficient envelope systems. 6. Conduct Air Barrier Research to determine moisture properties for membrane products. 7. Evaluate thermal performance of metal buildings. Investigate a potential gap in compliance where metal building roof and wall insulation is compressed between the roof or wall skin. Develop a plan and resolution schedule for the possible issuance of a de-rating process within ASTM or ASHRAE. 8. Develop the necessary standards that guarantee building envelope material and system selection is fair and objective so that this work can be carried out by the private sector.
Future directions	1. Conduct SIP facer development to address environmental sensitivity of existing technology, develop new foam insulation products that have higher R-values, and develop advanced joining techniques that are less installation sensitive 2. Develop new types of low-density insulations that are more opaque to radiative heat transfer and have thermal inertia 3. Develop roofing products for cooling dominated climates that are aesthetically pleasing to the consumer but reflect large percentages of solar radiation 4. Develop new types of wall systems that are inexpensive and insensitive to moisture ingress 5. Develop new construction techniques that allow the use of the attic space, but allow air distribution systems to be inside the conditioned space 6. Develop energy-efficient slab and basement foundation systems 7. Develop tools and standards that allow for the appropriate thermal and hygric design of building envelope systems 8. Work with Asian-Pacific Partnership to deploy technologies to India and China
Projected end date(s)	*2008:* Improved low density insulation; Exterior insulation systems *2009:* Next generation SIPs *2010:* Required standards for industry moisture testing *2015:* Highly-efficient attics
Expected technology commercialization dates	Reflective roofing products: 2007-2009 Improved low density insulation: 2008 Next generation SIPs: 2009

A building's envelope is what divides the working or dwelling space from the outside; it includes roof and attic systems, walls, and foundations. The most common roof and attic system found on single family residential buildings consists of a wooden truss system with blown-in loose-fill fiberglass insulation, though other, newer materials are also used. With current technology the most common wall is wood-framed with a 3.5-in cavity filled with fiberglass batts, which provide R13 or R15. On the other hand, many foundations are un-insulated. Crawlspaces are commonly lined with R11 insulation on the underside of the floor in existing homes but ventilation depends on local building codes.

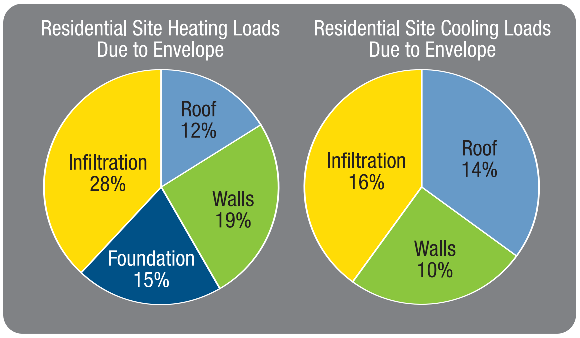
Emerging technology for envelopes focuses on the development of new materials and systems to improve the performance of the building envelope. Technologies developed through BT R&D progress from inception into the marketplace through a technical pathway. Each major Envelope portfolio component progresses from identification of need, allocation of resources, and continuous measurement of results against milestones, with the end objective being deployment into ZEH by Building America.

Commercial buildings have high internal loads due to lighting, miscellaneous electric loads, and other heat sources. A tight envelope increases the heating load, and the energy required to cool the building, which is counterproductive to ZEB goals. Therefore, the Envelope subprogram focuses on Residential Integration needs.

2.5.1 Envelope Support of Program Strategic Goals

The Building Technology Program's long-range goal of developing ZEB by 2025 will require more cost-effective, durable and efficient building envelopes. To make ZEB affordable, efforts to reduce the energy required for buildings are a necessary complement to efforts aimed at reducing the cost of renewable power. Forty-three percent of the primary energy used in a residence is spent on space heating and cooling (Figure 2-19).[64] Reducing envelope energy consumption will greatly contribute to reaching ZEB since a significant amount of space heating and cooling energy is lost through inefficient envelopes. The importance of the Envelope subprogram has been recognized by the Residential Integration subprogram, as exemplified by the ambitious envelope targets in the Building America list of optimization-critical component needs.[65]

Figure 2-19 Envelope Contribution to Site HVAC Energy Consumption in Quads[66]



The strategic goals have been defined with consideration of their energy saving potential toward the ZEB goal and the research gaps noted in a recent Building America planning meeting.[67] These objectives have been organized to address major building envelope systems, promising new material developments, and enabling technologies.

- Develop the Next Generation of Attic/Roof Systems: By 2015, develop advanced attic and technologies for single-family residences that reduce the space conditioning requirements attributable to attics by 50 percent compared to Building America regional baseline new construction at no additional operating cost and no additional envelope failure risk.
- Develop the Advanced Wall Systems: By 2015, develop advanced wall technologies for single-family residences that achieve R-25+ and 40% solar reflectivity at a small added cost.

64 BED

65 ZEH

66 BED

67 Building America Meetings Series: Quarterly All-Teams Planning Meeting Notes, November 16-18, 2004, U.S. Department of Energy, Building America Program. Washington, DC.

- Develop the Next Generation of Envelope Materials: By 2015, develop and demonstrate innovative materials that either: (1) will have effective thermal performance improved by 50 percent relative to functionally-comparable components of the Building America regional baseline new construction; or (2) resolve durability-related problems (moisture, termite, structural, etc.) that may increase envelope failure risk.

Table 2-31 Envelope Performance Goals

Characteristics	Units	Calendar Year 2008 Status	Calendar Year 2010 Target
Advanced attic/roof system	R-Value	Conventional R-45	Dynamic annual performance equal to conventional R-45
Color reflectivity (applicable to both walls and roofs)	Solar reflectivity	30%[68]	40%[69]
Advanced wall system	R-Value	Static R-20 in 3.5in. thick space	Dynamic annual performance equal to conventional R-25[70]
Foundation Systems	Development		Field experiments underway; model development advanced
Phase change energy storage within lightweight building system	Development	Prototype material, laboratory testing, field testing	Commercial PCM-enhanced fiber insulation at no or little
Thermochromic surfaces for commercial and low-slope residential roofs	Development	Prototype material, field testing, industry demonstrations.	Assessed surface durability; improved prototypes
Improved weather resistive barriers (WRBs)		Define optimal characteristics	Optimized prototype in market

68 Durability not yet assured at interim target

69 With attractive dark appearance, and with long-term durability of both reflective properties and appearance

70 Subject to no additional operating cost, within the traditional 3.5-inch wall dimension, with acceptable durability characteristics

71 *High-Performance Commercial Buildings: A Technology Roadmap,* U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, October 2000.

72 *Technology Roadmap: Information Technology to Accelerate and Streamline Home Building, Year One Progress Report,* U.S. Department of Housing and Urban Development, Office of Policy Development and Research. Prepared by Newport Partners, LLC, June 2002.

73 *High-Performance Commercial Buildings: A Technology Roadmap,* U.S. Department of Energy , Office of Energy Efficiency and Renewable Energy, October 2000.

74 *Technology Roadmap: Whole House and Building Process Redesign,* 2003 Progress Report, U.S. Department of Housing and Urban Development, Office of Policy Development and Research. Prepared by Newport Partners, LLC, August 2003.

- Conduct enabling research that fosters private industry investment in energy-efficient products, examples include air barrier research, performance test protocols, ASHRAE SP 160 Interior Moisture Conditions, etc.

- Develop construction guidelines for optimal foundation performance by 2015.

2.5.2 Envelope Support of Program Performance Goals

The table below, Table 2-31, lists the performance goals for the Envelope subprogram. All performance measurements are relative to historical baselines that have been set as the Building America regional baseline for new construction. One important constraint included for many components of strategies is that of "no additional operating cost", which is defined here as the sum of the mortgage-amortized installed cost and the annual energy costs savings. Ensuring the durability of the envelope is also an integral aspect of these targets.

2.5.3 Envelope Market Challenges and Barriers

Building envelope designs and material selections are typically constrained by cost. This is particularly true during new construction when many homes are built using price estimates. Even for retrofit applications, improvements that add cost are very difficult to market unless those costs can be recovered through reduced energy bills.

Table 2-32 Envelope Market Challenges and Barriers

Barrier	Title	Description
A	First-cost sensitivities	There is often an economic disconnect between builders and building occupants.[71] Builders are sensitive to first cost and typically receive no benefits from long-term energy performance improvements.
B	Resistance to change	The building industry is fragmented and diverse, with a strong resistance to change.[72, 73] Industry rules of thumb often take precedence over technical recommendations based on extensive building envelope research.[74]
C	Local code variability	Local building codes vary greatly, with thousands of code jurisdictions in the United States. Although there has been great progress in bringing the code bodies together on the national level, local codes for residential construction and, more importantly, code enforcement are less uniform. In many locations, only the electrical system is inspected. In others, outdated codes preclude the application of recent advances in building science.

Table 2-33 Envelope Technical Challenges/Barriers

Barrier	Title	Description
D	Thermal performance versus durability performance	All materials and systems must meet both thermal and durability performance requirements. For example, reflective paint pigments must not only provide the desired radiative properties, but also be colorfast over long periods of time and resist wear due to weather exposure.
E	Unknown interactions	Understanding of the physical interactions between building components and systems is incomplete. For example, early efforts to reduce infiltration often led to moisture problems.[75]
F	Material developments	Building industry practices are relatively rigid, so that material developments are necessary to provide certain desirable properties, such as increased heat capacity, within the limitations of typical light-frame building practices.
I	Structural support requirements	There are conflicts between structural support requirements and the need to limit heat-flow paths between the conditioned space and the external environment.[76]
J	Material property data	Data are unavailable for a number of critical material properties. Physical models are unable to accurately predict performance without accurate material property data.
K	Benchmark system data	Benchmark performance data are unavailable for a number of existing systems and for all novel/proposed systems.

2.5.4 Envelope Technical (Non-Market) Challenges and Barriers

The building envelope industry is highly fragmented; it is unlikely that an envelope is constructed with products from a single manufacturer. Often, an envelope constructed in the field joins elements that are combined differently in each building, so product integration and performance issues are seldom addressed. Table 2-33 describes the technical challenges and barriers associated with Envelopes.

2.5.5 Envelope Approach/Strategies for Overcoming Challenges and Barriers

The Envelope subprogram focuses on meeting the building envelope objectives outlined by conducting collaborative R&D with national laboratories, industry partners, standards and professional societies, and universities, including international participation as appropriate.

Develop the Next Generation of Attic and Roofing Systems

The goal for the advanced attic systems project is to make attics constructed by 2010 twice as efficient as Building America's regional benchmarks. The Envelope Performance Goal for the advanced attic/roof system is a dynamic annual performance equal to conventional R-45 by 2010. The attic system is defined broadly to include the roof structure as well as the space between the roof and the finished ceiling. Attics were selected because practical solutions for constructing an energy-efficient attic do not exist and that attic and roofing systems represent a significant percentage of the aggregate residential building component loads.[77, 78] Achieving this ambitious goal will require a well-coordinated collection of technical advances, using an effective collaboration of engineering and scientific resources.[79, 80]

The major components of the strategy for attic systems are:

- Integration of PCM, Cool Colors, ASV, Radiant Barrier and Advanced Lightweight Insulations
- Regionally Optimization of Above-Sheathing Ventilation
- Best Practice for Integration of PCM in Roof and Attic Assembly
- Demonstration of Dynamically Active Roof and Attic
- Consolidation of Existing Energy Estimating Tools

75 *Technology Roadmap: Whole House and Building Process Redesign*, 2003 Progress Report, U.S. Department of Housing and Urban Development, Office of Policy Development and Research. Prepared by Newport Partners, LLC, August 2003.

76 *Technology Roadmap: Advanced Panelized Construction*, 2003 Progress Report, U.S. Department of Housing and Urban Development, Office of Policy Development and Research. Prepared by Newport Partners, LLC, May 2004.

77 BED

78 Anderson, Ren, et all; *Analysis of System Strategies Targeting Near-Term Building America Energy-Performance Goals for New Single-Family Homes*, November 2004, National Renewable Energy Laboratory. Report No. TP-550-36920.

79 *Building Envelope Technology Roadmap,* U.S. Department of Energy , Office of Energy Efficiency and Renewable Energy, May 2001.

80 *Technology Roadmap: Energy Efficiency in Existing Homes, Volume Three: Prioritized Action Plan*, U.S. Department of Housing and Urban Development, Office of Policy Development and Research. Prepared by Newport Partners, LLC, May 2004.

Develop the Advanced Wall Systems

Developing a more air tight and energy efficient envelope will significantly facilitate reaching ZEB goals, as exemplified by the ambitious envelope targets in the Building America list of optimization-critical component needs.[81] The Envelope Performance Goal for wall insulation is to meet durability requirements for an R-20 wall by 2010. The goal for the advanced wall systems project is to make these systems constructed by 2010 twice as efficient as Building America's regional benchmarks. These regional benchmarks are based upon the 2003 IECC and vary from a total resistance (including sheathing, framing, and finishes) of R-12 in warm climates to R-26 in cold climates.[82]

A market resistance to increased wall thickness has posed constraints on strategies to improve the energy efficiency of wall systems in many regions. Therefore, advanced materials and systems must deliver significant improvements in energy performance without increasing wall thickness.

The major components of the strategy for wall systems are:

- Demonstrate the next generation of exterior insulation finish systems (EIFS)
- Develop a non-organically faced Structural Insulated Panel (SIP)

81 Navigant Consulting, Inc., Zero Energy Homes' Opportunities for Energy Savings: Defining the Technology Pathways Through Optimization Analysis, October 2003

82 R. Hendron, Building America Research Benchmark Definition, Updated December 15, 2006, NREL/TP-550-40968, January 2007

83 *Building Envelope Technology Roadmap*, U.S. Department of Energy , Office of Energy Efficiency and Renewable Energy, May 2001.

84 *Technology Roadmap: Advanced Panelized Construction*, 2003 Progress Report, U.S. Department of Housing and Urban Development, Office of Policy Development and Research. Prepared by Newport Partners, LLC, May 2004.

85 *Technology Roadmap: Energy Efficiency in Existing Homes, Volume Three: Prioritized Action Plan*, U.S. Department of Housing and Urban Development, Office of Policy Development and Research. Prepared by Newport Partners, LLC, May 2004.

Develop Advanced Foundations

At this point, work on foundations is limited, but the goal is to have field experiments underway and model development advanced by 2010. Earlier work in this field, especially the results from very long-term exposure tests, will serve as the starting point. Careful experimental design will be used to answer the questions associated with the inter-related aspects of foundation performance, recognizing that the thermal performance may not be the most important. As the other envelope thermal loads are reduced as the program progresses, the thermal losses and gains through the foundation become more important.

Develop the Next Generation of Envelope Materials

The program strategy is to create the opportunity for envelopes to contribute to ZEB by advancing a portfolio of new insulation and membrane materials, including the exterior finishes, having residential and commercial application. Currently goals for envelope materials focus on field testing, durability assessment, and prototyping for market introduction. The needs for new envelope materials have been expressed in a number of roadmaps.[83, 84, 85]

The major components of the strategy for envelope materials are:

- Develop improved weather resistive barriers (WRBs)
- Develop phase change energy storage within light-weight building system
- Determine the feasibility and energy saving potential for dynamic roofing surfaces such as thermochromic materials

Durability issues, lack of technical data, and insufficient standards are key barriers that are preventing more energy-efficient building envelopes from becoming routine practice. Moisture is responsible for the largest percentage of building envelope failures, leading to losses in energy efficiency, structural failures, and poor indoor environmental quality.

Enabling Technology

All of the tasks included in this plan address previously listed building envelope issues; enabling technology tasks focus on broader challenges that are applicable to all of the envelope components. These challenges include moisture issues, standards organizations expertise and leadership, and leveraging resources. The major enabling technology strategies that address these broad barriers are:

- Apply world class scientific and engineering analysis to solve moisture issues through analysis and material properties studies identified by Building America and others[86, 87]
- Provide impartial expertise and/or leadership to standards organizations, such as ASTM, ASHRAE, CRRC, and IEA and government agencies
- Leverage public resources with industry collaborations through User Centers with unique experimental facilities[88]

Table 2-34 Envelope Strategies for Overcoming Barriers/Challenges

Barrier	Title	Strategy
A	First-cost sensitivities	First, work to reduce the cost of advanced envelope technology and then improve communication with the general public to raise their awareness and increase their demand for better buildings. Finally, promote the incorporation of improved technology into standards that require industry use.
B	Resistance to change	Work to incorporate the advanced technology into codes and standards to compel industry acceptance. Continue with education programs to expand the knowledge-base among building industry members.
C	Local code variability	Continue to work with standards organizations that local code officials rely upon. Expand communication with the general public to raise their awareness and increase their demand for better buildings. Make supporting information available to other elements of the BT program that interact directly with code officials.
D	Thermal performance versus durability performance	Continue cooperative product development programs and continue ambitious testing programs that include both age-acceleration and field-exposure elements in conjunction with laboratory thermal performance testing programs. Use work with standards organizations to accelerate adoption of new energy-conserving products and systems.
E	Unknown interactions	Expand modeling capabilities, with important benchmarks extracted from both field tests and large laboratory experiments.
F	Material developments	Work with building envelope component manufacturers to identify possible modifications that improve energy performance with minimal changes to application mechanics.
G	Structural support requirements	Use modeling capabilities to explore the thermal performance of proposed new building configurations.
H	Material property data	Continue to make the sophisticated measurements necessary to expand the data library. Also, develop new measurement techniques as appropriate.
I	Benchmark system data	Collaborate with industry, using unique experimental facilities to make needed experimental measurements.

86 Technology Roadmap: Whole House and Building Process Redesign, 2003 Progress Report, U.S. Department of Housing and Urban Development, Office of Policy Development and Research. Prepared by Newport Partners, LLC, August 2003.

87 Building America Meetings Series: Quarterly All-Teams Planning Meeting Notes, November 16-18, 2004, U.S. Department of Energy, Building America Program. Washington, DC.

88 Technology Roadmap: Advanced Panelized Construction, 2003 Progress Report, U.S. Department of Housing and Urban Development, Office of Policy Development and Research. Prepared by Newport Partners, LLC, May 2004.

Using the strategies described, the Envelope subprogram will focus on the following tasks over the next five years (Table 2-35).

Technology development is managed using the Stage-Gate methodology adopted by BT in FY 2005. The Envelope subprogram follows the five gate process and then hands-off developed components to Building America where the envelope technologies are installed in homes.

2.5.6Envelope Milestones and Decision Points

The Envelope subprogram follows the schedule shown in Figure 2-20. Key technologies for Residential Integration are completed by 2015 to incorporate into Building America research homes.

Table 2-35 Envelope Tasks

Task	Title	Duration	Barriers
Task 1. Advanced roof systems and construction methods			
1-1	Integration of PCM, Cool Colors, ASV, Radiant Barrier and Advanced Lightweight Insulations	2008-2015	A, C, D, F
1-2	Regionally Optimize Above-Sheathing Ventilation	2008-2015	B, C, D
1-3	Best Practice for Integration of PCM in Roof and Attic Assembly	2008-2015	A, B, F
1-4	Demonstration of Dynamically Active Roof and Attic	2008-2015	E, F
1-5	Consolidation of Existing Energy Estimating Tools	2008-2015	I
Task 2. Advanced Wall Systems			
2-1	Whole-House Demonstration of Advanced Wall System	2008-2011	A, B, D
2-2	Improved Wall Panels	2008-2011	D, E, F
Task 3. Advanced Foundations		2009-2015	D
Task 4. Envelope Materials		2008-2015	F, H
Task 5. Enabling Technologies			
5-1	Moisture Analysis	2008-2020	H, I
5-2	Air Barriers: Moisture Material Properties	2008-2020	H
5-3	Thermal Performance of Metal Buildings	2008-2020	B, D, E
5-4	National/International Standards	2008-2020	A, B, C, H

Figure 2-20 Envelope Gantt Chart

2.5.7 Envelope Unaddressed Opportunities

Additional technology pathways are required to meet the performance targets and overcome barriers within the Envelope subprogram; several tasks have been identified as unaddressed opportunities. Foundations research has only been conducted on a limited basis and as other areas of the envelope are improved, the fraction of energy that is lost through the foundation will become a much larger portion of the total energy consumption. Foundations are generally poorly insulated and there are several opportunities for improvement. Roofs are a high priority within the core funded program; however, virtually all of the research is focused on the next generation of technology for residential homes. While there is Materials research in the core program, there are a multitude of other materials research topics that should be investigated. Lastly, while the Residential program concentrates on the integration of technological solutions with our Building America Team partners, there are sophisticated integration issues that can only be addressed within a high technology laboratory setting. Once these issues have been resolved and optimized on a laboratory basis, then they can be validated in a field setting with the Building America Teams. The tasks listed below are not currently funded.

- Roofing Membranes and Underlayments
- Moisture Buffering Investigation
- Thermally Enhanced Insulation Performance Using Nano-Scale Infrared Opacifiers
- Building Envelopes Residential Test Facilities to remove barriers to collaboration
- Air Pressure Dynamics Testing Facility
- Integrated Building Envelopes

2.6 Windows

Table 2-36 Window Summary

Start date	1980
Target market(s)	New and existing residential and commercial buildings
Accomplishments to date	• Supported the SAGE and LBNL collaborative design and build of the first highly insulating, switchably glazed window unit. • Completed the New York Times building project, the largest fully daylighted space in the US. • Instrumental in the development of low-e windows that resulted in $8 billion dollars in net benefits to homeowners.[89] • Demonstrated technical feasibility of thin-film dynamic windows, and supported industry efforts to achieve market-ready first generation products (R&D 100 Award). Measured energy savings with first generation products. • Developed innovative methods for plasma-assisted sputtering to improve manufacturability of energy-efficient coated glazings (R&D 100 Award). • Highly-insulating windows – first field demonstration of window products that outperform insulated walls in cold climates • Enabling technology research for efficient products - suite of software tools in widespread use throughout the industry leading to rapid innovation and product development cycle, reducing the time it takes industry to develop a new product . • Partnered with industry in development of the National Fenestration Rating Council (NFRC) window energy rating system, now used to rate over 100,000 products in U.S. and referenced by the ENERGY STAR Window program and most state and federal standards. • Daylighting – demonstrated measured lighting energy savings of 40 to 70 percent in daylighting applications; encouraged industry adoption of techniques with new handbooks, tools and initial web site to provide design guidance. • Advanced façade systems – demonstrated integration concepts and control strategies for dynamic, high performance systems that reduce heating, cooling and lighting using a unique, highly instrumented façade test facility.
Current activities	1. Dynamic windows – first generation smart windows introduced to market, coating improvements aimed to reduce market prices, initial field test results define issues and potentials, and technical progress in second generation alternative designs 2. Highly-insulating windows – progress in aerogel development, new concepts for high-R windows using gas fills and low-e coatings resulted in demonstration prototype, and thermally improved frames for commercial buildings under development 3. Enabling technology research for efficient products – development of WINDOW6 and supporting THERM6, optics modules, and adding complex glazings and shadings to the tool suite 4. Daylighting and advanced façade systems – enhancement of the Commercial web site, development of first COMFEN software tool prototype, and field measurements of integrated daylight dimming and motorized shades
Future directions	1. *Dynamic windows:* Reduced manufacturing costs and improved switching range and durability for first generation coatings as well as new second generation coatings that intrinsically provide better performance at lower costs. Extensive field testing in partnership with industry to develop new operational control strategies that optimize energy performance and comfort for different building types and climates. *Highly-insulating windows:* Improved aerogel and vacuum glazings at lower costs; multi-layer glazing, low-e and gas-filled windows reaching R-10 glass values; and improved sash and frame insulating values. Integrate high-R technology with dynamic technology to achieve net-zero window performance. *Enabling technology research for efficient products:* Complete modeling capabilities for complex glazings and shadings within the WINDOW suite, and examine other applications for software and other functionality that should be added to serve industry's development of advanced products and for understanding advanced fenestration impacts on whole building energy use and peak loads. *Daylighting and advanced façade systems:* Explore and develop new high performance optical materials for daylight control; and continue façade integration studies (e.g. with major building owners), with the goal of stimulating market pull to provide cost-effective hardware and systems solutions to optimize energy performance and comfort. Complete a suite of tools for specifiers, consultants, architects, engineers and owners for engineering and optimizing high performance façades.
Projected end date(s)	2020
Expected technology commercialization dates	1. Dynamic windows: 2008 – 2015 2. Highly-insulating windows: 2008 – 2015 3. Enabling technology research for efficient products: 2008 – 2020 4. Daylighting and advanced façade systems: 2008 – 2020

89 Energy Research at DOE: Was it Worth It? Energy Efficiency and Fossil Energy Research 1978 – 2000, 2001, National Academies Press. Hereafter, NAP.

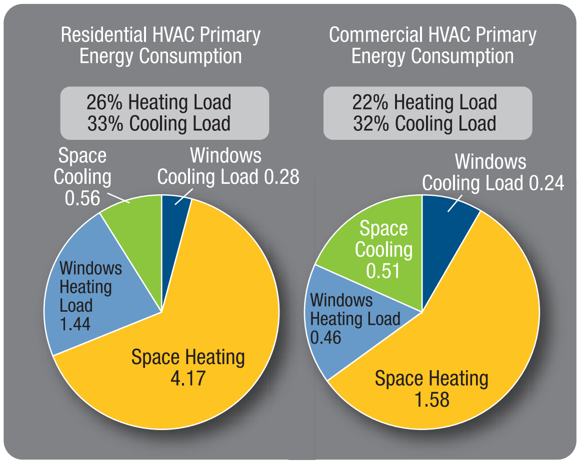
The term “windows” is used generically here for a wide range of fenestration systems: combinations of glazing, sash, frames, shading elements, and other energy control features. These windows can be inserted into vertical walls or become the entire façade; they can be used in sloped glazing applications; and they are used as skylights and other forms of roof glazings. Custom units are applied to light wells, light pipes and other daylighting redirection technologies.

Windows are applicable in all building types in all parts of the country. About 60 percent of window sales are to the residential sector and 40 percent to commercial, and approximately half of all windows sold are in new construction and half are installed in existing buildings. Therefore, windows for new and existing residential and commercial buildings are included in the R&D subprogram.[90]

2.6.1 Windows Support of Program Strategic Goals

Windows typically contribute about 30 percent of overall building heating and cooling loads with an annual impact of about 4.4 quads (Figure 2-21)[91] and there is the potential to reduce lighting impact by 1 quad through daylighting. The energy and demand impacts of windows are complex as they do not intrinsically consume energy resources. A non-optimal window can add to a heating or cooling load, and the building requires additional energy to maintain comfort. On the other hand, a window can provide heat to a home in winter by letting light– and thus heat– pass through the building envelope without consuming energy in the process. A window can also comfortably light a room throughout most of the day without requiring electricity. Since windows are not directly connected to metered and purchased energy flows, their impacts on building energy use are via other building systems, such as space conditioning and lighting. These linkages are sometimes complex and the net quad impacts of these systems in buildings must typically be calculated rather than metered.

Figure 2-21 Residential and Commercial Energy Loads Attributed to Windows in Quads[92]



The potential role of windows as a *net energy gainer*[93] is a unique role for windows relative to most other building systems that simply consume energy. Furthermore, building owners do not need to be convinced to add windows to their buildings because they include windows for other reasons such as view, natural light, and aesthetics. Finding the best performing windows for specific applications is often challenging because building owners need to know which window technologies, sizes and applications are ideal for their building type, orientation, and climate. Unlike many building elements, the optimal window, from an energy performance perspective, is highly dependent on climate, orientation, and building use characteristics.

Windows have the technical potential to supply useful energy services to a building by providing solar heat gain in the winter and daylight year round, thus contributing to the BT ZEB goals. The overall BT approach is to first convert windows from their current role as significant thermal losses to the point where they are energy neutral (where useful gains equal reduced losses), and then move to a higher level of performance where they contribute to a net energy surplus. The thermal and daylighting benefits provided by high performance windows offset other building energy uses, and the surplus energy contributes to the BT goal of ZEB. In order to provide net benefits windows must be significantly improved in terms of their current impacts on heating, cooling and lighting.

90 *Characterization of the Non-Residential Fenestration Market*, Lawrence Berkeley National Laboratories and Northwest Energy Efficiency Alliance. Prepared by Eley Associates, November 2002. Report No. 02-106.

91 BED

92 BED

93 Windows do not directly produce energy as PV or wind power would; however, when optimized they have the potential to eliminate the need for lighting energy while reducing heating and cooling loads.

Furthermore, in order to meet the demanding ZEB performance goals windows must change their role from that of a static element to a dynamic element since performance requirements change by hour, season, and weather conditions. The details of windows' optimization strategy may vary with building type and location, but the general approach is to greatly reduce, thermal losses in winter, capturing solar gain when available (subject to comfort requirements, e.g. no overheating). In summer, sunlight must be carefully controlled (and typically excluded), subject to the need for view and daylight. Daylight is desired in almost all seasons and conditions, but it must be balanced with comfort constraints. Finally, these demanding energy performance goals must be met in the context of technology that addresses many other practical concerns (e.g. safety, affordability, appearance, view, durability, and maintenance). The challenge is to create a window system whose function, and therefore properties, will change dramatically throughout the year; thus, leading us in the direction of "smart, dynamic" systems, a key BT R&D priority.

2.6.2 Windows Support of Program Performance Goals

Windows supports BT performance goals by introducing advanced windows technologies and practices for both residential and commercial buildings. These activities enable Residential Integration to achieve a 70 percent reduction in energy consumption by 2020 and Commercial Buildings to develop technology packages that reduce consumption by 50 percent by 2015 and 70 percent by 2025. Table 2-37 lists the performance measurement targets for the Windows subprogram that work towards BT performance goals. All performance measurements are relative to the historical baseline set as new construction in 2003.

Table 2-37 Windows Performance Goals

		Calendar Year			
Characteristics	**Units**	**2007 Target**	**2010 Target**	**2015 Target**	**2020 Target**
Dynamic Solar Control	Price/SF	$50	$20	$8	$5
	Size (Sq. Ft)	16	20-25	25+	25+
	Visual Transmittance	60 to 4%	65 to 3%	65 to 2%	65 to 2%
	Solar Heat Gain Coefficient	0.50 to 0.10	0.53 to 0.09	0.53 to 0.09	0.53 to 0.09
	Durability* (ASTM Tests)	High	High	High	High
Enabling Technology Research for Efficient Products	Tool Capability for Residential (R), Commercial (C), and New Technology (N)	R – Fully C – Partial N – No	R – Fully C – Fully N – Partial	Assess need for industry support	Assess need for industry support
Highly Insulated Windows	U-Value	0.20-0.25	0.17	0.10	0.10
	Incremental Cost $\$/ft^2$	5	5	4	3
Daylight Redirecting	Percent Lighting Energy savings	50	50	60	60
	Perimeter Zone Depth (Feet)	15	20	20	30
	Incremental Cost $\$/ft^2$ – Glass	8	8	6	6

*Represents component durability; system reliability will be addressed in future years; < 20K cycles–Low; 20K-50K Cycles–Medium; > 50K Cycles–High

Given the target windows improvements above, and the impact of windows on energy use in the nation's building stock, the Windows R&D subprogram has four objectives. They are listed below with a rationale for how the performance requirements above are translated into these objectives.

Dynamic Windows

Develop optical switching coatings that provide dynamic control of sunlight over a wide-range (center glass: Visible Transmittance VTc: 0.65 - 0.02; SHGCc: 0.5 - 0.1) while meeting market requirements for cost, size, durability, and appearance. The dynamic windows should be integrated into building control systems to provide energy and comfort improvements in all buildings in all climates.[94]

Enabling Technology Research for Efficient Products

Develop the tools, test facilities and data resources needed to accurately predict component, product, and systems thermal, optical, daylighting, and energy performance under a full range of operating conditions. Support industry product rating efforts to facilitate deployment of efficient technologies. Ensure that tool capabilities are updated, so they remain a relevant and integral part of industry's R&D process.[95]

Highly-insulating Windows

Reduce heat loss rates of windows and skylights from current market values (ENERGY STAR) of 0.35 to 0.1 Btu/°F-hr-ft^2 using technology solutions that meet market needs for cost, optical clarity, weight, durability, manufacturability, and other key features. Provide solutions with high solar heat gain for use in northern climates. The overall objective includes not only improvements in center of glass, but in edge and frame conditions also.[96]

Daylighting and Advanced Façade Systems

Develop daylighting technologies that displace 50-90 percent of annual electric lighting needs in perimeter zones, and extend perimeter zones to increase building-wide savings. Develop integrated façade solutions that achieve net 60-80 percent energy and demand savings compared to façades that meet ASHRAE requirements for typical climates.[97]

2.6.3 Windows Market Challenges and Barriers

Window designs and material selections are typically constrained by cost, performance, appearance and additional non-energy factors. The relative importance of these parameters varies between new versus retrofit, residential and non-residential, and owner-occupied versus leased space. Windows are a very visible element in most homes, unlike insulation or HVAC equipment which are typically hidden from view. However, evaluating window performance is complex; since windows do not directly consume energy, their impacts on home or business energy bills are often misunderstood. Many benefits of advanced windows show up as systems benefits (i.e. reduced HVAC sizes and duct runs, greater flexibility in space use, and increased comfort). Thus energy reductions and financial benefits are not directly attributable to windows, which make marketing high-performance windows challenging. These benefits have many secondary financial benefits and will influence decision-making and adoption of new technology, but there must be educated demand from builders and users (Table 2-38).

Table 2-38 Windows Market Challenges and Barriers

Barrier	Title	Description
A	High first cost for innovative products	New technologies that can increase the energy efficiency of windows can lead to higher first cost for innovative window products.
B	Lack of educated demand	There is a lack of "educated demand" for innovative products – builders and end users can be unaware of the significant benefits that are afforded by energy-efficient window products.

94 The range of control is needed to provide the equivalent of a clear window in the clear state and a highly-reflective window that can modulate bright sun to comfortable levels. The range of control can be provided functionally in two ways: intrinsically in the glass system, or as an "add-on" shade, blind, or similar element that modifies the window properties. These "mechanical" devices inevitably have operating mechanisms that require replacement periodically. Thus, the ultimate objective for the industry is to provide the control function within the glass system.

95 Windows are unlike almost any other building system in that a single set of windows will never provide optimal performance in all building types and climates. State of the art measurement and simulation tools are essential to guide public and private sector R&D investments in new technology, to guide architects and engineers in their integrated design of complete building systems, and provide feedback on how actual field performance compares to predictions. These tools and resources provide enormous leverage since they are made available to the entire industry, and have been shown to be accurate and unbiased.

96 An end use breakdown of window energy impacts shows that heating energy is currently the largest end use. The most direct way to reduce heating energy is to reduce thermal losses as addressed in this objective. The reduction in U-value must be balanced by providing a suitably high solar heat gain coefficient in winter to capture sunlight.

97 The single largest energy use in most commercial buildings is lighting and the use of daylighting technologies in smart façades to capture daylighting benefits addresses this need. To offset electric lighting energy, three requirements must be met: daylight must be admitted and distributed as needed, overall intensity must be controlled to provide glare control and prevent overheating or adverse cooling impacts, and electric lighting must be controlled, e.g. dimmed, to save energy and reduce demand. Success thus requires a degree of integration that is not currently available in U.S. markets.

2.6.4 Windows Technical (Non-Market) Challenges/Barriers

The fundamental technical challenge is to produce technologies that are so efficient that they can convert the window from a net energy drain to energy neutral, and then to a net energy gainer. In order to reach these goals, windows need better static properties (e.g. much lower U-value). In addition, windows need dynamic performance properties to balance tradeoffs in winter versus summer, glare versus view, and daylight versus solar gains to decrease space conditioning loads while promoting comfort. The Windows subprogram needs to capture the benefits of daylighting in all buildings and all climates, but primarily in commercial buildings where the lighting bills are higher.

Windows will increasingly become dynamic and "smart" with sensors and active control elements. These units must be integrated with other smart building elements (e.g. dimmable lighting) and into the overall building control system. Currently, the industry is not well positioned to aggressively pursue these kinds of partnerships.

Finally, the window technologies and systems listed here are not inherently self-optimizing and self-assembling; architects, engineers, homebuilders and homeowners need data and tools to guide decision-making and optimization. Since windows are intended to last 20 to 50 years,[98] access to sufficient information is critical during the design and building process because windows are only changed at a greater cost later.

The barriers to commercially available innovative window technologies were identified in the Windows Technology Roadmap, published in 1999 (Table 2-39).

Table 2-39 Windows Technical Challenges/Barriers

Barrier	Title	Description
C	Technical risks inhibit investments	There are technical risks associated with industry's investment in new technology.
D	Inability to predict performance	Industry may be unable to adequately predict the performance benefits from new technology.
E	Inadequate or inconsistent building codes	Building codes are dissimilar from state to state and across regions. They can also be poorly enforced, and inconsistent with national and international guidelines and codes.
F	Lack of integration tools	Industry lacks integration tools that are necessary to achieve system integration.
G	Durability issues	Industry lacks assurance that durability issues have been adequately addressed for advanced technologies.

2.6.5 Windows Approach/Strategies for Overcoming Challenges and Barriers

All of the barriers represent areas where the federal government can provide support to change the energy marketplace; the ideal BT role varies in different project areas. In the case of high-risk technical R&D, government support in the form of cost shared R&D reduces the risk for companies to develop innovative technology. In many cases, the company with the new idea has neither the market experience nor the capital to set up manufacturing and distribution. BT might play a partnering role to expose small innovative firms to market leaders with the capability of commercializing the window once the R&D is successfully completed. Once a technology development project moves beyond specific technical milestones, the activity may exit the Windows subprogram as manufacturers take a lead role in development and commercialization.

98 Historically windows have lasted over 100 years because they were single pane. Since double pane windows have greater failure modes, the window industry is experiencing a paradigm shift.

In other cases, technology R&D may be successfully concluded, but the functional impacts of the technology are not well understood or accepted by potential purchasers. In this case, field testing or other third-party testing provides accurate unbiased data on technology performance. Measurement and evaluation protocols are often not available for new technologies and BT support can provide accurate unbiased approaches. In a similar way, designers must have the analysis tools to assess performance of design options when new materials and systems are being used. Designers are risk-averse, and will not risk their professional reputation to try technologies for the first time if they cannot confidently predict performance. The product manufacturers often do not have the capability or resources to produce the evaluation tools and specifications, and even if they did, designers would unlikely to put full faith in the information due to perceived producer biases in favor of their own products.

In terms of technology development, there is profit motivation for a company to complete the R&D and get the technology to market so that it can begin to earn money. In other non-technology areas such as providing accurate information and tools, BT may need to play a longer-term role if there is no suitable business for industry to take over the BT role and if the lack of such activity would significantly reduce energy savings impacts. In such a case, Windows strategy may eventually involve developing a mechanism for those in industry who benefit from the service to pay for it, as done in 2006 with the International Glazing Database. Finally, BT is not the only public sector partner with an interest in more efficient energy use and demand control. State energy agencies, non-profits, and utilities all have an interest in sustaining public goods activities such as those supported by BT. An explicit strategy in this subprogram is to partner whenever possible with other parties for co-support of R&D. The electrochromic field test program is an example where the California Energy Commission (CEC) has matched BT's funding for a three-year field test program.

The fenestration marketplace serves a variety of distribution pathways, price points and architectural styles. Early adopters (and therefore potential partners) may be large existing manufacturers (e.g. Andersen windows led the market with Low-E products) or a smaller niche player catering to a specialty market (Southwall offered highly-insulating glazings in the 1990s). Each has different needs and interests to facilitate market impacts. BT can facilitate product innovation and development by methods other than direct support of product development. Through leveraging the purchasing power of owners when incremental innovation is needed, BT can provide cost-shared support of a demonstration with a major building owner. The owner's willingness to sign large procurement contracts induces manufacturers to invest in R&D to develop new product lines for large projects, and the products become available to everyone.

However, the building industry traditionally has been slow to innovate, and slow to adopt demonstrated technology into the marketplace. The commercialization of low-E and other innovations has been studied to better understand the drivers of successful innovation leading to large-scale market impacts. Based on this work, the subprogram leverages several market trends to overcome obstacles in the marketplace.

Windows serve numerous non-energy needs (e.g. view, acoustics, appearance), and are valued by most building owners. Coupling energy functions with other desired occupant benefits is a strategy for maximizing market impacts of efficient products. Low-E market penetration was accelerated by marketing their improved comfort and ultraviolet-fading resistance.

Utilizing the strategies listed in Table 2-40, the subprogram addresses market and technical barriers. In addition, cross-cutting support within BT subprograms could facilitate industry progress towards high-end, high-performance windows.

Table 2-40 Windows Strategies for Overcoming Barriers/Challenges

Barrier	Title	Strategy
A	Lack of educated demand	Develop tools to inform consumers, and recruit partners to maintain tools in the future. Work with voluntary program sponsors (i.e. CEE, LEED, NAHB, etc) to promote advanced windows
B	High first cost for innovative products	Reduce cost through fundamental research on dynamic and highly-insulating windows.
C	Technical risks inhibit investments	In association with fundamental technology development, conduct case studies and field studies with partners.
D	Inability to predict performance	In association with the National Fenestration Rating Council, work to ensure all products (dynamic and highly-insulating) are properly rated.
E	Inadequate or inconsistent building codes	Provide fundamental tools regarding energy performance of windows so that other government and non-government organizations can promote improved codes
F	Lack of integration tools	Develop control and system performance algorithms to optimize dynamic and advanced façade systems for energy savings and peak demand reduction, while addressing comfort, glare and occupant acceptance.
G	Durability issues	Assist industry with the establishment of universal certification for today's and the next generation of fenestration products. Develop fundamental test protocols to predict durability.

Development of cost-effective, highly-efficient glazing and fenestration systems for all building types and all parts of the country will require a portfolio of projects that address the key barriers through the strategies outlined above. The general approach for the subprogram can be considered as three key elements:

1. R&D on dynamic windows, highly insulating windows, daylighting and advanced façades

2. Lab and field testing to quantify and demonstrate the benefits of new technologies for industry

3. Development of improved analytical tools and software to enhance the ability of industry to assess, adopt, and commercialize new technologies; thereby, reducing industry risk

The subprogram R&D will focus on breakthrough, high-risk technologies that are likely to product large energy savings if successful and technologies that have the potential to be readily adopted by industry. Windows will also address technology areas in which industry under invests—e.g. there is no profit motive to engaging in the R&D, or there are no established market mechanisms to support the efforts.

Below are key task areas of research conducted in the Windows subprogram.

Dynamic Windows

- **Reflective hydride dynamic window**: The presence or absence of sunlight is effectively the single largest natural energy flow in a building. Therefore, switchable coatings for glass or plastic that would enable dynamic control of this energy flow are sought by the Windows subprogram. BT research will continue to develop the second generation of materials, chemical engineering applications, and advanced manufacturing processes that can offer substantial reductions in cost for dynamic windows while maintaining a high level of reliability and durability with a broad range of optical properties. The key goal will be to further improve durability and scale the prototypes up to larger sizes. The second generation of dynamic windows is targeted to enter the market in the 2010 to 2015 timeframe with substantially lower prices.

Highly-insulating Windows

- **Develop high-R frame designs and advanced materials solutions**. When high-R glazing systems are used in typical residential window frames, about half of the heat loss through the entire window is through the frame. Improving the heat transfer of a frame system is difficult because frames must perform so many functions: in addition to being structural components, they must be weather resistant, operational, and durable. BT will develop advanced materials with innovative thermal properties which can be used to reduce heat loss in all building types. FY08 efforts will develop strategies for design and construction of high-performance frames for residential applications. Topics examined will include: how low-conductivity materials are used, the potentials of insulating voids, the use of thermal breaks in selected areas, suppression of radiation and convection within voids, interactions of spacers, impacts of hardware, and product design for function.

- **Develop low-cost, high-R value insulating glazing units**. The best performing windows in the U.S. market today have U-values in the range of 0.15-0.35. Many of these windows achieve these performance levels using multiple glass panes and gas-filled air spaces. These designs tend to be heavy and costly, and have not achieved significant market share. The cost and market acceptance of these prototypes are critical design features for consideration. Technical progress must be coupled with other research activities that integrate the new glazings into full frame and façade systems. The optimal tradeoffs for heat loss and solar heat gain must be considered for each climate. Developing new high performance glazing variants using proven, available components allows industry to better utilize their existing manufacturing infrastructure and keep costs low.

Enabling Technology Research for Efficient Products

- **Develop tools to assist manufacturers in designing more efficient products**. In the past, product innovation was slowed by the time and costs required to design, build, test, assess, and refine the prototype, and then repeat the process until desired results were obtained. Powerful new computer tools have been developed that enable manufacturers to quickly and cheaply design and prototype new "virtual products." The same toolkit has been adapted for use to determine rating and labeling properties. Tools include software packages for heat transfer and solar gain through glazing, heat transfer through framing, and the associated databases that are required to operate the tools. The tools need to be carefully validated by BT with state-of-the-art measurement in appropriate thermal test facilities. The capabilities of these tools need to be extended so that they stay current with (but preferably ahead of) materials R&D efforts. The lack of such tools will slow industry investment in innovative technology if the properties and benefits cannot be objectively quantified.

- **Provide technical assistance for BT mandatory and voluntary programs**. BT leverages its work by partnering formally and informally with other organizations that promote energy efficiency such as utilities and state and local agencies. BT partners with these groups to ensure that its information is made available to encourage widespread adoption of the energy-efficient windows. One of the largest beneficiaries of the Windows R&D activity is the ENERGY STAR Windows program which is based in part on simulation results from BT tools.

Daylighting and Advanced Façade Systems

- **Develop daylighting technologies.** The Windows subprogram will develop and assess performance of new daylighting technologies that increase savings in perimeter spaces and permit deeper penetration of daylight, allowing extension of the effective zone of daylighting savings. Compared to 20 or even 50 years ago, there are few products today on the market that employ significantly different optical performance to obtain better daylight management (this contrasts with thermal management where there have been major advances). Optical technologies continue to evolve quickly in other fields and some represent a potential use in buildings. The subprogram will scan emerging optical technologies, assess the subset that make sense for use in buildings, and develop these into viable daylighting products. Several high performance systems are in the marketplace for roof lighting applications (e.g. light pipes), so the near-term emphasis is on optical systems for vertical façades.

- **Façade system integration and optimization**. Façade systems use more than glazing and framing. The best systems today employ some form of dynamic shading and link to dimmable lighting controls. The subprogram will develop control algorithms, new sensor technology, shading controllers, etc. and demonstrate overall performance of the complete system in test facilities and in the field. Commissioning and operation strategies ensure that projected savings are realized. Collaborative work with the International Energy Agency (IEA) and other international partners serves as a vehicle for exploring more options at lower cost and gaining access to additional product and performance data.

- **Field testing of façade systems**. Façade systems are complex entities whose overall operation is often more that the sum of the parts. Many aspects of performance can best be assessed by direct observation and extensive testing in a completed building. Accurate data for calibrating simulation models can best be obtained in highly instrumented controllable facilities where comparative and absolute measurements can be made under controlled conditions. BT funded the construction of a unique three room test facility which has been designed to accommodate a range of glazing, window and façade systems. To date the facility has been used extensively for electrochromics testing but it is now being reconfigured to study dynamic motorized façade shading and daylighting systems.

- **Develop information resources for system designs**. Develop a series of decision support materials to assist designers and building owners to select appropriate daylighting and façade systems. This includes a tiered set of tools to address the differing needs of various users, such as a book, a website and of other information resources. These include daylighting modeling tools, a custom annual energy model specifically for fenestration performance assessment at the whole building level, as well as addressing non-energy impacts, such as glare, that are critical to decision-making. Measurement tools and protocols will be used to assess qualitative and quantative aspects of daylighting performance in buildings.

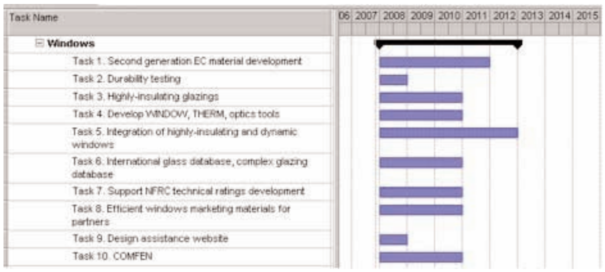
Table 2-41 provides an overview of BT's currently planned or funded core tasks that support Windows' strategies.

Table 2-41 Windows Tasks

Task	Title	Duration	Barriers
1	Second generation EC material development	2008-2011	B, D
2	Durability testing	2008-2009	G
3	Highly-insulating glazings	2008-2010	B, D
4	Develop WINDOW, THERM, optics tools	2008-2010	A
5	Integration of highly-insulating and dynamic windows	2008-2012	DB, D
6	International glass database, complex glazing database	2008-2010	C
7	Support NFRC technical ratings development	2008-2010	C, E
8	Efficient windows marketing materials for partners	2008-2010	A
9	Design assistance website	2008-2009	A
10	COMFEN	2008-2010	A

2.6.6 Windows Milestones and Decision Points

Figure 2-22 Windows Gantt Chart



2.6.7 Windows Unaddressed Opportunities

The Windows subprogram has identified several tasks as unaddressed opportunities. These tasks are recognized as integral steps to addressing the barriers and meeting performance targets. However, there is currently either inadequate or no funding for these opportunities listed below:

- New integrated window systems for airflow control and natural ventilation
- Smart glazings and coatings
- Field demonstration of net-zero-energy fenestration solutions
- Software tools for zero-energy façade and building design
- Green design and sustainable fenestration products
- Laboratory tests for emerging products
- International collaboration

2.7 Analysis Tools

Table 2-42 Analysis Tools Summary

Start date	1977
Target market(s)	Architects, engineers, energy consultants, researchers, standards developers, building owners
Accomplishments to date/Past activities	• EnergyPlus, Award for Excellence in Technology Transfer, 2004, Technology Transfer and Intellectual Property Office, Lawrence Berkeley National Laboratory • EnergyPlus, R&D 100 Award, 2003 • EnergyPlus, Award for Excellence in Technology Transfer, 2002, Federal Laboratory Consortium • EnergyPlus, IT Quality Award for Technical Excellence, 2002, U.S. Department of Energy Chief Information Officer Annual Awards • DOE-2, Energy 100 Award[99]
Current activities	Development, validation and testing of increasingly more capable energy simulation program, EnergyPlus.
Future directions	• Add capability to model absorption chillers that use exhaust heat from distributed generation sources as the energy source for the chiller desorber component • Include radiant heat transfer between attic surfaces, including radiant barriers, and duct surfaces because of the large temperature differences and large exposed areas that occur in attic zones • Model piping pressure drops to better account for pump energy • Add a cooltower model (similar that used at Zion National Park Visitor Center) • Add model for wind turbine power generation at the building scale • Window modeling upgrades to match or use the capabilities of Window 6 and its successors
Projected end date(s)	2020
Expected technology commercialization dates	Commercialization of EnergyPlus began in 2001 with release of first version (1.0), continuing with two releases per year

Architects, engineers, and other building designers have always “envisioned” buildings before beginning construction. In the 20th century this process began with pencil sketches and inked drawings. These 2-D representations were sometimes supplemented with 3-D scale models to better understand spatial relationships and appearance. The engineering side of construction was supported by an elaborate infrastructure of tables and manuals that documented workable solutions derived from analytical calculations, cumulative empirical data, and the rules of thumb widely used in the construction industry. With built-in safety factors and incremental advances based on new findings, these approaches were adequate to support the slowly evolving buildings sector through most of the last century.

The sudden interest in building energy efficiency in the 1970s changed the information management needs of designers. The subsequent availability of cheap desktop computing and its software infrastructure continue to revolutionize virtually all aspects of design and construction. However, in most cases computers are relegated to doing conventional tasks, albeit more quickly and accurately. But there are also emerging opportunities where computers and simulation tools can provide novel analysis of complex interactions between systems and new performance insights that are revolutionizing building design and operation. Computers are certainly useful tools to sum the overall heat loss of a building quickly and more accurately than by hand. But powerful new simulation tools—which in a few minutes can calculate the behavior of building control systems and the resultant impact on energy use, peak demand, equipment sizing and occupant comfort—provide performance insights that have been previously unattainable. It is precisely these insights that are needed if the building community is to break away from a “business as usual” approach to energy use in buildings and effectively design high performance and zero energy buildings.

99 Department of Energy Honors Most Notable Scientific and Technological Accomplishments. U.S. Department of Energy, Office of Science, January 8, 2001.

Building energy performance, particularly in ZEB, is the result of interactions among many elements including climate (outdoor temperature, humidity, solar radiation and illumination), envelope heat and moisture transfer, internal heat gains, lighting power, HVAC equipment, controls, thermal and visual comfort, and energy cost—and these complex interactions cannot be understood and quantified without simulation tools. For example, the effect of daylighting dimming controls on the electric lights with daylighting has several effects: lighting electricity use goes down as does the heat gain from lights. Lower heat from lights reduces cooling use (amount depends on cooling equipment efficiency), but in the winter it can significantly increase the heating energy. Thus, the annual impact of daylighting on energy use requires detailed calculations that consider these interactions. The simulation tool must include control sensors, strategies, and systems; building performance in operation; and integrated airflow analysis to account for the complex interactions within a building. In a series of field evaluation case study reports, the National Renewable Energy Laboratory found that simulation tools were one of the essential elements for tuning the building design as well as the operating building performance.

BT software tools are the benchmark against which other tools are tested, with BT tools dating to the 1970s. BT produced a series of increasingly more sophisticated energy analysis tools, collectively named DOE-2, which finished in 1997. The initial program, DOE-2.1E, is currently the underlying calculation engine[100] for more than 20 tools and the basis for building energy standards development and research throughout the world. The National Academy of Sciences in their review of the value of energy research at DOE, found:

> The development of this computer program [DOE-2.1E] also stimulated the promulgation of performance-based standards that provided designers with multiple ways to meet particular efficiency targets. The committee concludes that DOE-2 was influential in the development of both California's Title 24 and the American Society of Heating, Refrigerating and Air-Conditioning Engineers standards that have guided the development of building standards throughout the United States (and indeed the world). Compliance with these standards has resulted in significant energy, environmental, and security benefits.[101]

The Energy Policy Act of 2005 included tax deductions for commercial buildings, which creates both opportunities and challenges for the Analysis Tools subprogram. DOE developed processes for certifying energy analysis tools as qualified for use in calculating the commercial building tax deduction. The tax deduction has also increased demand for more capable building simulation software. Also, the California Energy Commission decided in late 2005 to move from DOE-2.1E to EnergyPlus for development and compliance with the Title 24 Standards (mandatory California building energy standards), partially for the 2008 standards and completely for the 2011 standards.

The goal of the Analysis Tools subprogram is to ensure robust and accurate tools exist and are used to easily evaluate the design and operating performance of low energy buildings and to support research, development, and eventual design and operation of zero energy commercial buildings. The key features driving R&D in the Analytical Tools plan are:

- *Simplicity* - For all but the simplest buildings, architects and engineers require tools that permit rapid analysis of multiple design choices to assess their costs and performance levels.

- *Controllability* - Facility managers need greatly improved controls and energy information tools if they are to operate buildings efficiently under a wide range of typical conditions (occupancy, weather, and energy cost); dynamic conditions (e.g., real-time pricing and demand limiting); and finally under more stressful conditions (unusually high energy prices, weather extremes).

- *Flexibility* - Product developers, researchers, educators and others need a tool with capabilities that surpass the limitations of today's widely used tools. Examples of these are given later in this plan.

- *Interoperability* - Architectural and engineering firms will not react well to a flood of new tools, each of which describes the building and its parts in a unique way. A superior approach is to organize all tools around a shared, open building data model that allows each tool to transfer information seamlessly to others.

- *Marketability* - Industries with large energy costs and highly concentrated and capitalized firms typically use energy simulation tools. However, the buildings industry often lacks sufficient incentives to promote widespread use, so the public sector must take a leading role in developing analysis tools.

100 BT develops an unbiased, reliably tested 'engine' for calculating building energy flows. This engine is then used by the private and public sectors as the underlying calculation engine for a wide variety of tools and user interfaces.

101 NAP

2.7.1 Analysis Tools Support of Program Strategic Goals

One of BT strategic goals is to develop the technologies and strategies that will allow zero energy commercial buildings to be constructed by 2025. Reaching this goal requires both improving the performance of individual building components (e.g. windows, appliances, heating and cooling equipment, lighting) and a revolutionary approach to building design and operation. Together, it should be possible to achieve up to 70 percent reductions in energy use with a careful integration of onsite or purchased renewable energy supplies. Similar technologies and design approaches can also be applied to improve the performance of existing buildings.

These high levels of energy efficiency and effective systems integration will not be achieved by basic technology substitutions or by expecting designers to simply meet tighter standards or apply prescriptive approaches to design. Achieving efficiency goals requires new capabilities such as a powerful simulation tool that supports evaluation of new ZEB demand-reduction and energy-supply technologies, as well as support for various decision points throughout the life cycle of building design and operation.

The Analysis Tools subprogram is working with other BT subprograms to transition their simulation program needs to EnergyPlus. To support BT activities that work towards ZEB, the Analysis Tools subprogram is extending the functionality of EnergyPlus, training the BT subprogram staff and lab researchers, and assisting with the transition to new methodologies. EnergyPlus is also being positioned by BT as the primary software tool for planning and analysis for codes and standards development. The focus continues on developing increasingly more robust versions of EnergyPlus that can be used to design net-zero energy and high performance buildings.

The primary technical goal of the Analysis Tools subprogram is to establish BT software tools as the primary calculation engine for evaluating the design and operating energy performance of integrated low and net-zero energy buildings, the BT strategic goal.

102 Including advanced and near-market technologies and systems, building integrated PV, on-site Combined Heat and Power (CHP)/Distributed Energy Resources (DER), controls strategies, predictive/optimization control systems, and multizone airflow and pollution transport

103 See Table 2 for current status of validation methods of test

104 Includes CAD geometry, CAD HVAC, CAD lighting and electrical, HVAC design, cost estimating, and project management. Current status is full interoperability with CAD geometry (the most difficult issue for interoperability) and the capability for interoperability with CAD HVAC, but there is no other tool yet able to share data.

2.7.2 Analysis Tools Support of Program Performance Goals

The performance goals for Analysis Tools are shown in Table 2-43, and through meeting these goals, the subprogram will enable BT to meet its performance goals for energy reductions by evaluating buildings energy use. The first strategic goal for Analysis Tools is to establish the software tools as the primary calculation engine of choice for evaluating the design and operating energy performance of integrated low and net-zero energy buildings. This objective will be measured by the percent coverage of state-of-the-art building energy efficiency, renewable energy and energy supply technologies that EnergyPlus can evaluate as compared to other similar software including DOE-2 and BLAST. In this case, the objective is considered met when EnergyPlus can evaluate 90 percent (by 2010) of the state-of-the-art technologies under development (by 2010) or planned (by 2015) by BT R&D.

Table 2-43 Analysis Tools Performance Goals

		Calendar Year	
Characteristics	**Units**	**2010 Target**	**2015 Target**
Extend Capabilities of Energy Analysis Tools:			
Support development, analysis and compliance with building energy standards (ASHRAE 90.1, 189.1, California Title 24)	Percent of technologies covered	80	100
Support BT RD&D (elements that currently employ building simulation tools that use EnergyPlus for research and analysis)	Number of BT elements	8	11
Coverage of state-of-the-art building energy efficiency and renewable energy and other ZEB technologies that analysis tools can evaluate[102]	Percent	75	90
Validate Energy Analysis Tools:			
Methods of test coverage of whole building analysis tools[103]	Methods Covered	4	6
Deploy Analysis Tools:			
Interoperability with other building design tools[104]	Percent	50	75
Design firms trained and provided continuing assistance on the use of EnergyPlus	Number	9	20
Extend EnergyPlus to other broader based engineering design tools	Number	2	2

The second aspect of the strategic goal is to establish EnergyPlus as the primary software tool for BT program research, planning and analysis. This objective is measured by the ability of EnergyPlus to address technical aspects of the BT subprogram, for instance, integrated building controls. Additionally, success is measured by the number of subprograms that rely upon building simulation tools that in turn use EnergyPlus. In both cases, the objective is met when 90 percent of the subprograms can use and are using EnergyPlus by 2010. By utilizing a common tool as well as analysis benchmarks, BT research and standards development will be more consistent and effective.

The second Analysis Tools goal is to work with designers of high volume, high visibility, and large buildings to demonstrate the value of building simulation. This effort initially focused on the leading firms, which now use DOE-2 for building energy simulation, and now aims to move them towards EnergyPlus through training workshops (three each year for three years with continued support). This objective will be measured by how many of these firms successfully transition to EnergyPlus; if two-thirds of these firms are using EnergyPlus regularly by 2008 the objective is met. Secondly, continuous testing and validation (using industry standards) as new capabilities are added will demonstrate that EnergyPlus can accurately simulate actual building performance and energy savings.

Each of the performance goals includes measurable progress that includes how well EnergyPlus approaches state-of-the-art technologies for net-zero and low-energy buildings and how many other BT subprograms have transitioned from alternative tools to EnergyPlus.

2.7.3 Analysis Tools Market Challenges and Barriers

Market challenges are the predominant barriers to simulation tool adoption (Table 2-44). Use of powerful tools to accurately simulate and emulate all aspects of product life-cycle performance is not a new concept: the aerospace, automobile and industrial process industries have developed such tools and routinely and successfully use them. These industries are typified by large energy costs, and highly concentrated and capitalized firms. However, in the buildings industry there is often little incentive to use energy simulation tools—the cost of energy is usually a secondary consideration in most building design. This gives private investors little motivation to make significant investments in building energy tool development. Thus if the large but diffuse energy savings in buildings are to be captured, it is up to the public sector to lead the development effort and to support deployment at least until the value of the tools is well established.

Table 2-44 Analysis Tools Market Challenges and Barriers

Barrier	Title	Description
A	Unrecognized value	The building industry does not realize the bottom-line value of simulation analysis, and has not adopted it as part of regular practice. An analysis tool, regardless of functionality, cannot provide benefit if no one uses it.
B	Lack of interoperability	On today's design projects, most designers routinely use CAD and cost-estimating tools. However they often do not use energy simulation tools, in part because of the time and cost of data input and output, all constrained by limited design fees. The interoperability paradigm is necessary so energy simulators can quickly begin energy analysis using building design and geometry data imported directly from CAD tools.
C	Ease of use	An easy-to-use simulation tool is an important aspect of market acceptance. The private sector has already developed two major interfaces for EnergyPlus, but the pace is slow and an impediment to full adoption and use in the market.

2.7.4 Analysis Tools Technical (Non-Market) Challenges/Barriers

Much of the underlying technical research required to establish models of technologies, systems, and controls for new simulation capabilities is performed elsewhere – either by other BT subprograms or external research organizations, universities, and sponsoring organizations. For example, BT is not developing an easy-to-use interface for EnergyPlus because development is expensive and time consuming. One interface typically cannot serve all user needs so the private sector is better suited to develop interfaces that serve specific needs. Therefore, the technical challenges for the Analysis Tools subprogram focus on balancing accuracy of energy estimation techniques with usability and speed of calculation, and are not considered to be significant barriers

2.7.5 Analysis Tools Approach/Strategies for Overcoming Challenges and Barriers

The Analysis Tools subprogram will revolutionize the ways buildings are designed and operated. The Analysis Tools subprogram has identified a plan, relying on four strategic elements, to achieve the subprogram's goal and overcome challenges and barriers.

- *Extend Capabilities*: support standards development, incorporate advanced technologies, and enable zero-energy buildings evaluation through design and operation.
- *Validate Tools*: use a well-established internal process for in-house products and robust, widely adopted test methods for all building simulation tools.
- *Deploy*: target key owners and design firms through training and establish the value of energy simulation, provide seamless interoperation of buildings design tools and energy simulations, and extend capabilities to building operation.
- *Exit*: develop the institutions, protocols, and mechanisms to sustain this effort without DOE's direct and continued involvement.

The strategies for overcoming the barriers and challenges identified above are shown in Table 2-45. Much of the development activities for Analysis Tools will focus on demonstrating the value of building simulation. By working with interface developers, market leaders, and other key groups, Analysis Tools will work to overcome the interoperability and easy of use barriers, demonstrating the value of simulation tools.

Table 2-45Analysis Tools Strategies for Overcoming Barriers/Challenges

Barrier	Title	Strategy
A	Unrecognized value	Extend the capabilities of energy analysis tools, and validate energy analysis tools. Demonstrating and deploying the right simulation tools to key design firms is a critical activity because it encourages utilization. These tools must prove accurate in their simulation of actual building operation.
B	Lack of interoperability	Deploy analysis tools. This vision of "interoperability" has been discussed for many years but is just now reaching commercial viability worldwide under the direction of the International Alliance for Interoperability (IAI).
C	Ease of use	Deploy analysis tools

EnergyPlus and its related tools, databases and documentation are an accessible portal, filter and archive for critical knowledge generated from BT research. The Analysis Tools activities within BT must be intimately linked to and supported by the other R&D and standards development activities to realize these benefits. As BT-developed technologies become market ready, the Analysis Tools subprogram will be ready with new modules which can easily allow others to simulate the benefits in an integrated, whole building design or retrofit. From the perspective of the building industry, a suite of tools which continuously embodies the best of BT R&D will effectively attract and maintain private sector interest in and involvement with EERE programs, making the tools a powerful deployment vehicle for BT.

Linking Analysis Tools with other R&D subprograms, BT management decided to adopt EnergyPlus throughout BT subprograms in 2005. This multi-year transition began in 2006 by focusing on Building America and training building simulation experts from key laboratories that were not yet using EnergyPlus. The transition requires a plan for each subprogram which identifies required capabilities that must be added to EnergyPlus and changes to the analytical infrastructure.

These strategies are implemented through the tasks shown in Table 2-46, which are described in more detail below.[105]

Table 2-46 Analysis Tools Tasks

Task	Title	Duration	Barriers
1	Support standards development, analysis, and compliance of ASHRAE 90.1 and California Title 24	2008-2015	A, B
2	Support BT R&D Elements	2008-2015	
3	Support evaluation, design, and operation of net-zero energy buildings	2008-2015	A, B
Validate Energy Analysis Tools			
4	Validate EnergyPlus	2008-2015	A, B
5	Develop "Methods of Test"	2008-2015	A, B
Deploy Analysis Tools			
6	Target key owners and design firms	2008-2015	C
7	Seamless extension of EnergyPlus and other tools	2008-2015	A, B
8	Tool-based services for operation	2008-2015	A, B
Exit Strategy			
9	Establish consortia	2008-2015	A, C

Incorporate Current Technologies, Systems and Controls into EnergyPlus. Energy standards, such as ASHRAE 90.1, ASHRAE 90.2 and California Title 24, were developed with whole building simulation tools and future improvements to these standards cannot be developed without analysis tools. New and currently available technologies cannot be considered in a standard unless the tool used to produce the standard can model that technology. Currently available energy efficiency technologies will be added and allow EnergyPlus to be used for development of future standards and compliance with current energy standards. EnergyPlus will be certified for Title 24 2008 ACM, with scheduled completion: FY 2008.

105 The Analysis Tools Multi-year Plan (November 2003) provided an initial list of capabilities and features which are needed to successfully model ZEB. In FY 2004, we completed an initial identification and prioritization of future ZEB features. In January 2005, the Residential Integration team held a workshop with the Building America teams on issues and needs for simulation tools. As the transition to EnergyPlus occurs in other BT subprograms, their issues and needs will be added to the prioritized features for future releases. These needs have been added to the prioritized list of features for future releases.

Develop Versions of EnergyPlus to Support Development and Evaluation of Low- and Zero-Energy Buildings. Based on prioritization completed in FY 2004, the subprogram will develop increasingly more ZEB-simulation capable versions of EnergyPlus. The prioritization will be reviewed and updated on an annual basis as new technologies reach the market, in consultation with leading design firms, and based on research progress in energy efficiency, renewable energy and energy supply technologies.

- EnergyPlus for 40 percent ZEB. Add prioritized features which allow EnergyPlus to be used in development and evaluation of 40 percent ZEB including simulating complex building control strategies and predictive-model control. Scheduled Completion: FY 2008.
- EnergyPlus for 60 percent ZEB. Add prioritized features which allow EnergyPlus to be used in development and evaluation of 60 percent ZEB including energy supply and control systems technologies. Scheduled Completion: FY 2009.
- EnergyPlus for 80 percent ZEB. Complete prioritized features which allow development and evaluation of 80 percent ZEB including multizone airflow, further controls technologies and strategies, as well as emerging energy supply technologies. Scheduled Completion: FY 2011.

Testing and Validation. Working with international and national industry groups, the subprogram will extend standard methods of test to cover the full matrix of validation methods for building simulation tools. Analysis tools will continue testing and validation of new features as they are added to EnergyPlus; testing for each EnergyPlus Release, FY 2008-FY 2011; complete IEA SHC Task 34, December 2007; addenda and periodic updates to ANSI/ASHRAE Standard 140 in FY 2008 and FY 2010.

Push Analysis Tools into the Marketplace. Analysis tools will work with and train two to four leading-edge engineering/architecture design firms to employ EnergyPlus as part of their everyday design practice and work with major HVAC manufacturers to adopt EnergyPlus as the calculation engine for their programs. The subprogram will also identify and support the analysis tools required for BT R&D and standards development efforts. BT will support efforts of national and international industry organizations that promote the use of analysis tools through training and conferences, and working through international interoperability standards, enable seamless and robust multi-directional data flow/exchange from CAD to EnergyPlus to cost estimating to facilities management and building operations. Support International and National simulation conferences, FY 2008-FY 2011.

The Stage-Gate process is used to manage Analysis Tools, ensuring the right projects are being funded, and the projects are working towards goals. Table 2-47 outlines the stages and gate criteria for Energy Plus.

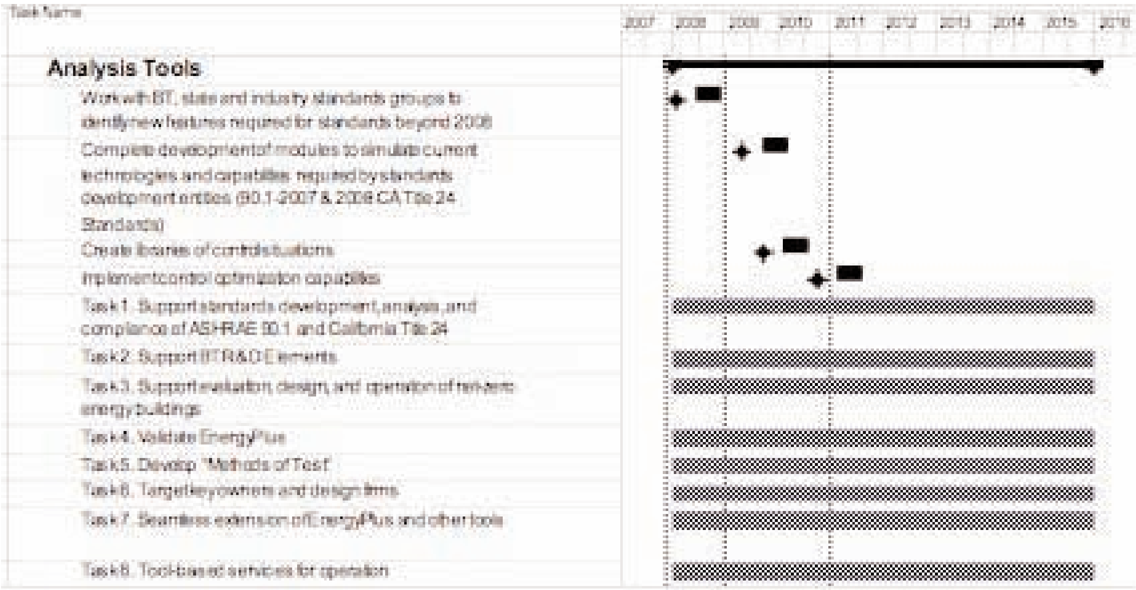
Table 2-47 Energy Plus Stage-Gate Management

Stage	Title	Activities	Criteria	Key Deliverables
0	Ideation	Update list of potential enhancements with input from: • Development team • EnergyPlus users • BT R&D staff • Surveys of outside groups such as code developers and interface developers	• None at this Stage	List of desired features and enhancements
1 & 2	Analysis and Prioritization	• Prioritize list of potential features and enhancements • Prioritization team: BT TDMs, development team leads	Must Meet Criteria • Meet MYP goals and EnergyPlus and BT objectives? • Funding to cover anticipated cost? • Algorithm model and validation data exist? Should Meet Criteria • Significant energy impact? • Increase in market attractiveness of EnergyPlus?	Prioritized list of new features for next FY AOP
3	Advanced Development	• Analyze and document the data requirements and data flow • Develop initial design (flow chart) of module/feature	Must Meet Criteria • Models, data, and "hooks" identified? • Input/output definitions created? • Module prototype developed? • Example input files and output tables and report variables created? Should Meet Criteria • Input/output and engineering documentation developed?	Design specifications for module or enhancement
4	Engineering Development	• Develop and test code	Must Meet Criteria • Prototype tested/ debugged/retested? • Passed formal full set of the Standard Method of Test?	Prototype module
5	Product Demonstration	• Develop documentation • Continue code testing in beta version of EnergyPlus	Must Meet Criteria • Documentation developed? • Validity tests completed and available? • Version test/debug complete? • All other significant bugs fixed? Should Meet Criteria • User support offered? • All other identified bugs fixed? • Deployment activities underway?	Final code and documentation, ongoing support
6	Commercializaton	• Licensing to interface developers • Support developers (interface and new modules) • Development of supporting tools	Must Meet • Licensed and distributed in other tools (interfaces) • Widespread use throughout BT for research and codes Should Meet • Growth in EnergyPlus licenses and downloads	EnergyPlus integrated in other tools: interfaces, other analytical tools, and code development/ compliance

2.7.6 Analysis Tools Milestones and Decision Points

The following milestones in the Gantt chart (Figure 2-23) cover the Analysis Tools activities, milestones and decision points in FY 2008 and beyond.

Figure 2-23 Analysis Tools Gantt Chart



2.7.7 Analysis Tools Unaddressed Opportunities

Several tasks within the Analysis Tools subprogram have been identified as unaddressed opportunities. The tasks listed below are outlined for overcoming barriers and meeting milestones of the subprogram; however, they are not currently funded.

- Work with leading-edge architecture and engineering firms to encourage their use of EnergyPlus
- Work with key HVAC manufacturers to encourage their adoption of EnergyPlus
- Work with the International Alliance for Interoperability to ensure that building energy is integral to the interoperability standards
- Provide technical assistance to user interface developers with operational issues of EnergyPlus