U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Building Technologies Program

Buildings R&D Breakthroughs:

Technologies and Products Supported by the Building Technologies Program

April 2012

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Executive Summary

The purpose of the project described in this report is to identify and characterize commercially available products and emerging (near-commercial) technologies that benefited from the support of the Building Technologies Program (BTP) within the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy. The investigation specifically focused on technology-oriented research and development (R&D) projects funded by BTP's Emerging Technologies subprogram from 2005-2011.

To perform this analysis, Pacific Northwest National Laboratory (PNNL) investigated building technology R&D projects funded directly by the Emerging Technologies subprogram, via the Small Business Innovation Research and Small Business Technology Transfer programs, or as part of the American Recovery and Reinvestment Act. This effort identified 20 commercially available products and 78 emerging technologies. These technologies were grouped according to the following major R&D areas: building controls, envelope, HVAC and refrigeration, LED devices, LED materials, OLEDs, other lighting, water heating, and windows. The number of commercially available and emerging technologies identified in each major R&D area is shown in Figure ES.1.

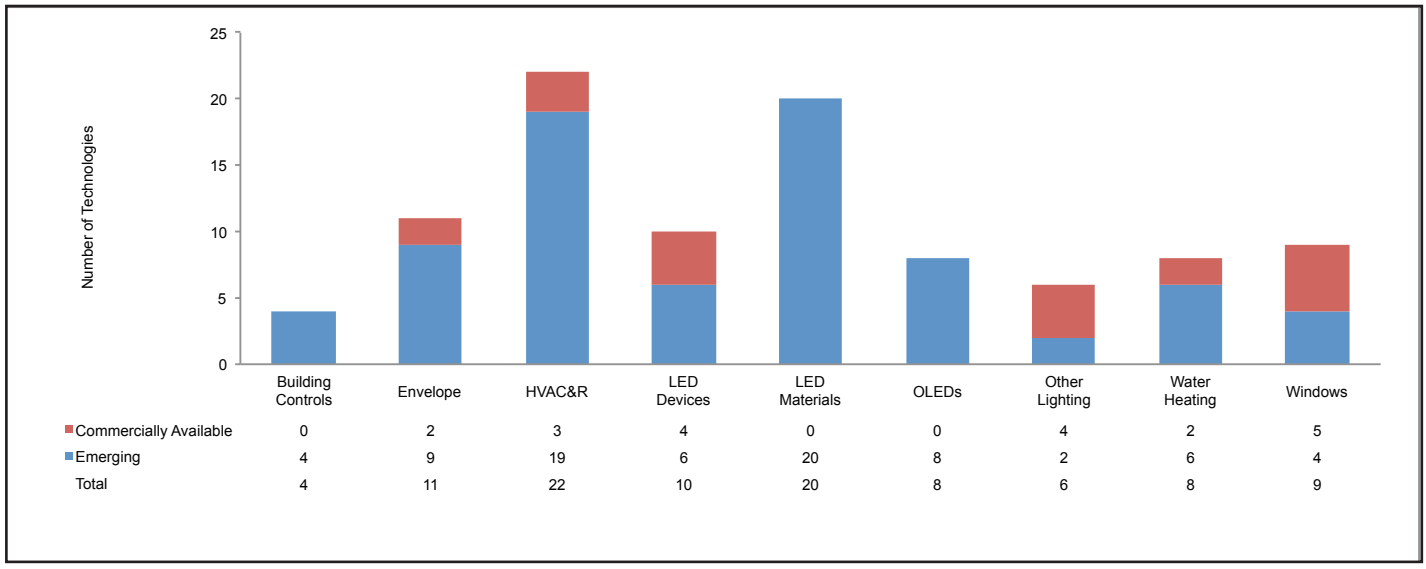


Figure ES.1. Commercially Available and Emerging Technologies by Research Category

In addition, PNNL identified 86 "potential" technologies that are still being developed but are more than three years from commercialization. A breakdown of the potential technologies is shown in Figure ES.2.

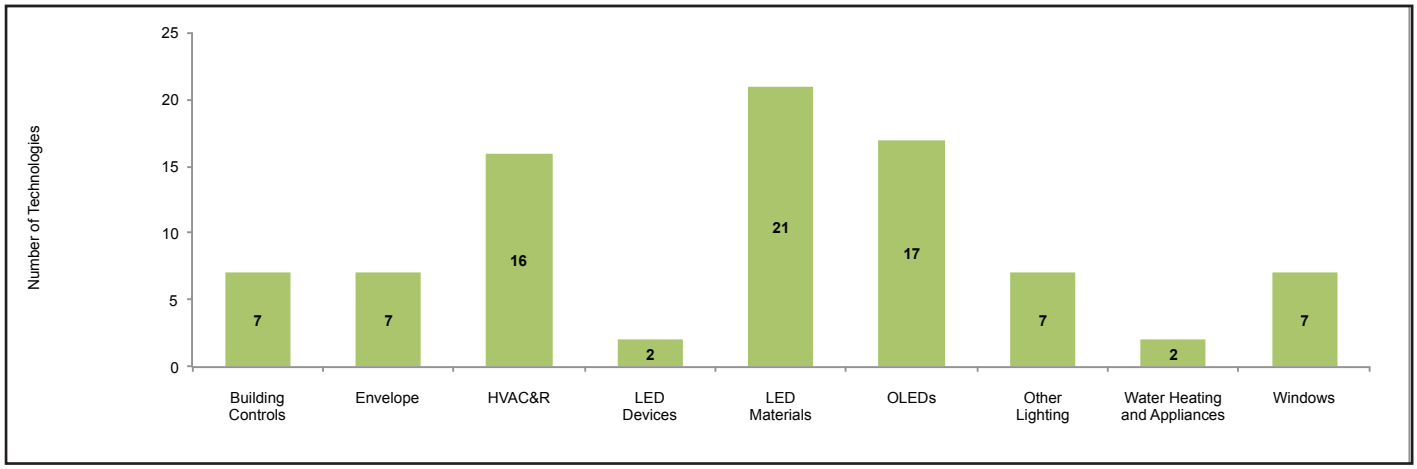


Figure ES.2. Potential Technologies by Research Category

Three types of organizations received grants to develop these building technologies: private companies, universities, and national laboratories. Private companies accounted for 75.5% of commercially available and emerging technologies and 56% of potential technologies. Universities had a much more prominent representation among potential technologies (23%) than commercially available/emerging technologies (5%), while national laboratories had an almost identical representation (19%-21%) among both groups.

Where possible, PNNL also quantified the energy savings and emissions reductions benefits resulting from the use of commercially available technologies that are more energy efficient than the established baseline technologies they were designed to replace. These results are presented on a per-technology basis as part of a set of detailed descriptions that was developed for each commercially available and emerging technology. This report documents the methodology and results of PNNL's technology tracking effort, including various analytical cross-sections and descriptions of the commercially available and emerging technologies that were funded by the Emerging Technologies subprogram from 2005-2011.

1.0 Introduction

This report documents the methodology and results of an effort to identify and characterize commercially available products and emerging[1] technologies that benefited from the support of the Building Technologies Program (BTP) within the U.S. Department of Energy's (DOE's) Office of Energy Efficiency and Renewable Energy (EERE). The investigation specifically focused on technology-oriented research and development (R&D) projects funded by BTP's Emerging Technologies subprogram from 2005-2011. Pacific Northwest National Laboratory (PNNL) has been conducting similar technology tracking activities for EERE's Industrial Technologies Program (and its predecessors) for more than 20 years and for EERE's Fuel Cell Technologies Program since FY 2008.

Commercialization of technologies that were developed in a government R&D program is generally viewed as an indicator of that program's success. The information presented in this report on commercially available and emerging technologies therefore fulfills the initial objectives of assessing BTP's technology R&D efforts during 2005-2011 and identifying technologies that are close to entering the commercial marketplace. The long-term intent of the PNNL effort is to periodically provide BTP with an updated report, thereby continually capturing the energy savings and other benefits of new BTP-funded technologies as they transition from R&D to the marketplace.

To provide some context, this chapter presents an overview of BTP's organization and core program areas, including the relationship of the Emerging Technologies subprogram to the rest of BTP. The chapter concludes with a brief summary of the information appearing within the remaining chapters and appendices of this report.

1.1 Organization of BTP and the Emerging Technologies Subprogram

BTP is tasked with increasing energy efficiency and decreasing carbon emissions in the buildings sector of the U.S. economy. To achieve these goals, BTP works with private companies, national laboratories, universities, and other government agencies to drive the development and adoption of technologies and practices that help builders, businesses, homeowners, and others reduce energy use in buildings. Key energy efficiency activities conducted by BTP include research and development (R&D), market stimulation, and building codes and equipment standards.[2]

The Program is divided into four subprograms: Emerging Technologies, Residential, Commercial, and Regulatory. The Emerging Technologies subprogram is responsible for carrying out R&D and technology transfer activities associated with energy-efficient products and technologies for residential and commercial buildings. Projects funded by this subprogram were therefore the focus of the technology tracking efforts presented in this report.

The major technology-oriented research thrusts of projects funded by the Emerging Technologies subprogram are summarized below. Each focus area represents a specific group of technologies that can be combined with the other groups to achieve BTP's goal of cost-effective, energy-efficient commercial buildings and homes.

Building Controls: Control technologies improve the energy efficiency of buildings by responding to changes in both the internal (e.g., occupancy) and external (e.g., weather) environment and delivering real-time information on the performance of building systems and components. Building controls also enable cost-saving opportunities such as peak shifting (e.g., nighttime thermal energy storage) and participation in demand-response programs by communicating with the external utility grid. Advanced techniques for monitoring the performance of individual electric loads within buildings also provide building owners and homeowners with the information necessary to make energy-saving purchases and operating decisions with regard to their appliances and equipment.

[1] "Commercially available" technologies, as defined in this report, are those available for purchase and that have been sold to at least one party in the United States. "Emerging" technologies, as defined in this report, are those projected to be commercialized within the next three years, based on the opinion of the technology developer.

[2] http://www1.eere.energy.gov/buildings/activities.html, accessed by PNNL May 2012.

Envelope: Building envelope R&D contributes to BTP goals by developing new materials, systems, and designs that reduce energy losses through a building's outer surfaces. One important focus of this R&D work is the development of a next-generation attic/roof system that will reduce energy losses by 50% compared with the Building America baseline. In pursuit of this goal, BTP sponsors the development and integration of key individual envelope technologies, including cool roofs, radiant barriers, and above-deck ventilation. Another key focus area is improved wall insulation, which includes developing exterior insulation and finish systems (EIFS) that offer improved thermal and moisture performance. Additional research areas include the development of phase change materials (PCMs), which add thermal mass to building insulation, and the reduction of energy losses through basements and foundations.

HVAC and Refrigeration (HVAC&R): Space conditioning and refrigeration account for 44% of primary energy consumption in the buildings sector.[3] BTP is developing air-source and ground-source integrated heat pump systems that can meet residential HVAC and water heating requirements. Another subset of HVAC research is solar heating and cooling, which is developing technologies that capture the sun's energy to help meet various electrical and thermal loads in buildings. The development of next-generation refrigerants and foam blowing agents that offer reduced global warming impact is another key focus area for BTP. Refrigerants are the working fluids used in vapor-compression-cycle equipment, the predominant technology used to provide HVAC&R services in the commercial and residential sectors. The deployment of new refrigerants with lower global warming potential (GWP) values is a priority of international climate change policy; new refrigerants must also be able to work efficiently in various vapor-compression systems. BTP's working fluids research supports both of these goals. BTP also works to identify alternative technologies that can replace conventional vapor-compression equipment to provide energy savings or environmental benefits. These alternative technologies include (but are not limited to): thermoelectric cooling, magnetic refrigeration, absorption-cycle heat pumps, and systems that provide cooling via high-speed flow of working fluids.

Lighting: The goal of lighting R&D is to develop lighting technologies with significantly increased efficacies[4] compared with today's most efficient lighting products. The primary focus of this research is solid-state lighting (SSL) materials and devices, which include both light-emitting diodes (LEDs) and organic light-emitting diodes (OLEDs). In addition to efficacy, key performance goals for new lighting technologies include improved color quality (measured by a device's color rendering index, chromaticity, and correlated color temperature) and increased product lifetime. BTP-sponsored SSL activities include core technology R&D, product development, and improved manufacturing techniques to reduce costs and enhance product quality.

Water Heating: BTP is developing next-generation water heating technologies, which include CO_2 heat pump water heaters and natural-gas-fired, absorption-cycle heat pump water heaters. Additional water heating technologies supported by BTP include control systems for smart-grid-compatible water heaters and tankless (i.e., on-demand) water heaters.

Windows: Windows play an important role in determining a building's energy efficiency and the quality of living/working conditions for its occupants. Dynamic windows and advanced fenestration systems are being developed that can adjust to varying conditions and improve the insulating performance of windows to a target value of R-10. Such systems are also being designed to preferentially transmit visible light while reducing solar heat gain. The use of natural daylighting in buildings reduces energy consumption from artificial lighting sources and improves occupants' sense of connection to the outdoors. BTP is focused on developing advanced materials and manufacturing processes that can deliver cost-effective dynamic window systems with a high level of durability.

Many of the research activities conducted in the envelope and windows areas are focused on enabling the development of new commercially available products by providing design tools, access to unique test facilities and/or developing test protocols in support of private sector technology development. This work also involves information dissemination to the companies, researchers, academics and others (e.g., through free software tools) and advances in the science of energy-efficient building systems and construction techniques(e.g., closed crawl spaces and advanced attic/roof systems), but the commercially developed products cannot always be linked directly to DOE funding. For example, in the residential window market, well over 80 percent of all new windows being developed to meet new code and Energy Star requirements are developed with DOE-funded engineering design software. This report focuses only on the development of specific technological advances that are sold as commercially available products and are directly linked to

[3] *2010 Buildings Energy Data Book (Table 1.1.5)*, U.S. DOE, March 2011.

[4] Efficacy is measured in lumens per watt (lm/W), the number of lumens of light produced per watt of input power.

DOE funding. For this reason, some major successes from the envelope and windows areas (e.g., the High Performance Windows Volume Purchase Program and free versions of the WUFI-ORNL/IBP, WINDOW, and THERM software programs) are not included in this document.[5]

Investment in energy-efficiency R&D for the core areas described above offers significant potential for reducing U.S. energy consumption and greenhouse gas emissions. As shown in Figure 1.1, buildings accounted for 41% of U.S. primary energy consumption in 2010, more than any other individual sector of the U.S. economy.

HVAC&R, lighting, and water heating account for 67% of primary energy consumption in the buildings sector[3] and are major target areas of technology R&D funded by BTP's Emerging Technologies subprogram. Activities in the envelope and windows areas also play a major role towards reducing HVAC and lighting energy use through improved insulation and natural daylight harvesting.

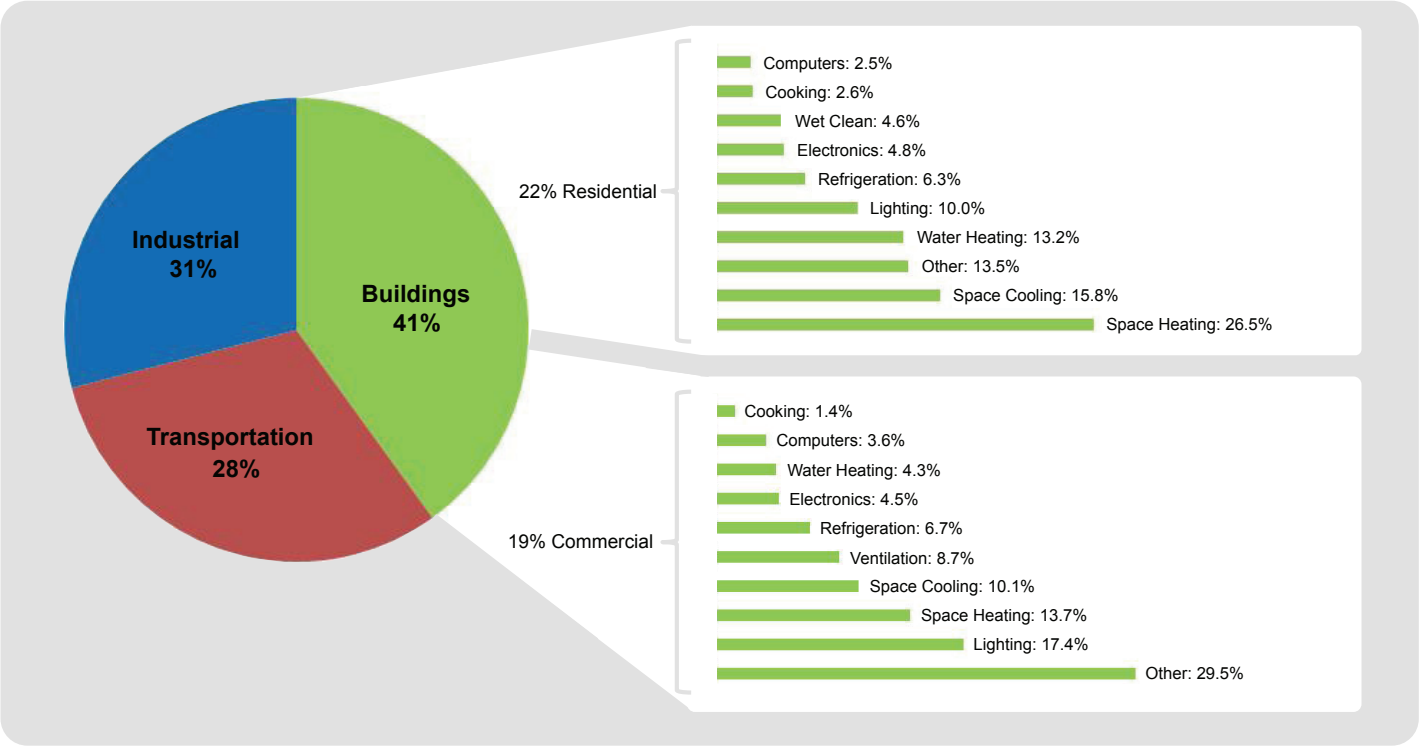


Figure 1.1. U.S. Primary Energy Consumption, 2010[6]

1.2 Contents of this Report

The remaining chapters of this report explain in greater detail the methodology used by PNNL to conduct this investigation and present the results of this effort in tables and graphics. The appendices provide details related to the data-gathering process and descriptions of each commercially available product and emerging technology identified in the study, along with a reverse directory of technology developer organizations.

[5] For additional information about the High Performance Windows Volume Purchase Program, visit http://www1.eere.energy.gov/buildings/windowsvolumepurchase/. Additional information about the WUFI, WINDOW, and THERM software programs can be found at EERE's Building Energy Software Tools Directory: http://apps1.eere.energy.gov/buildings/tools_directory/subjects_sub.cfm.
[6] *2010 Buildings Energy Data Book (Tables 1.1.3, 2.1.6, and 3.1.5)*, U.S. DOE, March 2011.

2.0 Approach

PNNL assembled a list of BTP-sponsored technology R&D projects to investigate and obtained contact information for each project's principal investigator (PI) or point of contact (POC). This list, a "living document" that changes over time, was generated from multiple data sources that covered various sets of BTP-funded projects. Once a working version of the technology tracking list (i.e., a list including PI/POC contact information for each project) was assembled, PNNL began contacting PIs/POCs to ascertain the status of their projects. Projects resulting in commercially available products or emerging technologies qualified for additional investigation, including development of a one-page technology description and calculation of energy savings for select commercially available products. This report is an update to the original study: *Building R&D Breakthroughs: Technologies and Products Supported by the Building Technologies Program* (May 2011). PNNL began updating this initial report in June 2011 with the results shown in this report. This chapter documents the process through which PNNL arrives at a working list of projects to investigate and provides a detailed description of the additional investigation performed for technologies identified as commercially available or emerging.

2.1 Selection of Projects to Investigate

PNNL obtained multiple lists of projects funded by BTP's Emerging Technologies subprogram and used these lists to assemble an initial pool of projects for investigation in the technology tracking effort. Projects on these lists were either kept or eliminated based on the following criteria:

- Projects ending prior to 2005 were removed from consideration based on a decision by PNNL staff and this effort's original DOE project manager. The period 2005-2009 was determined to be a good timeframe for capturing products that recently entered the market and technologies within three years of doing so.
- Projects not related to technology R&D (e.g., information centers, building energy codes and standards, and technical program management) were eliminated because they were determined to be outside the scope/focus of this effort.
- Projects terminated by DOE before their scheduled completion date or otherwise known to have failed were eliminated.

In November 2009, PNNL obtained a list of 535 projects that were from EERE's Corporate Planning System (CPS) database and that were funded by the Emerging Technologies subprogram during the past decade. The CPS data included the following information for each project: performing organization, short title, start and completion dates, and a brief project description. However, it did not include PI/POC contact information. PNNL staff narrowed down this initial list to 134 projects based on the criteria listed above.

In an effort to obtain contact information for the PIs/POCs associated with the initial list of projects, PNNL staff contacted the National Energy Technology Laboratory (NETL), which manages many BTP-funded projects. In April 2010, NETL sent PNNL three lists from their project management database that contained PI/POC contact information for different categories of projects funded by the Emerging Technologies subprogram. The first list contained 211 projects awarded to private companies and universities, the second included 86 Inter-Entity Work Orders awarded to national laboratories, and the third contained 60 congressionally-directed projects. PNNL staff worked with NETL to eliminate projects from these lists based on the criteria described above and to match up projects (and contact information) from these lists with the CPS data. The end result of this effort was an initial working list of 133 projects to investigate.

PNNL also investigated Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) grants awarded from 2005-2009 to organizations developing building technologies. SBIR grants are funded in two phases: Phase I grants focus on the feasibility of an idea and are funded at a low level (typically up to $100K); Phase II grants focus on R&D and are funded at a higher level (typically up to $500K). To receive a Phase II grant, a small business must have successfully completed a Phase I grant and been selected to continue their research. Like SBIR grants, STTR grants are awarded to small businesses, with the caveat that a nonprofit research institution (e.g., a

university or national laboratory) must also be involved. PNNL focused on SBIR Phase II and STTR grant projects for this technology tracking effort, and 18 of these projects were added to the working list.

The final source of information used by PNNL staff to find projects for the technology tracking effort was BTP's SSL website, which contains lists of current and completed LED and OLED projects. Of the 141 projects listed on these pages, 73 qualified for inclusion on the technology tracking list. After consolidating all of these data sources into a single set and making sure that projects appearing on multiple lists were not double counted, the final working version of the technology tracking list contained 190 projects for investigation.

As part of the effort to update the initial report, the PNNL team worked with the BTP Emerging Technologies staff to identify any new projects that needed to be investigated to determine their status. Projects that received funding as part of the American Recovery and Reinvestment Act (ARRA) were a majority of the new projects investigated. The 2010 SBIR Phase II and STTR grant projects were also added to the list to be investigated. In addition, all the previous PIs/POCs for the commercial and emerging technologies in the initial report were recontacted to update their status.

2.2 Technology Tracking of Commercially Available and Emerging Technologies

The PNNL team contacted the PIs/POCs for the 190 technology R&D projects to determine whether each technology was commercially available, emerging, potential,[1] or no longer being pursued. This initial round of investigation identified 11 commercially available products, 41 emerging technologies, 68 potential technologies, and 70 projects no longer being pursued. In the update to the initial report, there are now 20 commercially available products, 78 emerging technologies, and 86 potential technologies. Complete lists of all the commercially available, emerging, and potential technologies are shown in Appendix A.

For technologies identified as commercially available or emerging, a template (shown in Appendix B) was sent to the PIs/POCs to gather data on each technology. Data collected about the technologies were then entered into a BTP Technology Tracking Database. The database is divided into commercially available and emerging technology sections, each of which is sub-divided into following research categories: building controls, envelope, HVAC&R, LED devices, LED materials, OLEDs, other lighting, water heating, and windows. BTP personnel have access to the database, which is stored at PNNL. Periodically, PNNL will transmit an updated version of the database to BTP. In addition to the electronic database, hard copy files are kept for each technology that include the template (database) information and other supporting data such as annual progress reports, presentations, and information from the technology developer's website.

Using information supplied in the templates by technology PIs/POCs, PNNL staff developed one-page descriptions for each commercially available product or emerging technology. Those one-page descriptions are shown in Appendices C and D, respectively. PNNL staff reviewed all information received by the technology PIs/POCs for technical validity and accuracy and then gave the technology developers a chance to review the descriptions and suggest changes. An important condition of the technology tracking process is that all technology descriptions must be approved by the PIs/POCs before appearing anywhere in the public domain.

The long-term intent of the PNNL update effort is to periodically contact the technology developers currently listed in the report and obtain updated status information on their projects, which will be entered into the technology tracking database. At that time, any necessary changes will also be made to the technology descriptions (e.g., new product features or a changing R&D focus). During each update cycle of technology tracking, emerging technologies that have experienced their first U.S. commercial sale will be upgraded to commercially available status, and potential technologies that have moved to within three years of commercialization will be upgraded to emerging status. At the same time, the emerging and potential technology lists are continually replenished with newly funded BTP projects.

[1] "Potential" technologies, as defined in this report, are those that are still in the research stage but more than three years from commercialization, based on the opinion of the technology developer.

2.3 Quantifying Benefits of Commercially Available Technologies

One method that PNNL uses to quantify the benefits of government R&D programs is calculating the energy savings and emissions reductions realized through the use of commercially available products that made it to the marketplace with the assistance of government funding. Energy savings cannot be determined for some products, typically because they either do not directly take part in an energy-consuming process or have large numbers of highly variable applications and uses. For example, an improved lighting ballast and electronic driver technology can be used with many different lighting systems in a very large number of applications with varying energy consumption patterns. By comparison, residential hot water heaters are relatively homogenous in their application and energy consumption.

For a commercially available technology with quantifiable energy savings, PNNL staff work with the PI/POC to develop a calculation methodology for determining the technology's energy consumption on a per unit, per time basis. Both the PI/POC and PNNL staff must agree that the methodology is valid and accurate. PNNL staff then compare the technology's energy consumption to that of the established baseline product that the technology is intended to replace. (For example, the energy consumption of a heat pump water heater can be compared with that of a standard water heater.) The difference represents the amount of energy saved from use of the technology on a per unit, per time basis. Once this methodology is finalized, the technology PI/POC must provide the number of sales/installations of their product so that the total energy savings can be computed. Many organizations treat sales information as proprietary, which often makes it impossible to quantify the energy savings for certain commercially available technologies.

Once a technology's total energy savings have been determined, impacts on the environment are calculated by estimating the associated reduction of air pollutants. This calculation is based on the type of fuel saved and the pollutants typically associated with combustion of that fuel. For example, for every million Btu of coal combusted, approximately 1.25 pounds of sulfur oxides (known acid rain precursors) are emitted to the atmosphere. Therefore, every million-Btu reduction in coal use results in the elimination of 1.25 pounds of polluting sulfur oxides.

The cumulative energy savings and emissions reductions for individual technologies are provided in the commercially available technology pages in Appendix C.

3.0 Results

The results of the effort undertaken in the BTP technology tracking project are summarized in this chapter. The following pages provide a graphical analysis of the technology identification/tracking results and a tabular description of the technologies and their benefits.

PNNL staff identified 20 commercially available and 78 emerging technologies, which are described in detail in Appendices C and D, respectively. Figure 3.1 shows the number of commercially available and emerging technologies in each major research category. Lighting technologies (LED devices, LED materials, OLEDs, and other lighting) accounted for 45% of all commercially available and emerging technologies identified in this study. The large percentage of technologies coming from the lighting area is consistent with the fact that about 60% of the Emerging Technologies subprogram's total R&D budget from 2005-2011 was allocated to lighting R&D. The eight commercially available products from the lighting area consist of LED-based devices and other lighting-oriented technologies such as ballasts, reflectors, and controls. To date, none of the LED materials or OLED technologies identified in this study have been commercialized. The lack of commercialized LED materials technologies can be explained by the fact that materials-oriented work for LEDs is typically fundamental research that enables the commercialization of new and improved LED devices. OLED lighting technologies are still largely in the R&D phase of product development and have yet to achieve significant market penetration.

The other major end-use categories for energy consumption in buildings are also well-represented with technology R&D. Research related to HVAC, refrigeration, and water heating accounted for 31% of all commercially available and emerging technologies identified and five commercially available products. Envelope and windows technologies, which play a major role towards reducing HVAC and lighting energy use, accounted for 20% of the technologies identified and seven commercially available products. The remaining 4% of the technologies identified consisted of building-level control systems, which reduce energy consumption and costs through strategies such as occupancy-based control, peak shifting, and participation in demand response programs.

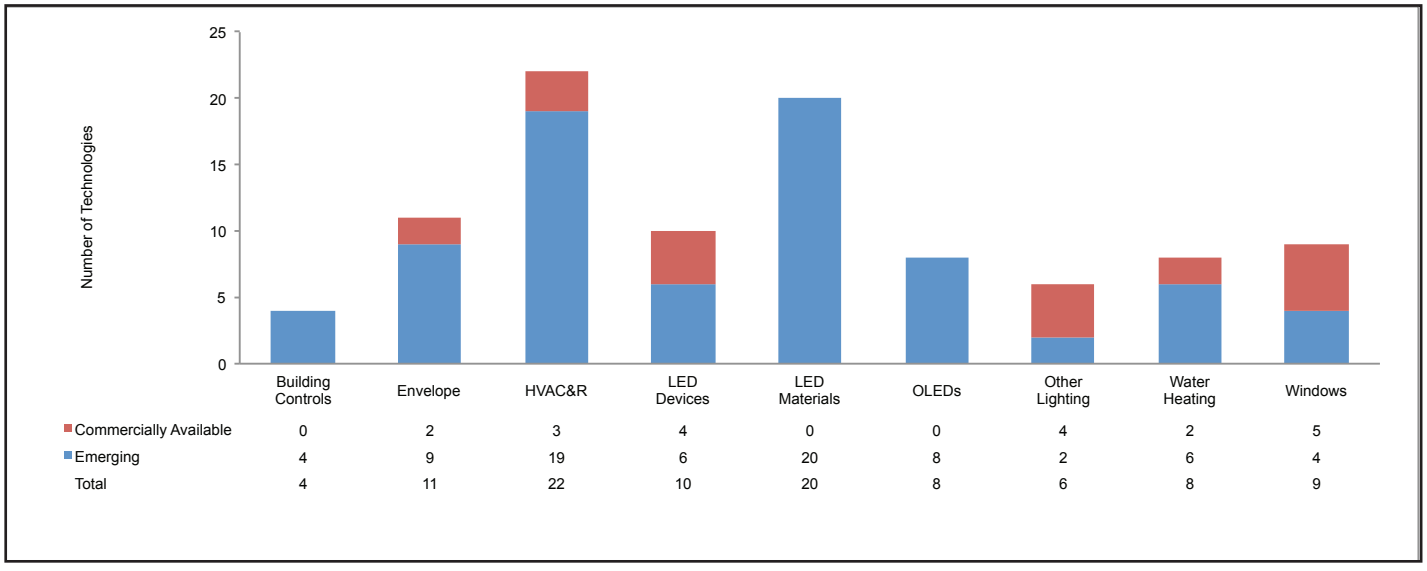


Figure 3.1. Commercially Available and Emerging Technologies by Research Category

Another way to view the commercially available and emerging technology data, shown in Figure 3.2, is by technology developer organization type. Three types of organizations were identified: private companies, universities, and national laboratories. Private companies accounted for three quarters of all commercially available and emerging technologies, with the majority of the remaining quarter being developed by national laboratories. The large percentage of private companies is partially due to the large number of technologies developed from ARRA-funded projects. National

laboratories tend to bridge the gap between fundamental science and technology commercialization, while universities usually focus on the advancement of fundamental scientific knowledge.

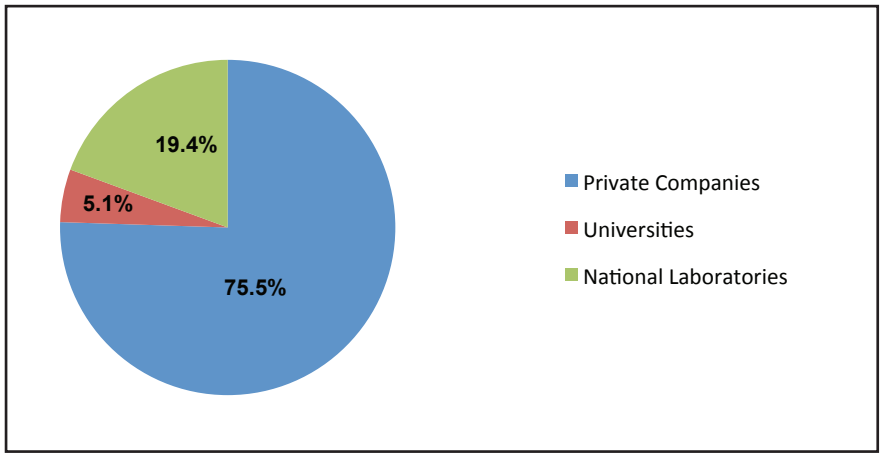


Figure 3.2. Types of Organizations with Commercially Available and Emerging Technologies

In addition to commercially available products and emerging technologies, PNNL identified 86 potential technologies, which are listed in Appendix A. The distribution of potential technologies by major R&D category is shown in Figure 3.3.

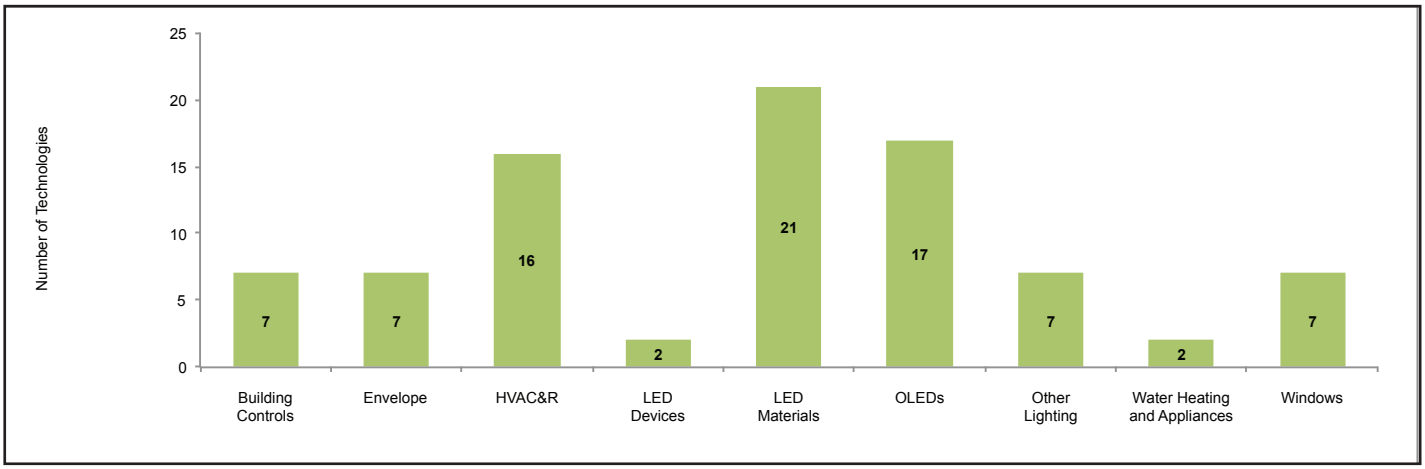


Figure 3.3. Potential Technologies by Research Category

Lighting-oriented R&D accounted for 55% of the potential technologies, an even larger fraction than its 45% share of commercially available and emerging technologies. Research related to HVAC&R, water heating, and laundry appliances accounted for 21% of potential technologies. Envelope and windows research had a similar percentage of potential technologies (16%) as it did among the commercially available and emerging technologies (20%). The remaining 8% of the potential technologies consisted of building control systems.

Potential technologies, which have the longest projected time to commercialization, typically represent research that is relatively new and projects that received their funding near the end of the analysis timeframe. Over the past few years, SSL R&D has expanded to include the new, rapidly-growing field of OLED research. This investigation identified zero commercially available OLED lighting products, eight emerging OLED lighting technologies, and 17 potential OLED lighting technologies (see Appendix A for details). This trend shows the results of increased funding levels for OLED research in the past few years. The large number of potential OLED lighting technologies suggests that it will take more than five years before OLEDs start to make a significant penetration into the commercial lighting marketplace.

The potential technologies can also be viewed by organization type, as shown in Figure 3.4. Private companies represented the majority of potential technology developers, but accounted for a smaller percentage of potential technologies (56%) than commercially available and emerging technologies (75.5%). Universities increased their

percentage of projects from Figure 3.2 (5% to 23%), while national laboratories maintained an almost identical percentage (19% to 21%). As discussed above, universities are more strongly represented among the potential technologies because they often perform work with the goal of advancing fundamental scientific understanding and are further removed from the technology development associated with emerging and commercially available technologies.

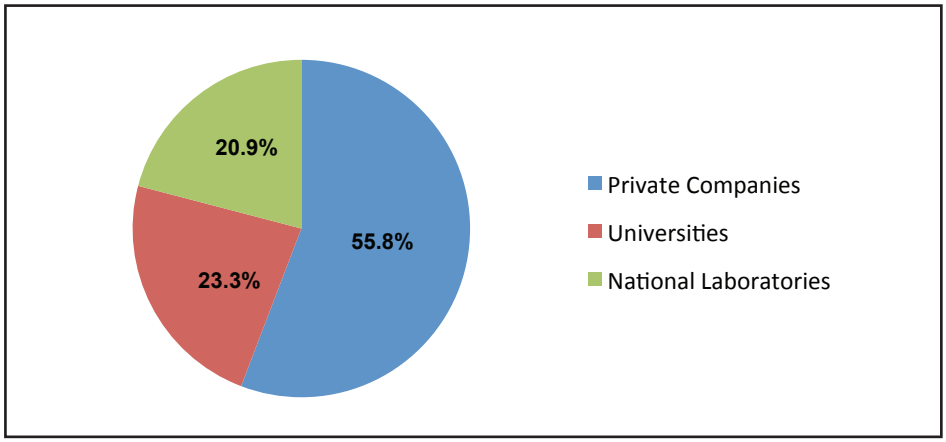


Figure 3.4. Types of Organizations with Potential Technologies

Table 3.1 briefly describes each of the 20 commercially available technologies and their benefits. The full descriptions of these technologies are provided in Appendix C.

Table 3.2 briefly describes each of the 78 emerging technologies and their benefits. The full descriptions of these technologies are provided in Appendix D.

An alphabetized directory of the organizations that developed the commercially available and emerging technologies described in Appendices C and D is provided in Appendix E.

Table 3.1. Commercially Available Technologies Summary

Technology	Organization	Description	Benefits	Commercial Status
Envelope				
Next-Generation Envelope Materials	Oak Ridge National Laboratory	An organic, microencapsulated, fire-resistant phase change material (PCM) that improves the thermal performance of building envelopes when blended into conventional insulation materials.	Reduces heat transfer through building envelopes by absorbing heat during peak cooling hours (changing from solid to liquid) and rejecting heat to the environment (by re-solidifying) when outdoor temperatures drop.	Commercialized in 2007. Small quantities have been produced for customers wishing to test the PCM.
ThermaDeck: An Insulated and Ventilated Roof System	Billy Ellis Roofing, LLC	A roof system that uses multiple features to reduce heat gain in attics. The system includes a polystyrene layer for reducing conduction-based heat transfer, an aluminum radiant barrier for reflecting radiant heat, and a natural-convection-based ventilation system.	Reduces peak daytime heat transfer through roofs by 85% compared with conventional roofing. Maintains attic air temperatures that do not exceed the ambient air temperature. Saves homeowners money by reducing heat transfer from the attic into air-conditioned rooms.	50 systems installed in U.S. homes.
HVAC&R				
Echo™: A Hybrid Solar Electric/Thermal System	EchoFirst, Inc.	A residential building solar system that provides electricity, heating, cooling, and hot water. The system can offset over 50% of a home's energy needs.	Achieves a high level of reliability by using an air-based (waterless) design. Provides a simple design that can be installed using standard roofing practices.	Commercialized in 2009. More than 350 systems installed in the U.S.
NextAire™ Packaged Gas Heat Pump	IntelliChoice Energy	An 11-ton rooftop packaged heat pump for commercial buildings that uses a natural-gas-fired engine (instead of an electric motor) to drive the vapor compression refrigerant cycle.	Reduces operating costs by avoiding expensive demand and time-of-use electricity charges. Saves an average of 2 gallons of water per kWh compared with similar-sized units consuming grid-generated electricity.	Commercialized in 2010, with 50 units installed in the U.S.
Quiet Climate 2: Efficient Heat Pump for Classrooms	Bard Manufacturing Company, Inc.	A 3- to 5-ton wall-mounted heat pump for site-built and portable classrooms. The unit improves classroom working conditions by reducing HVAC-related noise and improving indoor air quality.	Reduces audible noise levels to ≤42 dB while operating and ≤35 dB while in fan-only mode for ventilation. Reduces HVAC energy consumption and expenses by enabling occupancy-based ventilation of individual classrooms.	Commercialized in 2008, with more than 1000 units being used in schools throughout the U.S.
LED Devices				
Efficient LED System-in-Module for General Lighting	Philips Lighting	An LED module containing red, green, blue and/or white LEDs with integrated control circuitry for color variability and light level control.	Offers adjustable color and light output that can be programmed for differing applications. Device programming is compatible with daylighting and occupancy-based control. Has an operational lifetime of 50,000 hours.	Commercialized in 2011, with over 100 units sold.

Table 3.1. Commercially Available Technologies (*cont'd*)

Technology	Organization	Description	Benefits	Commercial Status
LED Devices (*cont'd*)				
High-Efficiency LED Lamp for Solid-State Lighting	Cree, Inc.	An LED high-power chip with an efficacy in excess of 92 lm/W for warm white and 120 lm/W for cool white. These chips, when packaged with an appropriate phosphor and optics for maximum light extraction, will produce LEDs suitable for SSL products.	Offers compatibility with low-cost phosphor application processes and simplifies white LED manufacturing. Increases lighting efficacy by up to 10 times compared with incandescent light bulbs. Enables customization of device geometry for different applications.	Commercialized in 2006. Continuing development to increase cool and warm white high-power LED performance. Over 1 billion LED chips have been sold worldwide.
Integrated, Solid-State LED Luminaire for General Lighting	Philips Color Kinetics	LED-based A-lamp and parabolic aluminum reflector (PAR) lamp replacement products. The technology won DOE's L-Prize competition for a replacement to the 60-W incandescent light bulb.	Achieves 25,000 hours lifetime and an 80% gain in energy efficiency compared with industry standard A-lamp equivalents.	Commercialized in 2009. Continuing development of new LED replacement lighting products.
LUXEON® A and LUXEON® S: Warm White Illumination-Grade LEDs	Philips Lumileds Lighting Company	Illumination-grade warm white LEDs that have a CCT range from 2700-3500 K, and an efficacy of 100 lm/W with a CRI ≥80. For end-user applications, the LUXEON S is assembled using an innovative "solderless" design, which provides a mechanical clamping mechanism for attachment to a heat sink.	Provides uniform, high-quality light output with a high luminous efficacy. Reduces energy consumption and cost per lumen in general lighting applications. Operates for >50,000 hours under normal operating conditions based on the lumen maintenance (LM-80) test.	Commercialized in 2011 and sold to luminaire companies for use in spot lamps and downlights. Continuing development to improve efficiency, CCT, and CRI.
Other Lighting				
Adapting Wireless Technology for Lighting Control	ELB Electronics, Inc.	A system of advanced wireless controls for lighting applications, including wireless-controllable actuators, electronic dimmable lamp ballasts, and sensors for light level and occupancy detection.	Reduces lighting energy consumption by monitoring occupancy and by integrating daylighting schemes. Achieves full-range dimming in fluorescent lamp ballasts.	Commercialized in 2007. Continuing development with Zigbee™ communication capabilities.
Ballast/Driver Technology for Metal Halide or Solid-State Lighting Systems	Energy Focus, Inc.	An electronic ballast/driver for optimizing lamp start-up and operation and for instantly switching on metal halide lamps or SSL systems.	Provides 92% efficient ballast circuitry and improves output lm/W and operational lifetime. Achieves military specifications and energy savings up to 80% compared with conventional lighting systems.	Commercialized in 2009. Developing SSL products for general and hazardous environment lighting applications.
Lighting Power and Control Network for SSL Systems	Redwood Systems, Inc.	An energy-efficient lighting system that uses SSL and centralized control capabilities. The system monitors room occupancy and analyzes traffic patterns/space use within a room, allowing building operators to preset dimming control and occupancy schedules for individual fixtures, room zones, or entire floors.	Reduces lighting electricity consumption by providing occupancy-based control of lighting systems down to the individual fixture level. Enables the integration of daylighting as part of an overall lighting strategy.	Commercialized in 2010. Currently managing over 500,000 ft^2 of lighting space at 30 installation sites.

Table 3.1. Commercially Available Technologies Summary (*cont'd*)

Technology	Organization	Description	Benefits	Commercial Status
Other Lighting (*cont'd*)				
Optical Performance-Enhancing Material for Lighting Applications	Luminit, LLC	A light shaping and diffusing film that improves light extraction efficiency and light output quality from OLEDs. The film is placed at the interface between the OLED structure and substrate, and provides a variety of configurable optical parameters for light transmission, diffusion, and beam shaping.	Improves the energy efficiency, light output uniformity, and color rendering of OLED products. Can be used on a variety of rigid or flexible substrates. Fabricated with a high-volume, roll-to-roll system, which reduces production costs.	Commercialized in 2009. Continuing development to support various SSL end-user application needs.
Water Heating				
GeoSpring™ Hybrid Water Heater	General Electric Company	A commercially released hybrid water heater that uses heat pump technology to heat water. The unit uses 62% less energy than an equivalent 50 gallon electric water heater. The unit meets ENERGY STAR criteria and qualifies for federal tax credits.	Offers simple installation by using existing utility connections. A GeoSpring water heater could save the average U.S. household $300 per year on its electric bills.	Commercialized in 2009. First ENERGY STAR qualified heat pump water heater. Installed units have saved over an estimated 340 billion Btu.
Vertex™ Residential Gas Condensing Water Heater	A.O. Smith Corporation	A product line of high efficiency gas water heaters. Lower cost and high performance were achieved by using standard heater components and strategic material choice and design strategies.	Installs easily using existing utility connections. Provides cost effective design with reliable performance. Achieves up to 30% energy savings compared with conventional gas water heaters.	Commercialized in 2006. Available nationwide.
Windows				
ATLAS™: An Energy-Efficient Triple IG Window Manufacturing System	GED Integrated Solutions, Inc.	A fully automated high-volume manufacturing system for producing high performance windows (R-5). The system can produce a variety of dual and triple pane insulating glass units (IGUs) in a fraction of the time compared to conventional methods.	Optimizes material usage, production schedules and is easily integrated with existing manufacturing equipment. Produces up to six IGUs per minute.	Commercialized in 2011. One unit operating in the U.S.
EnerLogic®: Low-Emissivity, Energy-Control Retrofit Window Film	Solutia Inc.	A low-cost film that can be applied as a retrofit to windows in order to reduce their thermal emissivity. The film improves the energy efficiency of buildings by reducing heat loss through windows in the winter.	Improves window energy efficiency without the need for expensive re-installation or replacement of existing windows.	Commercialized in 2011. Over one million square feet installed.
OptiQ™: An Advanced Commercial Window Technology	Traco, a division of Kawneer Company, Inc.	Window framing technology that uses low-emissivity coatings and advanced thermal break and foam-filling techniques for improved U-value. The techniques have improved U-values by as much as 30% and IR emissivity by 25%.	Reduces HVAC costs by inhibiting heat transfer through aluminum window frames. Allows low-emissivity coating to be applied to existing framing systems without any additional modifications.	Commercialized in 2011. Available from Traco/ Kawneer

Table 3.1. Commercially Available Technologies (*cont'd*)

Technology	Organization	Description	Benefits	Commercial Status
Windows (*cont'd*)				
SageGlass® Electrochromic Windows	SAGE Electrochromics, Inc.	Electrochromic window glazing that preserves natural daylight benefits. Glazing fully functions as a conventional insulating window but can be tinted to reduce sun glare and solar heat gain.	Can be used for either residential or commercial applications. Blocks glare without loss of visibility or comfort. Provides proven product durability and reliability.	Commercialized in 2007. Installed units have saved an estimated four billion Btu.
Suntuitive™: Sunlight-Responsive Thermochromic Window Systems	Pleotint, LLC	Dynamic windows that adjust their amount of tint based on the amount of solar energy they absorb. The windows continuously and passively adjust to changing sunlight conditions without requiring manual or electrical intervention. Visible light transmission ranges from 55%-60% in indirect sunlight (e.g., cloudy days) to ≤10% in direct sunlight.	Reduces air conditioning loads by reducing solar heat gain during peak hours. Provides glare-free natural daylighting, which reduces lighting electricity consumption. Simplifies the installation and use of dynamic windows by operating without electricity (e.g., no electrician required for installation and no control system needed for operation).	Commercialized in 2011. Over 20,000 square feet installed.

Table 3.2. Emerging Technologies Summary

Technology	Organization	Description	Benefits
Building Controls			
Advanced Load Identification and Management for Buildings	Eaton Corporation	An advanced power outlet/strip technology that identifies miscellaneous electric loads (MELs) in buildings based on their current and voltage characteristics. The technology automatically monitors load performance and safety protection information and delivers this information to building owners via low-cost communication methods.	Enables building owners and homeowners to make energy-saving purchases and operating decisions with regard to MELs by providing them with detailed information about MEL energy consumption. Uses advanced fault protection functions to protect equipment and building occupants.
Integrated Predictive Demand Response Control for Commercial Buildings	Johnson Controls, Inc.	Integrated predictive demand response (IPDR) control algorithms that enable commercial buildings to participate in a variety of demand response markets. The controls minimize building energy costs based on electric pricing or curtailment signals, while protecting equipment and ensuring occupant comfort and safety.	Reduces costs by providing the financial benefits of demand response without the need for new capital equipment purchases. Improves the reliability/efficiency of the electrical grid and reduces the occurrence of brownouts and rolling blackouts.
Plug-and-Play Distributed Power Systems for Smart-Grid-Connected Buildings	United Technologies Corporation	A plug-and-play building energy microgrid that integrates building-level energy sources, storage, and loads with the external utility grid. The microgrid can operate in grid parallel or islanding modes, and seamlessly transition between these modes while monitoring energy usage and power quality levels.	Uses integrated energy storage to take advantage of cost-saving opportunities such as shifting electric loads to off-peak hours (thereby avoiding high-priced peak electricity rates), or curtailing loads on request from utilities under a contract. Improves grid stability by enabling on-demand load reductions in response to high levels of stress on the grid.
Predictive Optimal Control of Active and Passive Building Thermal Storage Inventory	Clean Urban Energy, Inc.	A control technology that predictively optimizes thermal storage strategies in commercial buildings to shift HVAC electricity consumption from peak to non-peak hours.	Reduces HVAC operating costs. Increases grid efficiency by shifting consumption from peaking power plants to more efficient baseload plants. Reduces daytime strain on the grid and helps combat the problem of negative nighttime electricity prices due to an excess of generation capacity and a lack of demand.
Envelope			
Advanced Building Insulation by Carbon Dioxide Foaming Process	Industrial Science & Technology Network, Inc.	An improved foaming process for building insulation production that uses supercritical CO_2 as the blowing agent.	Eliminates the use of ozone-depleting and high-GWP gases in foam insulation without sacrificing insulating performance.
Energy-Efficient EIFS Wall Systems	Dow Corning Corporation	An improved EIFS design that uses encapsulated, vacuum-insulated panels to increase the R-value of a typical wall to R-30 with only three inches of exterior insulation. The technology offers an improved R-value per inch of insulation compared with current envelope systems. The thin cross-section has a minimal impact on wall thickness and typically does not require extension of roof overhangs when used in retrofit applications.	Reduces HVAC energy consumption in buildings by improving the insulating performance of exterior walls. Enables increased use of EIFS in commercial building retrofit applications due to thin cross-section and high R-value per inch. Simplifies installation by using modular panels that are shipped to the jobsite already made to the proper size.

Table 3.2. Emerging Technologies Summary (*cont'd*)

Technology	Organization	Description	Benefits
Envelope (*cont'd*)			
Exterior Insulation and Finish System (EIFS)	EIFS Industry Members Association	Research and testing of the moisture-resistant performance of various EIFS products. The information resulting from these tests will enable the development of improved EIFS products and accelerate the market penetration of EIFS. The EIFS studied have several enhancements for moisture control, including liquid-applied air/water-resistive barrier coatings, interior wall element moisture management, and ventilated exterior claddings.	Improves understanding of EIFS moisture control capabilities and performance. Accelerates the market penetration of EIFS products, which provide improved hygrothermal performance compared with other exterior construction materials such as brick and stucco.
Insulating Form System for Concrete Foundation Edges	Davis Energy Group, Inc.	A leave-in-place concrete slab form board that also serves as insulation. The product consists of PVC extrusion and Styrofoam™ filler, which reduces foundation heat loss.	Reduces residential building heating loads (and associated greenhouse gas emissions) by reducing heat loss through slab-on-grade foundations. Prevents termite damage to wall framing and reduces construction waste.
Low-Cost Phase Change Materials For Building Envelopes	Syntroleum Corporation	A low-cost process for producing form-stable PCMs for building envelope applications (e.g., gypsum wallboard). The technology converts fatty acid chains in canola and soybean oils to PCM-range (C16-C18) paraffins. The resulting PCMs meet preliminary performance targets for melting point (22-23°C) and heat of fusion (≥100 J/g).	Reduces HVAC energy consumption by reducing heat transfer through building envelopes during peak cooling hours. Reduces the cost of producing form-stable PCM products by using continuous, high-throughput pelletizing instead of the conventional batch micro-encapsulation process. Uses bio-based, renewable feedstock materials.
Nano-Enabled TiO_2 UV Protective Layer for Cool-Color Roofing Application	Nanotrons Corporation	A titanium-dioxide-based coating that protects colored cool roof pigments from ultraviolet light damage, thereby extending cool roof lifetime.	Reduces building air conditioning loads by reflecting infrared radiation that would otherwise be absorbed by the roof and transferred into the building. Enables a wide range of cool roof colors to be used (as opposed to just white), which will accelerate adoption of cool roofs in the residential sector.
Reflective Elastomeric Roof Coating	Oak Ridge National Laboratory	An accelerated testing protocol for expeditious development of new cool roof finishes. Using data from extensive testing of cool roofs, reflectance degradation parameters have been developed that enable simulation of various long-term environmental effects (e.g., solar exposure, weathering, and soiling) in a reduced timeframe.	Reduces the time and costs associated with testing new cool roof products. Enables new products to be on the market more quickly.
Shape-Stable and Highly Conductive Nano-Phase Change Materials	Technova Corporation	A new type of PCM that makes use of molecular interactions with functionalized nanomaterial surfaces and support from a networked, thermally stable polymer to achieve a balance of desirable qualities (e.g., high latent heat capacity, shape stability at high temperatures, and fire resistance) for use in building envelope and energy storage applications.	Reduces heat transfer through building envelopes, thereby reducing peak hour cooling loads. For solar heating applications, the PCM allows excess daytime energy supply to be stored and then released to meet nighttime demand.

Table 3.2. Emerging Technologies Summary (*cont'd*)

Technology	Organization	Description	Benefits
Envelope (*cont'd*)			
Three-Dimensional Building Energy Performance Measurement and Modeling System	University of Nebraska-Lincoln	A system that generates a 3D model of a building's envelope with thermal resistance information for the envelope materials (e.g., walls, roofs, windows, and doors) stored at each point in space.	Offers visual information about building envelope energy performance, which is easier for homeowners to understand compared with numerical or graphical data. Helps building owners make informed envelope technology retrofit decisions.
HVAC&R			
Advanced Sequential Dual Evaporator Cycle for Refrigerators	Whirlpool Corporation	A new technology that improves refrigerator energy efficiency by using two evaporators (one for the fresh food compartment and one for the freezer). The two evaporator circuits (which are supplied with refrigerant by a single compressor and are isolated by valves) operate sequentially and at different pressures/temperatures.	Saves energy by satisfying the cooling needs of the freezer and fresh food compartments individually. The evaporator in the fresh food compartment operates at a higher pressure/temperature than the evaporator in the freezer compartment. This arrangement increases the unit's COP compared with conventional units, which cool air from both compartments with a single evaporator coil.
Air Bearing Heat Exchanger	Sandia National Laboratories	An air bearing heat exchanger that transfers heat across a narrow air gap from a stationary heat spreader to a finned heat sink that rotates at several thousand rpm. The rotating finned design significantly improves heat transfer and is not susceptible to dust or dirt fouling.	Maximizes translation of mechanical work into relative motion between the heat sink and the surrounding air. Reduces the amount of audible noise generated during cooling compared with fans.
Air-Source Integrated Heat Pump	Oak Ridge National Laboratory	A variable-capacity air-source heat pump that captures heat normally rejected to the outside air from space cooling and uses it for water heating.	Reduces residential energy consumption by recovering previously wasted heat and optimizing operation at less than full capacity.
Ammonia Absorption Technologies for HVAC Systems	Rocky Research	Innovative technologies that provide energy-efficient absorption space conditioning for residential and light commercial applications. The initial system developed with these innovations was a 5-ton chiller, which is being modified for use as a heat pump.	Offers variable-capacity operation and reduces cycling losses by using a high-turndown gas burner and a pulsing thermal expansion valve for refrigerant flow control. Uses generator-absorber heat exchange to improve operating efficiency. The heat pump will operate at temperatures as low as -22°F and will not require supplemental electric resistance heating until approximately 0°F.
Bernoulli Principle Air Conditioning and Cooling System	Machflow Energy, Inc.	A new cooling system that is based on Bernoulli's principle. The system is driven by a high-speed blower, which circulates a mixture of noble gases as the refrigerant. When the refrigerant passes through the constricted section of a Venturi tube, an energy-conserving conversion occurs that reduces its temperature and pressure and increases its velocity. The temperature reduction allows heat to be absorbed from the environment, with subsequent heat rejection occurring in a high-temperature heat exchanger.	Reduces the weight of cooling systems compared with conventional vapor-compression equipment. Scales down to small sizes and can integrate well with computer chips and electronics. Uses inert, non-toxic refrigerants with no ozone-depletion or global warming potential.

Table 3.2. Emerging Technologies Summary (*cont'd*)

Technology	Organization	Description	Benefits
HVAC&R (*cont'd*)			
Cold Climate Multi-Stage Heat Pump	Oak Ridge National Laboratory	A high-performance cold climate multi-stage heat pump that uses a single- or multi-speed vapor-injected compressor. This setup improves the unit's performance at low ambient temperatures and eliminates the need for backup electric resistive heating.	Provides an energy-efficient heating alternative to technologies such as electric or natural gas furnaces. Achieves a COP of 4.5 at an ambient temperature of 47°F, with a maximum capacity degradation of 25% down to an ambient temperature of -13°F.
Comboflair®: An Integrated HVAC and Water Heating System	DeLima Associates	A 2- to 4-ton packaged HVAC unit for manufactured homes. Cooling is provided via a vapor-compression system. A natural gas water heater provides space heating (via a hydronic coil) and hot water for the home.	Reduces manufactured home energy costs compared with separate water heating and electric resistance space heating arrangements. Offers easy installation and a small footprint for minimal space consumption.
Energy-Efficient Façades for Green Buildings	Rensselaer Polytechnic Institute - CASE	A building façade that uses solar cells to provide electricity and heating. The system is compatible with daylight harvesting, thus enhancing interior lighting quality and reducing the need for artificial lighting.	Reduces building cooling and lighting equipment requirements and operating costs. Reduces heat gain and glare from direct sunlight and provides diffuse daylighting. Modular design easily attaches to a variety of existing building structures or can be implemented during new construction.
Ground-Source Integrated Heat Pump	Oak Ridge National Laboratory	A variable-capacity ground-source integrated heat pump that transfers heat to or from the ground (depending on the season). The system allows normally rejected heat from space cooling to be recovered for water heating, thereby reducing a home's energy consumption/costs.	Increases efficiency by taking advantage of moderate underground temperatures (compared with air temperatures) for heat exchange. Uses a variable-capacity design for efficient part load operation.
HyPak: A High-Efficiency Rooftop Packaged HVAC System	Davis Energy Group, Inc.	A 10- to 30-ton rooftop HVAC system that provides energy-efficient space conditioning in commercial buildings.	Reduces peak HVAC electricity consumption by using evaporative cooling, which is most effective at high outdoor temperatures.
Improving Efficiency of Fuel-Fired Furnaces for Space and Water Heating Systems	Oak Ridge National Laboratory	An inexpensive solar air heater for preheating combustion air fed to furnaces used in space heating and water heating applications. The unit produces 8 cfm of pre-heated air at a temperature of ≥95°F.	Reduces furnace fuel consumption/costs by taking advantage of the energy in preheated air. Can be easily retrofitted into existing furnace systems.
Improving Electric Motor Efficiency	SMMA – The Motor & Motion Association	An electric motor test method, test and measurement system and a software simulation and design package to improve motor efficiency. The expanded capability of the simulation and design package has demonstrated excellent agreement between simulations and actual prototype tests and measurements.	Automates testing procedures and streamlines the motor design and development process. Improves electric motor performance and efficiency.
Multi-Zone HVAC Options for Residential Applications	Oak Ridge National Laboratory	An HVAC system that provides full space conditioning to occupied portions of a home and saves energy by only partially conditioning less-used areas. The system uses an integrated heat pump that combines the functions of space conditioning and water heating.	Saves energy by not fully conditioning unoccupied spaces within a home and by capturing normally rejected heat from space cooling for water heating. Uses a variable-capacity design for efficient part load operation.

Table 3.2. Emerging Technologies Summary (*cont'd*)

Technology	Organization	Description	Benefits
HVAC&R (*cont'd*)			
Nanographitic Additive for Enhanced Heat Transfer and Lubricity of Refrigerant Systems	Oak Ridge National Laboratory	A refrigerant lubricant additive that improves the mechanical efficiency of HVAC system compressors (by reducing friction) and the thermal (i.e., heat transfer) performance of the refrigerant/lubricant.	Reduces power consumption in HVAC systems by 4%-11%. Reduces compressor frictional loading on startup, which reduces startup torque and the likelihood of premature compressor failure.
Next-Generation Refrigerant Lubricants	Chemtura Corporation	Synthetic ester refrigerant lubricants that provide an optimized balance between lubrication performance (i.e., minimizing friction in the compressor) and maintaining high-efficiency heat transfer in the refrigeration system. The structure of the lubricant molecules can be tailored for compatibility with a specific refrigerant.	Improves the balance of frictional properties and refrigerant heat transfer performance compared with current synthetic lubricants. Reduces compressor energy consumption and increases compressor service life. Optimized for use with next-generation, low global warming potential (GWP) refrigerants.
Residential Fuel-Fired, Multifunction Heat Pump	Oak Ridge National Laboratory	A 2- to 5-ton residential heat pump that uses a natural-gas-fired engine to drive the compressor (as opposed to an electric motor). Waste heat from the engine is recovered to improve space heating performance in the winter and supplement water heating during the summer.	Reduces primary energy consumption by avoiding the power plant conversion losses associated with electricity generation. Waste heat recovery can provide 60 gallons per day of domestic hot water at a temperature of 140°F.
Thermoelectric Materials for Waste Heat Recovery	Hi-Z Technology, Inc.	A thermoelectric (TE) material with an efficiency three times that of typical TEs. A TE with increased efficiency could be used to recover waste heat and as an alternative method for conventional refrigeration and air-conditioning systems.	Reduces manufacturing costs using an automated process and readily available Si, C, B, and N. Avoids using toxic and expensive materials.
Water-Based, Critical Flow, Non-Vapor-Compression Cooling System	Caitin, Inc.	A new refrigeration cycle that uses a pump to pressurize liquid water and force it through a nozzle, which causes its pressure and temperature to drop to the point where heat can be absorbed from the space to be conditioned (causing some of the water to boil). Passage through the nozzle increases the water's velocity to ≥ the speed of sound. Under these "critical flow" conditions, a compression wave is generated that "shocks" the water up to the ambient pressure as it exits the evaporator tube, resulting in condensation of the vaporized portion of the vapor/liquid mix.	Operates with a COP of up to 10, which is much greater than traditional vapor-compression systems (typical COP values between 2 and 5). Improves heat transfer by using a refrigerant (water) with a high enthalpy of vaporization. Achieves heat transfer coefficients in excess of 100,000 W/(m2-K). Offers a scalable cooling capacity from 1 to 25 kW. Provides an environmentally friendly alternative to hydrofluorocarbon refrigerants.
Wireless Remote Monitoring System for Residential Air Conditioners and Heat Pumps	Mainstream Engineering Corporation	A low-cost device that uses temperature, current, and voltage sensors to continuously monitor AC or heat pump performance. When a problem is detected, the system automatically sends a notification with problem-specific information to the homeowner and the AC service company that installed the unit.	Alerts homeowners to simple AC maintenance issues that can be fixed with a minimum of time and expense, preventing the costly replacement of a failed unit. Saves energy and money by enabling rapid detection and resolution of problems that degrade AC efficiency (e.g., low refrigerant charge). Records equipment operating history to enable energy consumption analysis and comparisons.

Table 3.2. Emerging Technologies Summary *(cont'd)*

Technology	Organization	Description	Benefits
LED Devices			
Advanced Manufacturing Methods for Warm-White LEDs for General Lighting	GE Lighting Solutions, LLC	Specialized manufacturing techniques that reduce the cost of remote-phosphor-based LEDs and improve their consistency and product quality.	Reduces the materials and labor costs associated with LED manufacturing. Achieves coating consistency using a remote phosphor molding process. Provides color binning characteristics within a four-step MacAdam ellipse of the black body curve.
Affordable, High-Efficiency Solid-State Downlight Luminaires with Novel Cooling	GE Global Research	Synthetic jet cooling to increase heat sink thermal transfer rates, allowing LEDs to be driven at higher currents. The increased lumen output per LED reduces the number of LEDs required by up to 40%.	Reduces system cost by using improved thermal management, which results in increased lumens per LED and reduced LED chip count. Offers a compact design that is half the size and weight of a 600 lumen, passively cooled lamp.
Epitaxy Tools for Manufacturing Light-Emitting Diode Devices	Applied Materials, Inc.	An advanced epitaxial growth system for manufacturing high-brightness LEDs. The system has MOCVD and hydride vapor phase epitaxy chambers, lamp heating, and automated in-situ cleaning. The resulting wafer growth process has been optimized for manufacturing high-brightness LED devices, increasing the internal quantum efficiency of LEDs, and improving production yield to reduce costs.	Reduces LED manufacturing costs and improves LED device quality and performance. Produces LEDs with consistent device parameters. Helps enable faster market penetration of solid-state lighting technologies.
High Flux Commercial Illumination Solution with Intelligent Controls	Osram Sylvania Inc.	An LED-based replacement for linear fluorescent lights that offers longer lifetime and improved steady-state system efficacy. The system will contain a high-efficiency light engine module designed to reduce cost and improve fixture-to-fixture color uniformity. The light engine, power supply, and control system will be integrated into a complete luminaire suitable for commercial production.	Reduces costs by extending system lifetime to 100,000 hours (compared with 12,000 hours for conventional linear lighting technologies). Provides high light output (luminous flux of 3200 lm) with high efficacy (92 lm/W) at a correlated color temperature of 3500 K and a color rendering index of 85.
LECD Technology for Lighting and Signage	Ecer Technologies, LLC	Electro-ceramescent technology for a variety of lighting and signage applications. These devices use layers of ceramic and phosphor materials deposited on a thin sheet of steel. The devices are durable and require very little power to operate.	Produces clear, non-glaring light with a power consumption of less than 0.2 W per square foot. Offers a product lifetime of >50,000 hours. Produces a negligibly small amount of heat and does not de-laminate over time. Provides non-glaring light in response to the dark-sky initiative.
Scaling Up: Kilo-Lumen SSL Exceeding 100 Lumens per Watt	Light Prescriptions Innovators, LLC	An efficient LED-based light bulb replacement that achieves an efficacy of 90 lm/W and a CRI >90 in a color temperature range of 2700-3100 K. The device uses a remote phosphor approach that achieves excellent color rendering. The device is dimmable and internally adjusts output to prevent damage from overheating.	Achieves 25,000 hours of operating lifetime. Improves the quality and efficacy of light using patented phosphor, thermal management, and dimming technologies. Can be used as an energy-efficient alternative to conventional incandescent and compact fluorescent lighting.

Table 3.2. Emerging Technologies Summary (*cont'd*)

Technology	Organization	Description	Benefits
LED Materials			
Automated Defect Detection, Inspection, Analysis and Yield Management for LED Manufacturing	KLA-Tencor Corporation	A yield management system that enables automated process control of the front-end LED manufacturing process (e.g., wafer substrate inspection, wafer epitaxy processing, and die fabrication). The system improves detection of yield-relevant defects such as micro-pits and micro-cracks, which reduce LED performance and reliability.	Reduces LED manufacturing costs by reducing process yield losses and improving material and time utilization. Improves the performance and durability of LED devices by reducing the number of defects in LED wafers. Can be used on a variety of semiconductor materials and wafer substrates, sizes, and types.
Bulk GaN Substrate Growth Technique	Sandia National Laboratories	A cost effective approach using electrochemical solution growth to produce bulk GaN substrates. The process is scalable and produces high quality bulk GaN materials compatible with current wafer substrate manufacturing processes.	Uses proven concepts from existing crystal growth applications. Produces GaN boules of industry-desired diameters for wafer substrates. Produces many different types of solid-state devices across multiple markets.
Enhancing Quantum Efficiency of InGaN-Based LEDs	Lehigh University - Packard Laboratory	Lattice structure improvements such as staggered InGaN quantum wells to increase the internal quantum efficiency of nitride LEDs.	Increases the output power, efficiency, and lifetime of InGaN-based LEDs.
Growth Technique for Large-Diameter AlN Single Crystal	Fairfield Crystal Technology, LLC	AlN substrate growth process for the fabrication of highly efficient LEDs. The process produces substrates that result in device epitaxy with fewer defects, which improves LED device performance and durability.	Produces substrates with fewer defects, which improves device yield. Improves product lifetime and device performance.
Heterointerfaces for High-Power LEDs	U.S. Army Research Laboratory	Improvements to the device structure of group III-nitride LEDs that increase the internal quantum efficiency, efficacy, and durability of LEDs.	Reduces LED efficiency droop at high current densities by 85% compared with conventional LED devices. Improves LED efficacy, which reduces the energy consumed by solid-state lighting products.
High-Efficiency, Nanocomposite White Light Phosphors	Nanosys, Inc.	Remote phosphors based on quantum dot technology to improve the efficiency and color of SSL products. Remote phosphors can be tuned to specific wavelengths and incorporated into existing manufacturing processes.	Provides color stability and improved lifetime, efficiency, and color rendering. Can be easily modified to produce products for different applications.
High-Efficiency Nitride-Based Solid-State Lighting	University of California, Santa Barbara	The use of bulk, non-polar GaN substrates in the LED fabrication process to reduce the occurrence of defects. The neutral polarity of the substrates reduces "LED efficiency droop" at high current density.	Improves internal and external light extraction efficiencies of LEDs. Reduces wavelength shift to below 2 nm when current is increased from 50 to 300 mA.
High-Efficiency, Non-Polar, GaN-Based LEDs	Inlustra Technologies, Inc.	GaN devices using native GaN substrates to manipulate the crystalline structure and minimize the number of defects. This approach promotes higher electrical-to-optical efficiency at increased drive current to produce more light per LED.	Reduces the cost of producing GaN-based devices by using shorter layer deposition times and simplified fabrication schemes. Improves LED efficacy, durability, and lifetime.
High-Performance Green LEDs	Rensselaer Polytechnic Institute	A high-efficiency green AlGaInN LED using high-quality bulk GaN. The epitaxial process controls material properties like piezoelectric polarization to improve device quality and performance, especially at high injection currents.	Increases LED energy efficiency by directly emitting desired wavelengths, thereby eliminating the phosphor-excitation losses of conventional LEDs. Maintains a color-stable emission wavelength that is independent of operating current.

Table 3.2. Emerging Technologies Summary (*cont'd*)

Technology	Organization	Description	Benefits
LED Materials (*cont'd*)			
High-Performance Structured OLEDs and LEDs	Lawrence Berkeley National Laboratory	A technique using micro- and nano-structured processes for improved OLED light extraction efficiency and high-quality crystalline structures for OLEDs and LEDs. The processes use materials that are less reactive, insensitive to air or water, and much easier to use in manufacturing.	Improves the lifetime and performance of solid-state lighting products. Simplifies manufacturing by using imprint-based fabrication and vapor deposition steps.
Key Technologies for White Lighting Based on LEDs: Precise Temperature Measurement	Sandia National Laboratories	An ultraviolet pyrometer that measures process temperature and provides epitaxy temperature control that was previously not possible.	Reduces LED fabrication costs by improving production control and yield. Allows specific InGaN device parameters (e.g., emission wavelength) to be targeted.
Low-Cost, Highly Lambertian Reflector Composite for Improved LED Fixture Efficiency and Lifetime	WhiteOptics, LLC	A polymer microfiber with highly effective light scattering and reflective properties. The material maximizes visible light reflection and can be used effectively in SSL systems to increase optical efficiency and reduce glare and "hot spots" from individual LEDs.	Provides diffuse light from LED luminaires with 97% reflectance. Improves luminaire optical efficiency by 15%-20% compared with existing finishes. Reduces overall system cost by reducing the number of LEDs needed for uniform light output.
Low-Cost Illumination-Grade LEDs	Philips Lumileds Lighting Company	Processes and techniques that reduce epitaxy manufacturing costs for illumination-grade, high-power LEDs. In part, costs will be reduced by using epitaxial deposition of GaN on silicon (Si) substrates. Replacing standard (75 mm diameter) sapphire substrates with larger (150 mm diameter) silicon substrates will enable a higher yielding epitaxy process. Higher yields are obtained from the superior material quality of silicon substrates, including improved thermal conductivity.	Reduces the epitaxy manufacturing costs of illumination-grade LEDs, thereby enabling faster market adoption of solid-state lighting technologies that will reduce U.S. lighting energy consumption. Optimizes epitaxy process parameters, leading to consistent device characteristics and performance.
Low-Cost Lithography for High-Brightness LED Manufacturing	Ultratech, Inc.	An automated lithography tool that enables low-cost, high-yield manufacturing of high-brightness LEDs. The projection-based lithography system aims to reduce lithography costs by 50% using an LED-based illuminator, auto-focusing light source, automated material handling, and process control. These features combine to increase throughput and decrease operation and maintenance costs.	Reduces the lithography costs associated with high-brightness LED manufacturing, thereby enabling faster adoption of energy-saving solid-state lighting technologies. Reduces lithography alignment errors and contamination, resulting in improved device durability and performance.
Nanowire-Templated Lateral Epitaxy of Low-Dislocation-Density GaN	Sandia National Laboratories	An innovative and inexpensive GaN crystal growth technique for fabricating LEDs. The process uses GaN nanowires to grow high-quality, low-defect GaN films on sapphire substrates. Lower defects in GaN improve LED device durability, reliability, and efficiency, which are needed for widespread adoption of SSL.	Provides a single-step process with reduced cost and complexity compared with other defect reduction methods. Low defect density improves device quality, leading to increased device output and lifetime.

Table 3.2. Emerging Technologies Summary (*cont'd*)

Technology	Organization	Description	Benefits
LED Materials (*cont'd*)			
Nitride- and Oxynitride-Based Phosphors for Solid-State Lighting	Lightscape Materials, Inc.	Nitride- (red) and oxynitride- (green) based phosphor materials for solid-state lighting applications. These materials offer improved quantum yield, thermal stability, and lumen maintenance, along with reduced internal scattering losses. The enhanced phosphors improve LED product quality and provide a wide range of lighting capabilities/options, enabling more opportunities for lighting designers to use SSL. A commercially viable preparation process for mass producing the enhanced phosphor materials is also being developed.	Increases LED product quality through improved lumen output, stability, durability, and increased quality of light. Achieves quantum yield of ≥90%, approaching DOE's 2020 target of 95%. Provides reduced thermal quenching of <10% at 300°F, exceeding DOE's 2020 target of 10%. Achieves a lumen maintenance of <10% loss after 5,000 hours at 185°F and 85% relative humidity.
Optimized Phosphors for Warm-White LEDs	GE Global Research	Phosphor materials that reduce the efficacy losses encountered when producing low CCT (warm white light) and high CRI LEDs. The phosphor synthesis processing has been modified to remove the fine particles that disproportionately back-scatter light into the LED light engine.	Optimizes LED system efficacy using high-efficiency phosphor down conversion. Produces white light with a CCT of 2700-3200 K, an efficacy of >100 lm/W, and a CRI >90.
Phosphor-Free Solid-State Lighting Sources	Cermet Inc.	A phosphor-free approach using blue LEDs and red, green and blue dopants for producing white light. This approach improves durability, efficacy, and color temperature.	Reduces fabrication cost of white LEDs by combining multiple processes into one step. Uses typical substrate growth techniques for LED epitaxy.
Photoluminescent Nanofibers for High-Efficiency Solid-State Lighting Phosphors	Research Triangle Institute International	Polymer nanofibers for use in optical diffusers and photoluminescent materials to improve LED light output. The materials can be adjusted to provide the desired light output with a color rendering index of 90 and an efficacy in excess of 55 lm/W.	Provides a cost-effective solution for diffuse, high-reflectance light management across the visible spectrum. Can be used in various geometries imposed by light fixtures, thus enabling new approaches to lighting designs.
Wafer Fabrication System for Decreasing High-Brightness LED Costs	Veeco Instruments Inc.	A wafer fabrication process that reduces the cost associated with the epitaxial growth of GaN-based LEDs. The process uses advanced metal-organic chemical vapor deposition (MOCVD) techniques.	Reduces the overall manufacturing cost of LEDs by reducing the cost of ownership of MOCVD systems. Reduces scrap by 50% and increases throughput of the MOCVD process.
OLEDs			
CCT-Tunable Phosphorescent OLED Luminaires for Energy Savings	Universal Display Corporation	Large-area phosphorescent OLED lighting panels that can be tuned to a specific correlated color temperature (CCT) and are very efficient at converting electrical energy to light. The materials may be coated on glass, flexible plastic, or metal foil substrates using thermal evaporation. The process is easily scalable to large-area manufacturing.	Provides an energy-efficient light source capable of >150 lm/W efficacy with high quality, no glare, and CCT-tunable output. Operates at a lower temperature compared with other light sources, eliminating the need for expensive heat sinking. Can be manufactured using relatively simple coating processes on flexible substrates.
Efficient Large-Area WOLED Lighting	Universal Display Corporation	White organic LEDs (WOLEDs) for large-area illumination. WOLEDs are energy-efficient, diffuse light sources. WOLED panels are also transparent in the off state, allowing integration into daylight harvesting schemes.	Reduces operating costs relative to conventional lighting. Can be fabricated on flexible substrates, including glass, plastics, and thin stainless steel.

Table 3.2. Emerging Technologies Summary (*cont'd*)

Technology	Organization	Description	Benefits
OLEDs (*cont'd*)			
Low-Cost Integrated Substrate for OLED Lighting	PPG Industries, Inc.	A large-area, coated float glass substrate for OLEDs that reduces OLED costs by using alternative materials. Cost-saving measures include the replacement of borosilicate substrate with float glass, the development of low-cost alternatives to indium tin oxide (ITO) anodes, and the use of improved light extraction layer technologies.	Can be used to increase the cost competitiveness of OLED lighting technologies compared with conventional lighting sources. Achieves similar performance to expensive ITO-anode-coated substrates and up to 2 times the light extraction compared with conventional light extraction techniques.
OLEDs for General Lighting	GE Global Research	Energy-efficient OLEDs that can be manufactured on flexible substrates using low-cost printing techniques. Flexible OLEDs could be used for portable roll-displays or displays with curved surfaces.	Offers low-cost manufacturing using high-volume, roll-to-roll manufacturing. Can be used in applications that would not be feasible with traditional light sources. Provides compatibility with a variety of substrates such as plastic, glass, and thin metal foil.
Stable Materials for High-Efficiency Blue OLEDs	Pacific Northwest National Laboratory	New hole transport materials (HTMs) and host materials (HMs) that are compatible with blue phosphorescent devices. These new materials have triplet energies higher than that of the phosphor dopant, which is known to reduce luminescence quenching (nonradiative transition), maximize efficiency, and provide charge transport properties analogous to state-of-the art HTMs.	Improves the stability and efficiency of OLEDs at currents useful for solid-state lighting products. Reduces energy consumption in OLED lighting applications and improves OLED durability.
Transparent Conducting Oxides and Undercoat Technologies for Economical OLED Lighting	Arkema Inc.	A zinc-based transparent conductive material and an atmospheric pressure chemical vapor deposition process for processing OLED glass substrates. The substrates can be used as an alternative to indium-tin-oxide (ITO) coated glass substrates.	Achieves >90% transmission in the visible spectrum. Offers material and performance specifications equivalent to commercially available ITO.
Transparent Conductive Oxides for OLEDs	Pacific Northwest National Laboratory	A low-temperature RF magnetron sputtering process to deposit indium-free, gallium-zinc-oxide (GZO) thin films to replace costly indium-tin-oxide. GZO is suitable for glass or flexible substrates, and the deposition process is scalable to large-area high-volume manufacturing.	Reduces costs by replacing indium with more abundant materials. Reduces energy consumed for lighting applications by increasing OLED efficiency. Enables high-volume manufacturing on flexible substrates.
Ultra-High-Efficiency 80-lm/W Phosphorescent White OLED (WOLED) Lighting Panel	Universal Display Corporation	An energy-efficient, large-area phosphorescent white OLED panel that can replace traditional light sources in general illumination applications.	Provides a diffuse, energy-efficient source of white light with a long product lifetime (30,000 hours at 3,000 lm/m^2). Can be manufactured at low cost on flexible metal and plastic substrates.
Other Lighting			
Advanced Coatings to Improve the Efficiency, Color Rendering, and Life of High-Intensity-Discharge Lamps	Acree Technologies Inc.	An inexpensive, robust, single-layer coating for increasing efficacy. The coating increases the plasma temperature, thus increasing lumen output and color rendering index. The coating is applied in a single step and is compatible with large-scale production.	Improves lamp efficacy, significantly reducing lighting cost and energy consumption. Provides a robust coating that lasts throughout the lifetime of the HID lamp. Improves light output and color rendering index of the lamp.

Table 3.2. Emerging Technologies Summary (*cont'd*)

Technology	Organization	Description	Benefits
Other Lighting (*cont'd*)			
Arc Tube Coating System for Color Consistency	Energy Focus, Inc.	An automated, production-oriented, lamp color modification system for metal halide lamps. The system will reduce lamp color variation to that of current market-accepted tungsten-halogen lamps. A lamp's spectral output is modified by applying a thin film organometallic coating. A color correction algorithm has been developed that measures the lamp's spectral output and then calculates the exact coating composition to be applied to achieve the desired lamp color.	Improves the quality of light output from metal halide lamps. Provides lamp-to-lamp color consistency by individually tailoring each lamp's color enhancement coating. Improves lamp durability (lifetime of >15,000 hours).
Water Heating			
Accurate Feed-Forward Temperature Control for Tankless Water Heaters	Building Solutions, Inc.	A new algorithm that improves temperature control in tankless water heaters by incorporating feed-forward control.	Improves the ability of tankless water heaters to maintain a specified outlet temperature and to quickly respond to changing flowrates.
CO_2 Heat Pump Water Heater	Oak Ridge National Laboratory	A CO_2-based heat pump water heater (HPWH) that is an environmentally friendly alternative to units that use hydrofluorocarbon (HFC) refrigerants. The technology can supply hot water at ≥135°F (a common setpoint used by residential consumers) without the use of resistive heating elements.	Improves HPWH capacity and efficiency at lower ambient temperatures and offers faster water heater recovery and a higher first hour rating. Uses a refrigerant with a low global warming potential (GWP).
Gas-Fired Residential Heat Pump Water Heater	Stone Mountain Technologies, Inc.	A natural-gas-fired heat pump water heater that uses an ammonia-water absorption cycle. The unit will have a water heating capacity of about 10,000 Btu/hr (3 kW) and a 60-80 gallon storage tank. Several high-efficiency heat exchanger technologies will be tested in single-effect and GAX (generator-absorber heat exchange) absorption cycles to determine the most cost-effective design.	Brings the inherent efficiency of a heat pump (i.e., moving heat instead of generating it directly) to the gas water heater market, enabling gas water heating with an energy factor of 1.5. Reduces natural gas consumption by ≥50% compared with conventional gas storage and tankless gas water heaters. Reduces primary energy consumption by avoiding the power plant conversion losses associated with electricity generation.
High-Efficiency CO_2 Heat Pump Water Heater for Commercial Applications	Creative Thermal Solutions, Inc.	A CO_2 heat pump water heater for commercial sector applications that have a simultaneous need for hot water and space cooling. The unit will provide 120,000 Btu/h (35 kW) of water heating and produce a simultaneous space cooling effect of 85,000 Btu/h (25 kW). The unit can provide high exit water temperatures (up to 180°F/82°C) without the use of electric resistance heaters (which are necessary when using conventional R-134a refrigerant).	Reduces energy consumption by providing simultaneous water heating and space cooling. Uses a low global warming potential (GWP) refrigerant. Reduces system footprint compared with R-134a HPWHs because of the high volumetric heating/cooling capacity of CO_2.
High-Performance Absorption Water Heater	Oak Ridge National Laboratory	An absorption water heater designed as a drop-in replacement for conventional gas storage water heaters. The technology enables gas-fired water heating with an energy factor of >1.0 and does not require any infrastructure modifications.	Improves the efficiency of natural gas water heating, thereby reducing water heating bills.

Table 3.2. Emerging Technologies Summary (*cont'd*)

Technology	Organization	Description	Benefits
Water Heating (*cont'd*)			
ZigBee Open Standard Wireless Controller for Water Heaters	Emerson Electric Company	A ZigBee open-standard-based wireless controller for controlling and integrating water heaters into a residential "smart energy" home area network. The network enables communication between utility companies and household appliances.	Manages water heater electricity consumption in response to signals from the electrical grid. Reduces power to the heater during times of peak electrical demand in order to prevent brownouts and blackouts. Can result in cost savings if time-of-use electricity rates are offered to residential customers by the local utility company.
Windows			
Adaptive Liquid Crystal Windows	AlphaMicron, Inc.	An active window glazing technology using liquid crystal deposited on flexible substrates. The process is compatible with high-volume roll-to-roll manufacturing.	Manipulates daylight transmission without excessive glare or darkness. Reduces emissions by lowering building energy consumption. Adapts to residential and commercial applications.
High-Rate Coating Technology for Low-Cost Electrochromic Dynamic Windows	Applied Materials, Inc.	A high-throughput process for manufacturing electrochromic (EC) windows. The technology provides high deposition rates for lithium and lithium phosphorous oxynitride (LiPON), two key EC materials.	Reduces the cost of EC windows, thereby encouraging the widespread adoption of energy-saving EC window products in commercial and residential buildings.
Low-Cost, High-Energy-Savings, Solid-State Dynamic Glass	Soladigm, Inc.	Dynamic, electrochromic glass technology, which is formed as a multi-layer coating stack applied to the inner surface of the outer pane of glass in a double-pane insulated glass unit (IGU). The glass can be tinted by applying a DC voltage of <3 volts; reversing the applied voltage causes the glass to become clear. The coating enables the window's solar heat gain coefficient to be tuned in real-time from 0.09 to 0.48, with visible light transmission from 4%-62%.	Controls the transmission of visible light and heat through windows, thereby reducing HVAC and lighting energy consumption. Reduces direct sunlight glare and provides unobstructed views to the outdoors, which improves occupant comfort.
Vacuum Glazing Development	EverSealed Windows, Inc.	A window frame sealing technology that provides a longer-lasting vacuum insulated glass window. The technique uses a gas-tight flexible metal seal that accommodates thermal expansion and contraction with a proprietary glass-to-metal bonding material.	Increases window lifetime by using a flexible, hermetically bonded seal. Reduces energy loss through windows. Provides compatibility with various glass types as required by city or county building codes.

Appendix A:
Technology Tracking Lists

Technology Tracking Lists A-2

Commercially Available Technologies

	Technology Title	Organization
Building Controls		
Envelope	Next-Generation Envelope Materials	Oak Ridge National Laboratory
	ThermaDeck: An Insulated and Ventilated Roof System	Billy Ellis Roofing, LLC
HVAC&R	Echo™: A Hybrid Solar Electric/Thermal System	EchoFirst, Inc.
	NextAire™ Packaged Gas Heat Pump	IntelliChoice Energy
	Quiet Climate 2: Efficient Heat Pump for Classrooms	Bard Manufacturing Company, Inc.
LED Devices	Efficient LED System-in-Module for General Lighting	Philips Lighting
	High-Efficiency LED Lamp for Solid-State Lighting	Cree, Inc.
	Integrated, Solid-State LED Luminaire for General Lighting	Philips Color Kinetics
	LUXEON® A and LUXEON® S: Warm White Illumination-Grade LEDs	Philips Lumileds Lighting Company
LED Materials		
OLEDs		
Other Lighting	Adapting Wireless Technology for Lighting Control	ELB Electronics, Inc.
	Ballast/Driver Technology for Metal Halide or Solid-State Lighting Systems	Energy Focus, Inc.
	Lighting Power and Control Network for SSL Systems	Redwood Systems, Inc.
	Optical Performance-Enhancing Material for Lighting Applications	Luminit, LLC
Water Heating	GeoSpring™ Hybrid Water Heater	General Electric Company
	Vertex™ Residential Gas Condensing Water Heater	A. O. Smith Corporation
Windows	ATLAS™: An Energy-Efficient Triple IG Window Manufacturing System	GED Integrated Solutions, Inc.
	EnerLogic®: Low-Emissivity, Energy-Control Retrofit Window Film	Solutia Inc.
	OptiQ™: An Advanced Commercial Window Technology	Traco, a division of Kawneer Company, Inc.
	SageGlass® Electrochromic Windows	SAGE Electrochromics, Inc.
	Suntuitive™: Sunlight-Responsive Thermochromic Window Systems	Pleotint, LLC

Emerging Technologies

	Technology Title	Organization
Building Controls	Advanced Load Identification and Management for Buildings	Eaton Corporation
	Integrated Predictive Demand Response Control for Commercial Buildings	Johnson Controls, Inc.
	Plug-and-Play Distributed Power Systems for Smart-Grid-Connected Buildings	United Technologies Corporation
	Predictive Optimal Control of Active and Passive Building Thermal Storage Inventory	Clean Urban Energy, Inc.
Envelope	Advanced Building Insulation by Carbon Dioxide Foaming Process	Industrial Science & Technology Network, Inc.
	Energy-Efficient EIFS Wall Systems	Dow Corning Corporation
	Exterior Insulation and Finish System (EIFS)	EIFS Industry Members Association
	Insulating Form System for Concrete Foundation Edges	Davis Energy Group, Inc.
	Low-Cost Phase Change Materials For Building Envelopes	Syntroleum Corporation
	Nano-Enabled TiO_2 UV Protective Layer for Cool-Color Roofing Application	Nanotrons Corporation
	Reflective Elastomeric Roof Coating	Oak Ridge National Laboratory
	Shape-Stable and Highly Conductive Nano-Phase Change Materials	Technova Corporation
	Three-Dimensional Building Energy Performance Measurement and Modeling System	University of Nebraska - Lincoln
HVAC&R	Advanced Sequential Dual Evaporator Cycle for Refrigerators	Whirlpool Corporation
	Air Bearing Heat Exchanger	Sandia National Laboratories
	Air-Source Integrated Heat Pump	Oak Ridge National Laboratory
	Ammonia Absorption Technologies for HVAC Systems	Rocky Research
	Bernoulli Principle Air Conditioning and Cooling System	Machflow Energy, Inc.
	Cold Climate Multi-Stage Heat Pump	Oak Ridge National Laboratory
	Comboflair®: An Integrated HVAC and Water Heating System	DeLima Associates
	Energy-Efficient Façades for Green Buildings	Rensselaer Polytechnic Institute - CASE
	Ground-Source Integrated Heat Pump	Oak Ridge National Laboratory
	HyPak: A High-Efficiency Rooftop Packaged HVAC System	Davis Energy Group, Inc.
	Improving Efficiency of Fuel-Fired Furnaces for Space and Water Heating Systems	Oak Ridge National Laboratory
	Improving Electric Motor Efficiency	SMMA - The Motor & Motion Association
	Multi-Zone HVAC Options for Residential Applications	Oak Ridge National Laboratory
	Nanographitic Additive for Enhanced Heat Transfer and Lubricity of Refrigerant Systems	Oak Ridge National Laboratory
	Next-Generation Refrigerant Lubricants	Chemtura Corporation
	Residential Fuel-Fired, Multifunction Heat Pump	Oak Ridge National Laboratory
	Thermoelectric Materials for Waste Heat Recovery	Hi-Z Technology, Inc.
	Water-Based, Critical Flow, Non-Vapor-Compression Cooling System	Caitin, Inc.
	Wireless Remote Monitoring System for Residential Air Conditioners and Heat Pumps	Mainstream Engineering Corporation
LED Devices	Advanced Manufacturing Methods for Warm-White LEDs for General Lighting	GE Lighting Solutions, LLC
	Affordable, High-Efficiency Solid-State Downlight Luminaires with Novel Cooling	GE Global Research
	Epitaxy Tools for Manufacturing Light-Emitting Diode Devices	Applied Materials, Inc.
	High Flux Commercial Illumination Solution with Intelligent Controls	Osram Sylvania Inc.
	LECD Technology for Lighting and Signage	Ecer Technologies, LLC
	Scaling Up: Kilo-Lumen SSL Exceeding 100 Lumens per Watt	Light Prescriptions Innovators, LLC

Emerging Technologies *(cont'd)*

	Technology Title	Organization
LED Materials	Automated Defect Detection, Inspection, Analysis and Yield Management for LED Manufacturing	KLA-Tencor Corporation
	Bulk GaN Substrate Growth Technique	Sandia National Laboratories
	Enhancing Quantum Efficiency of InGaN-Based LEDs	Lehigh University -Packard Laboratory
	Growth Technique for Large-Diameter AIN Single Crystal	Fairfield Crystal Technology, LLC
	Heterointerfaces for High-Power LEDs	US Army Research Laboratory
	High-Efficiency, Nanocomposite White Light Phosphors	Nanosys, Inc.
	High-Efficiency Nitride-Based Solid-State Lighting	University of California, Santa Barbara
	High-Efficiency, Non-Polar, GaN-Based LEDs	Inlustra Technologies, Inc.
	High-Performance Green LEDs	Rensselaer Polytechnic Institute
	High-Performance Structured OLEDs and LEDs	Lawrence Berkeley National Laboratory
	Key Technologies for White Lighting Based on LEDs: Precise Temperature Measurement	Sandia National Laboratories
	Low-Cost, Highly Lambertian Reflector Composite for Improved LED Fixture Efficiency and Lifetime	WhiteOptics, LLC
	Low-Cost Illumination-Grade LEDs	Philips Lumileds Lighting Company
	Low-Cost Lithography for High-Brightness LED Manufacturing	Ultratech, Inc.
	Nanowire-Templated Lateral Epitaxy of Low-Dislocation-Density GaN	Sandia National Laboratories
	Nitride- and Oxynitride-Based Phosphors for Solid-State Lighting	Lightscape Materials, Inc.
	Optimized Phosphors for Warm-White LEDs	GE Global Research
	Phosphor-Free Solid-State Lighting Sources	Cermet Inc.
	Photoluminescent Nanofibers for High-Efficiency Solid-State Lighting Phosphors	Research Triangle Institute International
	Wafer Fabrication System for Decreasing High-Brightness LED Costs	Veeco Instruments Inc.
OLEDs	CCT-Tunable Phosphorescent OLED Luminaires for Energy Savings	Universal Display Corporation
	Efficient Large-Area WOLED Lighting	Universal Display Corporation
	Low-Cost Integrated Substrate for OLED Lighting	PPG Industries, Inc.
	OLEDs for General Lighting	GE Global Research
	Stable Materials for High-Efficiency Blue OLEDs	Pacific Northwest National Laboratory
	Transparent Conducting Oxides and Undercoat Technologies for Economical OLED Lighting	Arkema Inc.
	Transparent Conductive Oxides for OLEDs	Pacific Northwest National Laboratory
	Ultra-High-Efficiency 80-lm/W Phosphorescent White OLED (WOLED) Lighting Panel	Universal Display Corporation
Other Lighting	Advanced Coatings to Improve the Efficiency, Color Rendering, and Life of High-Intensity-Discharge Lamps	Acree Technologies Inc.
	Arc Tube Coating System for Color Consistency	Energy Focus, Inc.
Water Heating	Accurate Feed-Forward Temperature Control for Tankless Water Heaters	Building Solutions, Inc.
	CO_2 Heat Pump Water Heater	Oak Ridge National Laboratory
	Gas-Fired Residential Heat Pump Water Heater	Stone Mountain Technologies, Inc.
	High-Efficiency CO_2 Heat Pump Water Heater for Commercial Applications	Creative Thermal Solutions, Inc.
	High-Performance Absorption Water Heater	Oak Ridge National Laboratory
	ZigBee Open Standard Wireless Controller for Water Heaters	Emerson Electric Company
Windows	Adaptive Liquid Crystal Windows	AlphaMicron, Inc.
	High-Rate Coating Technology for Low-Cost Electrochromic Dynamic Windows	Applied Materials, Inc.
	Low-Cost, High-Energy-Savings, Solid-State Dynamic Glass	Soladigm, Inc.
	Vacuum Glazing Development	EverSealed Windows, Inc.

Potential Technologies

	Technology Title	Organization
Building Controls	Advanced, Integrated Control for Building Operations to Achieve 40% Energy Savings	Siemens Corporate Research
	Building-Level Energy Management Systems (BLEMS)	University of Southern California
	Context Aware Smart Home Energy Manager (CASHEM)	Honeywell International, Inc.
	Converging Redundant Sensor Network Information for Improved Building Control	University of Nebraska, Lincoln
	Distributed Intelligent Automated Demand Response (DIADR) Building Management System	Siemens Corporate Research
	Energy Efficient and Comfortable Buildings through Multivariate Integrated Control (ECoMIC)	Philips Electronics North America Corporation
	Wireless Infrastructure for Performance Monitoring, Diagnostics, and Control in Small Commercial Buildings	NorthWrite, Inc.
Envelope	Advanced Building Envelope Surface Materials	Lawrence Berkeley National Laboratory
	Advanced Energy Efficient Roof Systems	University of Minnesota
	Advanced Engineered Manufacturing Methods & Materials for Environmentally Benign and Energy Efficient Housing	Institute for Advanced Learning and Research
	Advanced Insulation for High-Performance, Cost-Effective Wall, Roof and Foundation Systems	Dow Chemical Company
	Advanced Wall Systems	Oak Ridge National Laboratory
	Air Barriers	Oak Ridge National Laboratory
	Bio-Based Thermochromic Intelligent Roof Coating	United Environment & Energy, LLC
HVAC and Refrigeration	Adaptive Full-Spectrum Solar Energy Systems	University of Nevada, Reno
	Advanced Efficient Building Testbed Initiative	Carnegie Mellon University
	Advanced Magnetic Refrigerant Materials	General Electric Company
	Clean Technology Commercialization Initiative (PA)	Ben Franklin Technology Partners
	Development of a High Performance Cold Climate Heat Pump	Purdue University
	Energy Efficient Commercial Refrigeration with Carbon Dioxide Refrigerant and Scroll Expanders	TIAX, LLC
	Evaluation of Magnetocaloric Refrigeration Cycles for Commercial HVAC	Oak Ridge National Laboratory
	Heat Pump R&D	Oak Ridge National Laboratory
	High Technology Centrifugal Compressor for Commercial Air Conditioning Systems	State of Connecticut
	Magnetic Refrigeration Technology	Astronautics Corporation of America
	Natural Refrigerant Very-High Efficiency HVAC System	United Technologies Research Center
	Phase Change Thermal Energy Storage for Residential Units	Mainstream Engineering Corporation
	R&D on Low Global Warming Refrigerants (2 CRADAs)	Oak Ridge National Laboratory
	Solar Electric/Thermal Pathways to ZEH-NREL	National Renewable Energy Laboratory
	Solar Heating and Cooling for ZEH-Sandia	Sandia National Laboratories
	Unconventional Air Conditioning and Refrigeration System Based on Giant Electrocaloric Effect in Polar-Fluoropolymers	Strategic Polymer Sciences, Inc.
LED Devices	Efficient White SSL Component for General Illumination	Cree, Inc.
	Highly Efficient Small Form-Factor LED Retrofit Lamp	Osram Sylvania Products Inc.
LED Materials	Advanced Phosphor Technology For Efficient Lighting & Energy Harvesting	PhosphorTech Corporation
	Blue/UV LEDs with Very High Photon Conversion and Extraction Efficiency for White Lighting	Boston University
	Charge Balance in Blue Electrophosphorescent Devices	Pacific Northwest National Laboratory
	Development of High Efficiency m-Plane LEDs on Low Defect Density Bulk GaN Substrates	Soraa, Inc.
	Epitaxial Growth of GaN Based LED Structures on Sacrificial Substrates	Georgia Tech Research Corporation
	Fundamental Studies of Higher Efficiency III-N LEDs for High-Efficiency High-Power Solid-State Lighting	Georgia Institute of Technology
	GaN-Ready Aluminum Nitride Substrates for Cost-Effective, Very Low Dislocation Density III-Nitride LEDs	Crystal IS, Inc.
	High Efficiency Colloidal Quantum Dot Phosphors	Eastman Kodak Company
	High Efficiency m-Plane LEDs on Low Defect Density Bulk GaN Substrates	Kaai, Inc.
	High Extraction Luminescent Materials for Solid State Lighting	PhosphorTech Corporation
	Lattice Mismatched GaInP Alloys for Color Mixing White Light LEDs	National Renewable Energy Laboratory
	Low-Cost Substrates for High-Performance Nanorod Array LEDs	Purdue University
	Multicolor, High Efficiency, Nanotextured LEDs	Yale University
	Nanostructured High Performance Ultraviolet and Blue LEDs	Brown University
	Novel Defect Spectroscopy of InGaN Materials for Improved Green LEDs	Sandia National Laboratories
	Phosphor Systems for Illumination Quality Solid State Lighting Products	GE Global Research

Potential Technologies (*cont'd*)

	Technology Title	Organization
LED Materials Cont'd	Phosphors for Near UV-Emitting LEDs for Efficacious Generation of White Light	University of California, San Diego
	Semi-polar GaN Materials Technology for High IQE Green LEDs	Sandia National Laboratories
	Ultra High P-Doping Material Research for GaN-Based Light Emitters	Technologies and Devices International, Inc.
	White LEDs Using Nanophosphor-InP Blends	Sandia National Laboratories
	White-Light Emitting Active Layers in Nitride Based Heterostructures for Phosphorless SSL	University of California, San Diego
OLEDs	Development and Utilization of Host Materials for White Phosphorescent Organic Light-emitting Diodes	University of Rochester
	High Efficiency, Illumination Quality White OLEDs for Lighting	GE Global Research
	High Efficiency Microcavity OLED Devices With Down-Conversion Phosphors	University of Florida
	High Quantum Efficiency OLED Lighting Systems	GE Global Research
	High Stability Organic Molecular Dopants for Maximum Power Efficiency OLEDs	Pacific Northwest National Laboratory
	Long-Term OLED Device Stability via Transmission Electron Microscopy Imaging of Cross-Sectioned OLED Devices	Lawrence Berkeley National Laboratory
	Low-Cost Nano-Engineered Transparent Electrodes for Highly Efficient OLED Lighting	Oak Ridge National Laboratory
	Multi-Faceted Scientific Strategies Towards Better Solid-State Lighting of Phosphorescent OLEDs Phosphors	University of North Texas
	New Stable Cathode Materials for OLEDs	International Technology Exchange
	Novel Materials for High Efficiency White Phosphorescent OLEDs	University of Southern California
	Quantum Dot Light Enhancement Substrate for OLED Solid-State Lighting	QD Vision, Inc.
	Roll-to-Roll Solution-Processible Small-Molecule OLEDS	GE Global Research
	Solution Processable Transparent Conductive Hole Injection Electrode for OLED SSL	Cambrios Technologies Corporation
	Solution-Processed Small-Molecule OLED Luminaire for Interior Illumination	DuPont Displays, Inc.
	Surface Plasmon Enhanced Phosphorescent Organic Light Emitting Diodes	University of California, Santa Barbara
	Top-Emitting White OLEDs with Ultrahigh Light Extraction Efficiency	University of Florida
	Transparent Conductive Oxide for OLEDs	National Renewable Energy Laboratory
Other Lighting	High Efficiency Driving Electronics for General Illumination LED Luminaires	Philips Lighting
	High Quality Down Lighting Luminaire with 73% Overall System Efficiency	Osram Sylvania Products Inc.
	Light Emitting Diode Display Engineering	University of Nevada, Las Vegas
	Lighting with No Watt Left Behind	NEMOmetrics Corporation
	Novel Low-Cost Technology for Solid-State Lighting	Technologies and Devices International, Inc.
	SSL Luminaire with Novel Driver Architecture	Cree, Inc.
	Ultra-Compact High Efficiency Luminaire for General Illumination	Cree, Inc.
Water Heating and Appliances	Next Generation Clothes Dryer	Porticos, Inc.
	Systems Approach to an Energy Efficient Laundry Process	GE Global Research
Windows	Affordable Window Insulation With R-10/inch Rating	Aspen Aerogels, Inc.
	Electrochromic Coating Technology	Soladigm, Inc.
	Highly Insulating Windows With a U-Value Less Than 0.6	Aspen Aerogels, Inc.
	Low-Cost Krypton Extraction for use in Window IGUs	Lawrence Berkeley National Laboratory
	Low-Cost R10/High SHGC Heat Mirror® Window Development	Southwall Technologies, Inc.
	Polymeric Multilayer Infrared Reflecting Film Development	3M Company
	Solar Energy Windows and Smart IR Switchable Building Technologies	PPG Industries Inc.

Appendix B:
Technology Tracking Data Collection Template

Technology Tracking Data Collection Template B-2

Commercially Available or Emerging Technology Title

Short Phrase Describing the Technology's Primary Benefits and/or Achievements	**Primary Industry:**

Technology History:

- Who is developing the technology, and any key project partners.
- If applicable, who is selling the technology and the year it became commercially available.
- Current focus/direction of technology development.

Applications:
One or two sentences about where the technology will be used an what the impact of its use will be.

Capabilities:
Short phrases describing the technology's performance, preferably in a quantitative manner.

- Produces…
- Achieves…
- Saves…

Graphic:

Photo of the technology or graphic showing the process performed by the technology.

Description:
This section tells the story of how the technology fills a need, and typically contains three paragraphs of about 100 words each.

The first paragraph describes the situation before the technology. The second paragraph describes how the technology works and how it solves or improves upon the prior situation.

The third paragraph is typically used for additional description of the technology and its advantages, and usually ends with a mention of the project's future direction. For example: "advanced prototypes have been developed and a demonstration unit will be evaluated."

Benefits:
Two or three headings describing additional benefits of the technology, with a short phrase under each. Can be quantitative or qualitative in nature. Examples:

Cost Savings
Reduces costs by taking advantage of…

Durability
Improves product lifetime…

Efficiency
Optimizes the process by…

Emissions Reductions
Reduces emissions of…

Safety
Increases safety by detecting…

Productivity
Enables high-volume production…

Tracking Information (PNNL Internal):

Year Developed:

Year Commercialized:

Year First Tracked:

Year Stopped Tracking:

Associated Parties:

DOE Manager(s)
Contact information for DOE Program Manager(s). (PNNL Internal)

Technology Partner(s)
Contact information for the technology PI/POC, and any project partners. For commercially available products, contact info for a sales representative is also helpful.

Name of PI/POC
Organization Name
Address
Phone
Fax
E-mail
Website

Status Information (PNNL Internal):

Year:	Status:	Comments:
2010	Commercially Available or Emerging	This is a short summary of development progress in the prior calendar year, current status, and future commercialization plans.

Installations & Savings (PNNL Internal):

ID	Installation	Installed	Decommissioned	Savings
Info regarding the number of operational installations of commercially available products with energy savings.				

Description:

Also Known As:
This is an alternative name for the technology if one exists.

Technical Description:
This is an advanced technical description of the process/technology, typically containing information that is too detailed or discipline-specific to appear in the report's technology pages (Appendices C and D).

References:

Source List:
This is a listing of any additional places where information about the technology/product can be obtained, including organization websites, DOE fact sheets, conference presentations, quarterly or annual reports, etc…

Energy Savings Calculation Methodology (PNNL Internal):
For a commercially available product with quantifiable energy savings, PNNL staff work with the technology PI/POC to calculate the approximate amount of energy saved from use of the product on a per unit, per time basis. Information specific to the technology (e.g., energy consumption, fuel type, and number of units sold) is provided by the PI/POC. PNNL staff take this information and compare the technology to the currently established product(s) that it is intended to replace, and determine the per unit, per time energy savings rate.

Remarks:

History:
This is a short summary of when testing began and any major changes that have occurred over time.

General Comments:
This is a section for any additional comments that a technology PI/POC would like to make that do not fit into any other section of the template.

Markets and Economics:

Comments:
A short description of the markets an organization intends to reach with their technology, and any applicable information such as product lifetime, rebates, tax incentives, payback period, etc…

Selling Price:
For commercially available products, technology PIs/POCs can provide the approximate sale price if their organization considers it to be publicly available information.

Appendix C:
Commercially Available Technology Descriptions

C.1 Envelope Technologies C-3
- Next-Generation Envelope Materials C-4
- ThermaDeck: An Insulated and Ventilated Roof System C-5

C.2 HVAC&R C-7
- Echo™: A Hybrid Solar Electric/Thermal System C-8
- NextAire™ Packaged Gas Heat Pump C-9
- Quiet Climate 2: Efficient Heat Pump for Classrooms C-10

C.3 LED Devices C-11
- Efficient LED System-in-Module for General Lighting C-12
- High-Efficiency LED Lamp for Solid-State Lighting C-13
- Integrated, Solid-State LED Luminaire for General Lighting C-14
- LUXEON® A and LUXEON® S: Warm White Illumination-Grade LEDs C-15

C.4 Other Lighting C-17
- Adapting Wireless Technology for Lighting Control C-18
- Ballast/Driver Technology for Metal Halide or Solid-State Lighting Systems C-19
- Lighting Power and Control Network for SSL Systems C-20
- Optical Performance-Enhancing Material for Lighting Applications C-21

C.5 Water Heating C-23
- GeoSpring™ Hybrid Water Heater C-24
- Vertex™ Residential Gas Condensing Water Heater C-25

C.6 Windows Technologies C-27
- ATLAS™: An Energy-Efficient Triple IG Window Manufacturing System C-28
- EnerLogic®: Low-Emissivity, Energy-Control Retrofit Window Film C-29
- OptiQ™: An Advanced Commercial Window Technology C-30
- SageGlass® Electrochromic Windows C-31
- Suntuitive™: Sunlight-Responsive Thermochromic Window Systems C-32

C.1 Envelope Technologies

- Next-Generation Envelope Materials C-4
- ThermaDeck: An Insulated and Ventilated Roof System C-5

Next-Generation Envelope Materials

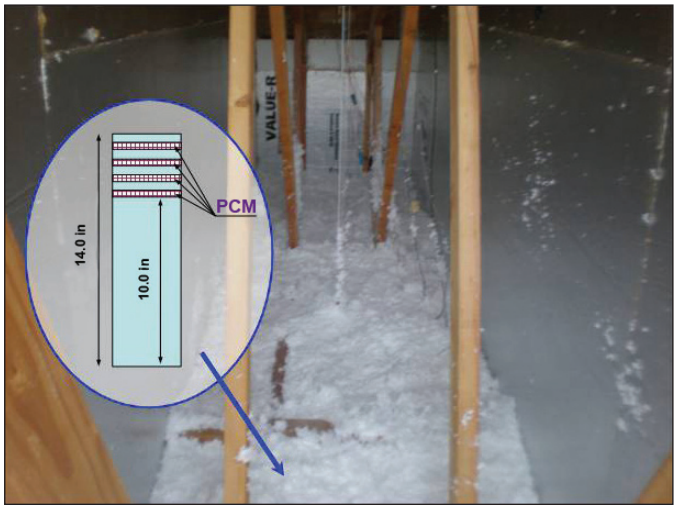
Commercial Technology

Phase Change Material Enhances Insulation Performance

Buildings consume more energy than either the transportation or industrial sectors of the U.S. economy. Energy conservation research has investigated how insulation materials can be used to provide potential savings. The performance of insulation materials can be improved by the addition of active thermal components such as phase change materials (PCMs). PCMs are solid at room temperature, melt when the temperature rises, and re-solidify as the temperature drops. When the material melts, it absorbs and stores heat, retarding heat flow into the building. When the material solidifies, it releases the stored thermal energy. Historically, PCMs have been proven to enhance building energy performance, but the high initial cost, loss of phase-change capabilities, corrosion, and sweating have prevented widespread adoption.

With funding from the U.S. Department of Energy's Building Technologies Program, Oak Ridge National Laboratory (ORNL) has developed insulation materials that will contribute to reducing energy use in buildings. The insulation materials are enhanced by either spraying with a microencapsulated PCM and adhesive mixture or encapsulating the PCM between two layers of plastic film to form an array of PCM cells. Microencapsulation of the PCM material has eliminated most of the drawbacks of past generation PCMs. Laboratory heat-flow measurements demonstrated that with a 20 wt % PCM content, the heat flow through the insulation was reduced by 30%. The phase change energy transfer (enthalpy) of the PCM is about 40% higher than competitive paraffinic PCMs.

ORNL's research has demonstrated that PCMs can be mixed with fiber insulations, incorporated into structural and sheathing materials, or packaged for localized application. The PCM is nonpetroleum-based, low cost, and flame retardant. The materials can be installed in retrofit applications, e.g., reconstruction of poorly insulated existing attics, or in new construction. The PCM material received a 2009 R&D 100 Award as the first-ever organic, fire-resistant PCM.



ORNL's Blown PCM Envelope Insulation Material

Technology History

- Developed by ORNL.
- Commercialized in 2007.
- Available from:
  Advanced Fiber Technologies
  www.advancedfiber.com

  Microtek Laboratories
  www.microteklabs.com

Applications

Can be used in residential or commercial building applications.

Capabilities

- Improves building energy efficiency by 25%-40% compared with Southeast building code levels of insulation.
- Can be installed in existing or new construction.

Benefits

Cost Savings

Uses recycled materials to maintain cost effectiveness and environmental friendliness.

Energy Efficiency

Achieves 30% energy efficiency gain compared with typical insulation material.

Environment

Uses sustainable plant and animal fats.

Safety

Provides fire-resistant PCM for insulation applications.

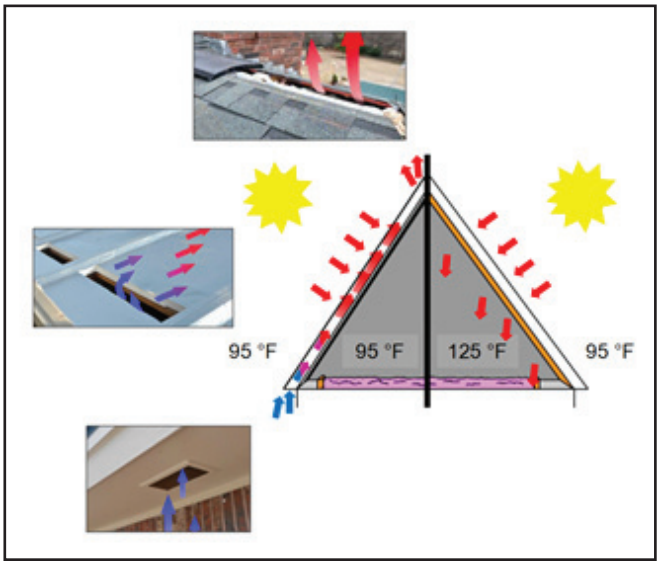
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ThermaDeck: An Insulated and Ventilated Roof System

New Technology Reduces Heat Gain in Attics

Asphalt shingle roofs, which are used on a majority of U.S. homes, are often dark-colored (e.g., brown, blue, gray, or green) in order to provide an aesthetically pleasing appearance. These shingles absorb radiant energy from the sun and can become very hot (surface temperatures of 150 °F) on summer days. This energy typically passes through the roof deck via conduction and heats the attic airspace, resulting in extremely high attic temperatures. In addition to creating an unpleasant environment for homeowners who need to retrieve something from the attic, these high temperatures can be detrimental to a home's energy efficiency. Heat transfer from the attic into air-conditioned spaces (or poorly insulated HVAC ducts that run through the attic) can increase a home's air conditioning load and monthly utility bills. A need exists for a roof system that can prevent the buildup of heat within attics.

To address this need, Billy Ellis Roofing, LLC, developed the ThermaDeck roof system. The ThermaDeck consists of a 1-inch-thick layer of polystyrene (for reducing conduction-based heat transfer) with a thin sheet of aluminum on top that serves as a radiant barrier (i.e., reflects radiant heat from the sun instead of absorbing it). The polystyrene layer has an insulating value of R-5 and the aluminum layer has a reflectivity of 97%. In addition to these features, the ThermaDeck has a 1-inch airspace between the polystyrene layer and the conventional plywood decking with asphalt shingles, which forms the top layer of the roof. As the sun's energy is absorbed by the shingles, it passes through the plywood decking to the air barrier via conduction and heats the airspace. The heated air becomes less dense and rises, exiting the roof through a vented ridge. The void left by the heated air is quickly filled with cooler outside air from underneath the roof's soffits. This natural-convection-based ventilation system continually rejects heat and works in conjunction with the ThermaDeck's other features to reduce heat gain in attics. Testing conducted by the U.S. Department of Energy's Oak Ridge National Laboratory (ORNL) demonstrated that the ThermaDeck reduces peak daytime heat transfer through roofs by 85% compared with conventional roofing.



Attic with ThermaDeck (left) vs. Attic with Standard Roofing (right)

Technology History

- Developed by Billy Ellis Roofing, LLC, with assistance from ORNL.
- 50 systems installed in U.S. homes.

Applications

Can be used to reduce heat gain in attics (and subsequent heat transfer from the attic to conditioned spaces) in residential buildings. The system can be installed as part of new or retrofit construction.

Capabilities

- Reduces peak daytime heat transfer through roofs by 85% compared with conventional roofing.
- Maintains attic air temperatures that do not exceed the ambient air temperature.
- Uses a passive, convection-based ventilation system that pulls cool air through soffit vents into a 1-inch airspace and exhausts warm air (heated by sunlight) through a vented ridge at the roof apex.

Benefits

Cost Savings

Saves homeowners money by reducing heat transfer from the attic into air-conditioned rooms.

Durability

Designed to last throughout the lifetime of a home without any need for maintenance or replacement.

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C.2 HVAC&R

- Echo™: A Hybrid Solar Electric/Thermal System C-8
- NextAire™ Packaged Gas Heat Pump C-9
- Quiet Climate 2: Efficient Heat Pump for Classrooms C-10

Echo™: A Hybrid Solar Electric/Thermal System

Innovative System Delivers Energy to Meet Residential Appliance and HVAC Loads

The idea of capturing waste heat from solar photovoltaic (PV) modules is well-developed, and several products based on this concept are currently on the market. However, all of these technologies use water as the working fluid, which creates systemic issues such as high cost, low reliability, and conflict with standard roofing installation practices.

With funding from the U.S. Department of Energy's Building Technologies Program, EchoFirst, Inc., has developed the Echo™ solar system for residential buildings. The system uses air as its working fluid and employs a patented mounting system to create a seamless rooftop solar array. Air is drawn under the array by a computer-controlled mechanical blower and thermal energy is transferred from the heated solar PV panels to the air. The air is then drawn through a filter and across a heat exchanger, where the thermal energy can be transferred to a variety of uses such as water heating or HVAC. The air-based design also enables nighttime passive cooling via an economizer cycle and radiative cooling to the night sky. An advanced controller governs the system's operation to optimize energy production and direct the thermal energy to the appropriate loads within the home. The system also comes with a web-based user interface so that homeowners can see how their system is performing and adjust system controls from their computer.

EchoFirst's technology is rapidly gaining market acceptance as an advanced and complete solar solution. Echo can offset over 50% of a home's energy needs, helping to move towards energy-efficient building goals. The system was commercially introduced to customers in 2009 and is now standard in multiple new home communities throughout Arizona and Utah. Future development efforts are focused on increasing the efficiency of thermal energy capture and load utilization, as well as using the system's advanced controls to drive total home energy-efficiency measures.



Residential Installation of EchoFirst's Echo Solar System

Technology History

- Developed by EchoFirst, Inc.
- Commercialized in 2009, with more than 350 systems installed in the U.S.

U.S. Energy Savings

(Billion Btu)

Cumulative through 2010	2010
13.7	12.0

U.S. Emissions Reductions

(Cumulative Tons)

Particulates	SO_x	NO_x	Carbon
0.062	2.96	2.21	269

Applications

Can be used to provide standalone electrical and thermal energy for residential buildings.

Capabilities

- Provides a complete solar energy solution for heating, cooling, hot water, and ventilation.
- Optimizes energy production and delivery to contribute towards meeting energy-efficient building goals.

Benefits

Durability

Achieves a high level of reliability by using an air-based (waterless) design.

Simplicity

Provides a simple design that can be installed using standard roofing practices.

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NextAire™ Packaged Gas Heat Pump

Rooftop Heat Pump Provides Low-Cost Space Conditioning for Commercial Buildings

Commercial buildings in the U.S. are predominantly cooled and heated using packaged rooftop HVAC units, most of which use an electric-motor-driven compressor to drive the refrigeration cycle. Unfortunately, the operating cost of these electric units can be very high due to expensive demand and time-of-use electricity prices. In addition, the high summertime peak electricity demand for space cooling puts stress on regional electrical grids and necessitates an excess of generation capacity that is underutilized during off-peak hours. An alternative source of power for operating space conditioning equipment is needed.

With funding from the U.S. Department of Energy's (DOE's) Building Technologies Program and the U.S. Department of Defense, IntelliChoice Energy has developed the NextAire 11-ton packaged gas heat pump (PGHP). The PGHP uses a natural-gas-fired engine (instead of an electric motor) to drive its pair of scroll compressors. The unit's efficiency is enhanced in heating mode by its ability to capture and use waste heat from the engine for space heating. In addition, the engine can operate at variable speeds to enable efficient operation at part load conditions. Many electric heat pumps are constrained to operating at full capacity, which can result in cycling losses from repeated startups and shutdowns after quickly meeting a small heating or cooling demand. The PGHP is well-suited for new commercial construction or retrofit applications because it occupies a similar footprint to traditional electric units currently in use.

Widespread use of the gas heat pump technology has the potential to result in large energy efficiency and resource conservation gains on the national level. According to the U.S. Energy Information Administration, more than 60% of the primary energy consumed to generate the nation's electricity is lost in power plants during the conversion process.[1] Shifting a significant fraction of commercial space conditioning to natural gas would avoid these conversion losses and the large amounts of water consumed during electricity generation.



IntelliChoice Energy's 11-ton NextAire PGHP

[1] *Annual Energy Review 2010 (fig. 8.0)*, U.S. EIA, October 2011.

Technology History

- Developed by IntelliChoice Energy, with assistance from Southwest Gas Corporation and Oak Ridge National Laboratory (ORNL).
- Commercialized in 2010 by IntelliChoice Energy, with 50 units sold and installed in the U.S.
- Received a 2011 R&D 100 Award along with Southwest Gas and ORNL.

Applications

Can be used to provide low-cost, energy-efficient space conditioning for commercial buildings.

Capabilities

- Uses a natural-gas-fired engine (instead of an electric motor) to drive refrigerant compressors.
- Provides 11 tons of cooling/heating capacity with a cooling coefficient of performance (COP) of 1.1 and a heating COP of 1.4.
- Captures waste heat from the engine to increase efficiency in heating mode.

Benefits

Cost Savings

Reduces operating costs by avoiding expensive demand and time-of-use electricity charges.

Water Savings

Saves a national average of 2 gallons of water per kWh compared with similar-sized electric units consuming grid-generated electricity.

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Quiet Climate 2: Efficient Heat Pump for Classrooms

New Heat Pump Provides Efficient, Cost-Effective Space Conditioning for Classrooms

The HVAC needs of most schools have historically been met by large, centralized systems that use boilers to generate steam or hot water for heating and chillers to generate chilled water for cooling. These centralized systems have several drawbacks such as high installation costs, complex maintenance requirements, and difficulty providing individualized climate control to classrooms.

With funding from the U.S. Department of Energy's Building Technologies Program and the California Energy Commission, Lawrence Berkeley National Laboratory (LBNL) and Bard Manufacturing Company, Inc., developed a packaged heat pump that offers schools an alternative to centralized systems. Known as the Quiet Climate 2 CH-Series, the unit is an improved version of the original Quiet Climate model developed by Bard in the late 1990s. The Quiet Climate 2 uses a built-in sound-reducing plenum to achieve operation at an audible noise level of ≤ 42 dB, and can be fitted with additional accessories (sound/vibration curbs and supply/return air acoustical plenums) to further reduce noise levels. The unit allows the flow of ventilation air in individual classrooms to be adjusted based on occupancy, which reduces operating expenses compared with centralized systems that often condition large volumes of fresh air whether the classrooms need it or not. The decentralized HVAC approach also minimizes the impact of repair and replacement. When a centralized system fails, the entire school suffers. If a Quiet Climate unit requires maintenance or replacement, only a single classroom is inconvenienced.

In July 2011, Bard introduced the next-generation model in the Quiet Climate product line: the TS-Series. This new model offers increased efficiency and provides greater cooling/heating capacity than the CH-Series, while maintaining the same quiet operation with the utilization of Bard's sound accessories.



Bard's Quiet Climate 2 CH-Series Heat Pump

Technology History

- Developed by LBNL and Bard Manufacturing Company, Inc.
- Commercialized in 2008 by Bard, with more than 1000 CH-Series units currently being used in schools throughout the United States.
- Named one of the Top 20 Products in 2009 by *School Construction News*.

Applications

Can be used to provide quiet, energy-efficient space conditioning and improved indoor air quality for site-built and portable classrooms.

Capabilities

- Provides 3 to 5 tons of cooling/heating capacity with an integrated part-load value (IPLV) of 13.6 to 14.5.
- Reduces audible noise levels to ≤ 42 dB while operating and ≤ 35 dB while in fan-only mode for ventilation.
- Delivers up to 480 CFM of ventilation air, or 15 CFM per occupant in a 32-person classroom.

Benefits

Cost Savings

Reduces HVAC expenses by enabling occupancy-based ventilation of individual classrooms.

Indoor Air Quality

Reduces indoor concentrations of CO_2, VOCs, and aldehydes. A CO_2 sensor can be added to the unit to enable ventilation control based on the measured CO_2 level in the room.

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C.3 LED Devices

- Efficient LED System-in-Module for General Lighting C-12
- High-Efficiency LED Lamp for Solid-State Lighting C-13
- Integrated, Solid-State LED Luminaire for General Lighting C-14
- LUXEON® A and LUXEON® S: Warm White Illumination-Grade LEDs C-15

Efficient LED System-in-Module for General Lighting

SSL Device Offers Adaptable Color and Light Output Control for Illumination

Solid-state lighting (SSL) devices for general illumination applications have the potential to dramatically reduce the amount of energy used for lighting across the U.S. commercial, residential, and industrial sectors. For widespread adoption of the technology to occur, SSL products that are adaptable to current applications and lighting infrastructure are needed. In the near term, products that are compatible with conventional light fixtures and wiring are likely to be the most desirable.

With funding from the U.S. Department of Energy's Building Technologies Program, Philips Lighting has developed a family of SSL products for general lighting in the professional market, the Lexel LED DLM system (light-emitting diode digital lighting management). The system consists of an LED module containing red, green, blue and/or white LEDs and control electronics, and a dedicated LED driver. Modules can be interconnected and controlled with a centralized controller via digital addressable interface (DALI) or direct-matrix architecture (DMX) commands. The system allows a variety of programming options for color variation, dimming, correlated color temperature (CCT), and either color rendering index (CRI) or flux maximization. High-quality color and intensity control are achieved by using intelligent feedback through photodiode and temperature sensor inputs to the software algorithms. This highly flexible control allows the SSL systems to be used in many applications where color consistency, color variability, or multiple light levels are required. Because the unit is fully dimmable, occupancy and daylighting control can be controlled via the centralized controller. Although not implemented in the products, the onboard photodiode could be used, in principal, for daylighting compensation.

Philips' Lexel LED DLM system has an efficacy of 40 lm/W, which is 2.5 times more efficient in white light applications and 20 times more efficient in color-mixing applications compared with conventional incandescent lighting technologies used in similar applications.



Philips' Lexel LED DLM Lighting Products

Technology History

- Available from Philips Lighting.
- Commercialized in 2011.
- Being adapted into various SSL-related components and products.

Applications

Can be used for general illumination applications requiring color-controlled white or multi-colored lighting.

Capabilities

- Achieves an efficacy of 35-70 lm/W, depending on device configuration and output mode.
- Produces white light with CCT from 2700-6500 K and CRI >80.
- Uses color and light output level control to create a variety of lighting atmospheres and color tones.
- Achieves the full range dimming without experiencing color shift.

Benefits

Adaptability

Provides adjustable color and light output that can be tailored to suit differing applications.

Durability

Provides 50,000 hours of operation.

Energy Savings

Enables daylighting and usage (occupancy) control.

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High-Efficiency LED Lamp for Solid-State Lighting

LED Emitter Increases Light Output and Reduces Manufacturing Costs

Lighting accounts for roughly 13% of primary energy consumption in the U.S. buildings (commercial and residential) sector.[1] Energy-efficient lighting technologies can therefore have a large impact on reducing the nation's energy consumption and greenhouse gas emissions. Solid-state light-emitting diodes (LEDs) have recently emerged as a viable new light source, with much greater efficiency than traditional lighting technologies (e.g., incandescent and halogen lighting). However, LED performance, durability, and color rendering still needs to be improved in order for large-scale adoption of the technology to occur.

White LEDs are mainly produced by combining a blue-emitting nitride-based LED with yellow-emitting phosphor materials, such as cerium-doped yttrium aluminum garnet. In the past, the performance of white LEDs for lighting applications was limited to about 50 lm/W. Given the relative cost of white LEDs, such performance levels were insufficient to challenge the incumbent lighting technologies. However, Cree, Inc., has developed blue EZBright® LED power chip technology, which enables lighting-class white LED products with efficacies of more than 100 lm/W. Continuing development by Cree has since increased the performance as high as 120 lm/W for cool white and 92 lm/W for warm white LEDs (based on commercially available EZBright LED chips).

Cree's EZBright LEDs combine highly efficient indium gallium nitride materials with proprietary optical design and device submount technology. The entire product family incorporates or builds on technology that was developed in part with funding provided by the U.S. Department of Energy's Building Technologies Program. The chip's optical design maximizes light extraction efficiency and enables a Lambertian radiation pattern, while the thin, vertical structure enables low forward voltage and efficient heat dissipation.



Cree Lighting CR6 Downlight with EZBright Die (inset)

[1] *2010 Buildings Energy Data Book (Table 1.1.5)*, U.S. DOE, March 2011.

Technology History

- Available from Cree, Inc.
- Commercialized in 2006.
- Continuing development to increase cool and warm white high-power LED performance.

Applications

Can be used for a broad range of applications, including general illumination, automotive lighting, and consumer mobile products.

Capabilities

- Achieves an efficacy of up to 120 lm/W when combined with suitable phosphors and packaging materials.
- Achieves die level power output of more than 380 mW at 350 mA drive current and 850 mW at 1 A drive current in the range of 450–460 nm.

Benefits

Cost Savings

Offers compatibility with low-cost phosphor application processes, which simplifies white LED manufacturing.

Energy Savings

Increases lighting efficacy by up to 10 times compared with incandescent light bulbs.

Versatility

Enables customization of device geometry for use in varying applications.

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Integrated, Solid-State LED Luminaire for General Lighting

Longer-Lasting, LED-Based Lighting Replaces Conventional Lamps

Light-emitting diodes (LEDs) have recently emerged as a viable new light source, with demonstrated efficiency levels up to 10 times that of traditional lighting technologies. The lighting industry could benefit greatly from energy-efficient lighting solutions, especially in spotlighting applications. A highly efficient, durable, and inexpensive spotlight is needed that can provide aesthetically pleasing illumination with a uniform beam pattern. Such a device would need to retain common form factors and accommodate existing hardware, sockets, and power connections.

With funding from the U.S. Department of Energy's (DOE's) Building Technologies Program, Philips Color Kinetics has developed an LED-based parabolic aluminum reflector (PAR) lamp with a standard form factor that allows the lamp to be used with existing lighting fixtures. The lamp contains a compact power supply and novel electronic control for operating high-intensity LEDs, as well as a heat sink for thermal management and optics for producing the desired beam. The concept lamp developed under this program used LEDs of different colors to produce warm white light with good color rendering. The lamp was designed to have a life expectancy of at least 35,000 hours, with an efficacy ≥40 lumens per watt (lm/W) and a color rendering index ≥90.

Philips Color Kinetics' LED 60 W lamp won DOE's L-Prize competition to replace the 60 W incandescent light bulb. The LED lamp was recognized by Time magazine as one of the 50 Best Inventions of 2009. Philips has introduced a complete family of LED PAR lamps, A-lamps, and decorative lamps, all using the technology developed under this DOE project. In addition, Philips Color Kinetics has introduced LED cove lighting and outdoor flood lighting using this technology. Philips continues to develop, improve and expand it's SSL product lines.



Philips 12 W A19 Ambient LED™ and eW Cove MX Powercore

Technology History

- Available from Philips Lighting.
- Commercialized in 2009.
- Continuing development of new LED replacement lighting products.

Applications

Can be used for a broad range of commercial and residential lighting applications.

Capabilities

- Achieves up to 64 lm/W in a 60 W equivalent LED A-lamp.
- Achieves ENERGY STAR certification for energy efficiency and savings (1st LED 60 W lamp).
- Produces soft white light and is fully dimmable.

Benefits

Durability

Provides up to 25,000 hours of useful life for LED A-lamps, and 50,000+ hours for LED cove lights.

Efficiency

Achieves an 80% gain in energy efficiency compared with industry standard A-lamp equivalents.

Environment

Does not contain mercury or give off an excessive amount of heat. Does not emit color-fading ultraviolet light and is safe for use around colored artwork and upholstery.

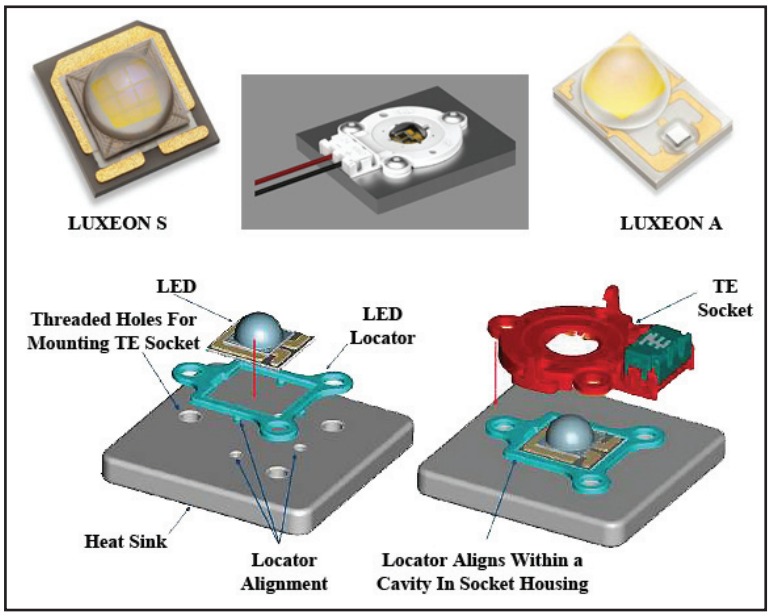
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LUXEON® A and LUXEON® S: Warm White Illumination-Grade LEDs

Improved LEDs Provide High-Efficiency Warm White Lighting

Over the last few years, rapid progress has been made in improving the performance of phosphor-converted indium gallium nitride (InGaN) light emitting diodes (LEDs). Efficacies of available phosphor converted LEDs have increased to over 100 lm/W in cool white or higher correlated color temperature (CCT). Lower color temperature or warm white LED performance lags behind cool white by up to 30% in efficacy and light output. Reduced efficacy is a tradeoff in order to provide warm white and/or higher color rendering index (CRI) values. Improved efficacy is needed so that warm white LEDs can replace incandescent, halogen, and compact fluorescent lamps in general illumination applications.

With funding from the U.S. Department of Energy's Building Technologies Program, Philips Lumileds Lighting Company has developed warm white LEDs for most commercial and residential applications. These illumination-grade warm white LEDs have a CCT range from 2700-3500 K, and an efficacy of 100 lm/W with a CRI ≥80. Philips Lumileds has commercialized two products: the LUXEON A, that uses a 2 mm^2 InGaN chip, and the higher power LUXEON S, that uses several 1 mm^2 InGaN chips. Both products use a new phosphor material, called Lumiramic®, with an optical lens on a ceramic submount. The LUXEON A chip-on-ceramic package is surface mounted by conventional reflow soldering processes, whereas the LUXEON S is designed to mount directly onto a heat sink using a similar chip-on-ceramic configuration bonded to a copper substrate with a thermal pad. For end user applications the LUXEON S is assembled using an innovative "solderless" design, which provides a mechanical clamping mechanism for attachment to a heat sink and an onboard TE socket electrical connector.



Philips Lumileds' Illumination-Grade Warm White LED Packages

Technology History

- Available from Philips Lumileds Lighting Company.
- Commercialized in 2011.
- Continuing development to improve efficiency, CCT, and CRI.

Applications

Can be used for retrofit applications such as A19 bulbs, spotlights and downlights.

Capabilities

- Produces warm white light at 100 lm/W and a CRI ≥80.
- Achieves "freedom from binning" by narrowing color bin distribution and hot testing the LEDs.

Benefits

Cost Savings

Reduces cost per lumen and energy consumption in general lighting.

Durability

Operates >50,000 hours under normal operation based on lumen maintenance (LM-80) test.

Performance

Provides high luminous efficacy and uniform, consistent quality of light output.

Product Quality

Provides optimized product thermal and mechanical design, enabling simple assembly.

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C.4 Other Lighting

- Adapting Wireless Technology for Lighting Control C-18
- Ballast/Driver Technology for Metal Halide or Solid-State Lighting Systems C-19
- Lighting Power and Control Network for SSL Systems C-20
- Optical Performance-Enhancing Material for Lighting Applications C-21

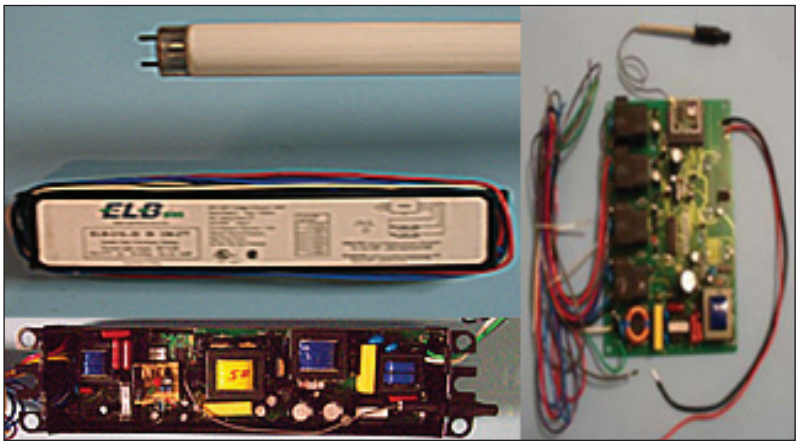
Adapting Wireless Technology for Lighting Control

Cost-Effective, Advanced System Control Reduces Energy Consumption

The high cost of retrofitting buildings with advanced lighting control systems hinders more widespread use of this technology. The energy-saving and occupant comfort benefits of advanced lighting control have not been realized on a large scale because of the cost and difficulty of installing and commissioning electronic dimmable ballasts and supporting hardware. Retrofitting existing buildings with dimmable ballasts and appropriate sensors requires running new control wires, which makes the cost and complexity of installing such systems prohibitive. Wireless technology offers a solution to mounting installation costs because it requires no additional wiring. Cost-effective, low-power, low-data-rate wireless networking devices could reduce the barriers to implementing advanced lighting control and provide reliable transmission of remote sensor data and control commands to and from remote system components.

With funding from the U.S. Department of Energy's Building Technologies Program, ELB Electronics, Inc., and industry partners have developed advanced wireless controls for lighting applications. The system consists of a network of wireless-controllable actuators, electronic dimmable lamp ballasts, and sensors for light level and occupancy detection. The system can monitor and control the lighting network by computer software, which was developed to implement advanced lighting control algorithms, including daylighting, occupancy control, and demand response.

Based on standard industry practices, an analysis estimated that the installation cost of a wireless advanced lighting control system for a retrofit application is at least 30% lower than a comparable wired system for a typical 16,000 square-foot office building, with a payback period of less than 3 years. Occupants will benefit from improved workplace comfort; building owners will benefit from improved energy efficiency and flexible lighting control; and utilities will benefit from energy savings that are responsive to peak demand periods. Commercial lighting consumes approximately 3 quads per year.[1] A 35% long-term market penetration with an average of 40% energy savings could save about 0.4 quad annually from using advanced lighting control strategies.



ELB's Wireless Dimmer, Ballast, and Relay Modules

[1] *2010 Buildings Energy Data Book (Table 3.1.5)*, U.S. DOE, March 2011.

Technology History

- Developed by ELB Electronics, Inc.
- Commercialized in 2007.
- Continuing development with Zigbee™ communication capabilities.

Applications

Can be used in commercial, retail and educational building applications.

Capabilities

- Provides localized control and centralized programmable monitoring and control for entire lighting system.
- Reduces energy consumption by monitoring use, demand, and occupancy and by integrating daylighting schemes.
- Achieves full-range dimming in electronic fluorescent lamp ballasts.

Benefits

Cost Savings

Improves return on investment by reducing installation cost of lighting control systems.

Durability

Meets UL and ANSI industry standard test specifications for safety and performance.

Flexibility

Supports small scale to entire building installations and can be reconfigured to changes in space utilization.

Installation

Provides a cost-effective, drop-in, retrofit solution that is designed to be compatible with existing lighting components.

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Ballast/Driver Technology for Metal Halide or Solid-State Lighting Systems

Energy-Efficient Power Control Circuit Improves Lamp Performance

New energy-efficient accent lighting systems must overcome the challenge of providing adequate performance (instant-start and light levels) compared with incandescent-based systems at a competitive first cost. Compact fluorescent lamps are not suitable for accent lighting because of their low light output and delayed start. Metal halide (MH) lamps have adequate light output, but do not start instantly and cannot be scaled to very low wattages, resulting in higher system costs.

With funding from a U.S. Department of Energy Small Business Innovation Research grant, Energy Focus, Inc., tackled the major performance challenges in existing accent lighting systems. Energy Focus developed a lamp ballast technology that achieves the instant-on operation of a low-power MH-lamp based accent lighting system. The technology works by incorporating efficient topologies for lamp ignition, power-factor-corrected (PFC) power conversion, and constant-current regulation. Optimized lamp start-up and operation is achieved by programmable control of the lamp current. This work led to the development of Energy Focus' next-generation constant-current light-emitting-diode (LED) driver, which increases the reliability of solid-state lighting (SSL) products.

The ballast technology is currently used in Energy Focus' MH-based products, and in fixtures that have passed military specification testing for shock, vibration, and electrical surge conditions. The military-qualified SSL fixtures are in production and include berth lights, general lighting fixtures, and globe lights, to be used as part of the Office of Navel Research's Green Fleet program which will reduce the U.S. Navy's fossil fuel energy consumption by 50% over the next decade. SSL-based explosion-proof fixtures are currently under development for military and NASA applications. Future LED driver electronics based on this technology could include wireless enabled, individually addressable, networked drivers or fixtures.



Energy Focus' MILSPEC SSL products

Technology History

- Available from Energy Focus, Inc.
- Commercialized in 2009.
- Currently developing SSL products for general and hazardous environment lighting applications and the Office of Naval Research's Green Fleet Program.

Applications

Can be used in MH- and SSL-based lighting systems.

Capabilities

- Provides instant-start operation.
- Enables advanced power factor correction with low total harmonic distortion and efficient constant-current control.
- Provides 92% efficient ballast circuitry, which improves the efficacy (lumens per watt) of lighting systems.

Benefits

Durability

Achieves military specifications for harsh environments. Units have operated in the field for more than three years without experiencing a single failure.

Efficiency

Achieves an 80% gain in energy efficiency relative to existing incandescent/halogen systems.

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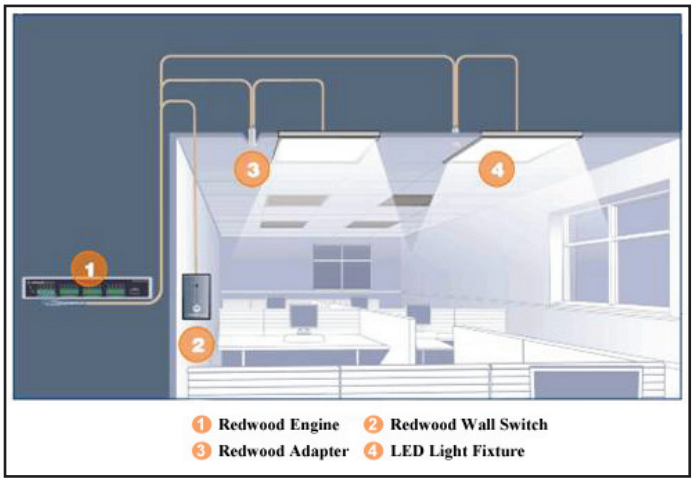
Lighting Power and Control Network for SSL Systems

System Provides Real-Time Monitoring and Control of Building Operations

In 2010, buildings consumed 40% of the energy in the United States at a cost of over $400 billion.[1] The U.S. Department of Energy (DOE) has set a 50% cost-effective energy savings target for 2020, and improving building energy efficiency is expected to significantly contribute to meeting that target. Several components of building construction and operation have been identified to improve energy efficiency: insulation, heating, cooling, and lighting. Lighting energy efficiency can be greatly improved by deploying compatible daylighting systems and occupancy controls as well as installing higher efficacy lighting fixtures such as solid state lighting (SSL).

With funding from DOE's Building Technologies Program, Redwood Systems, Inc., developed an energy-efficient lighting system using SSL and centralized advanced control capabilities. The system uses a high-density sensor network that operates on low voltage direct current; monitors room occupancy and lighting levels; and establishes space use and traffic patterns. Air quality and temperature monitoring (future release) will add optimal HVAC management for worker comfort and equipment performance. The system is accessible remotely via a standard web browser, or smartphone/iPad, or via Voice over Internet Protocol (VoIP) telephones.

The system is plug and play and provides quick and accurate system commissioning by auto detecting the lighting fixtures and their locations. The self-commissioning feature allows building operators to preset dimming control and occupancy schedules for individual fixtures, room zones, and entire office spaces or floors. The system gathers sensor array data and provides graphical analysis of traffic patterns and space use, which allows the lighting system's energy use to be further optimized. The system provides real-time dynamic lighting control, allowing automatic dimming or switching of individual fixtures without disturbing or disrupting the room occupants. The entire system can easily reduce lighting levels by 30%, which translates to 50%–80% energy savings compared with conventional lighting systems.



Redwood Systems' Networked Power & Lighting Control Overview

[1] *2010 Buildings Energy Data Book (Tables 1.1.3 and 1.2.3)*, U.S. DOE, March 2011.

Technology History

- Developed by Redwood Systems, Inc.
- Commercialized in 2010.
- Continuing system development and broadening customer base and market penetration.

Applications

Can be used in a variety of commercial, retail, and educational office building applications.

Capabilities

- Provides localized and centralized lighting control and space use monitoring of the entire lighting system.
- Combines power, communications, and sensor arrays into one low-voltage network.
- Reduces energy consumption by optimizing system operation and integrating daylighting schemes.

Benefits

Cost Savings

Reduces installation, commissioning and maintenance costs.

Energy Efficiency

Provides real-time energy consumption monitoring, management, and adjustment.

Performance

Provides environmental monitoring (lighting and HVAC) for enhanced workplace productivity.

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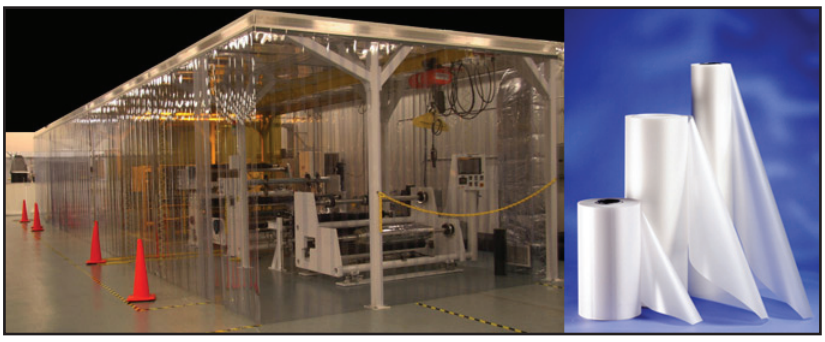
Optical Performance-Enhancing Material for Lighting Applications

New Light-Scattering Substrates Improve Light Extraction Efficiency

For solid-state lighting (SSL) technologies to become viable alternatives to conventional lighting sources, their energy efficiency must be improved. The two main SSL technologies, organic light-emitting diodes (OLEDs) and light-emitting diodes (LEDs), have had to overcome the technical challenge of internal reflections to improve light extraction efficiency. For example, OLEDs have used light-scattering layers in the OLED device stack, and LEDs have used various techniques such as epitaxy, surface roughening, and chip shaping during die fabrication. Additionally, the directional nature and the size of an LED light source can lead to objectionable light output non-uniformity, requiring light diffusing and shaping in the luminaire design.

With funding from a U.S. Department of Energy Small Business Innovation Research grant, Physical Optics Corporation (POC) demonstrated that fabrication of the light-scattering layer on the inner surface of OLED substrates (i.e., at the interface between the OLED structure and substrate) improves photon extraction efficiency. POC's light shaping and diffusing (LSD) technology uses random surface topography and works in white, monochromatic, coherent, or incoherent light. The randomized structures eliminate Moiré and color diffraction. Incoming light is precisely controlled within well defined areas, increasing control and use of light, thus maximizing photon utilization. The technology can be used on both rigid and flexible glass and polymer substrates.

POC has applied the light-shaping and diffusing technology to other applications, including LED-based SSL lighting, avionics, automotive, lighted signage, consumer electronics, and machine vision. POC's technology is commercially available through their spinoff company, Luminit, LLC. The LSD technology is available in a variety of configurations for light transmission, beam shapes, and diffusion angle. Luminit recently expanded their production capacity and commissioned an integrated roll-to-roll system for mass production of Light Shaping Diffuser materials. This system increases Luminit's capacity by 10 times and can produce LSD films up to 100 feet per minute.



Luminit's LSD Manufacturing Facility and LSD Film Product

Technology History

- Developed by POC and available from Luminit, LLC.
- Commercialized in 2009.
- Continuing development to support SSL lighting application needs.

Applications

Can be used in lighting, bio-medical, machine vision, semiconductor metrology and display applications.

Capabilities

- Improves light extraction and light output quality.
- Provides a variety of configurable optical parameters for light transmission, diffusion, and beam shaping.
- Provides light shaping and control in the 400-1500 nm wavelength range.

Benefits

Cost Savings

Reduces product material cost using high-volume roll-to-roll manufacturing.

Manufacturability

Can be fabricated on a variety of rigid or flexible substrates, thereby broadening use of the material.

Performance

Improves efficiency, light output uniformity, and color rendering of lighting products.

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C.5 Water Heating

- GeoSpring™ Hybrid Water Heater C-24
- Vertex™ Residential Gas Condensing Water Heater C-25

GeoSpring™ Hybrid Water Heater

New Heat Pump Water Heater Uses up to 62% Less Energy than Standard Electric Models

Water heating is the third largest energy expense in U.S. households (behind space heating and space cooling).[1] About 40% of the nation's homes are served by storage tank electric water heaters,[2] which consume an average of roughly 4900 kWh annually. Standard electric water heaters are a mature technology, and it is therefore unlikely that significant energy savings can be achieved without fundamentally altering the way stored water is heated.

With funding from the U.S. Department of Energy's (DOE's) Building Technologies Program, General Electric Company (GE) has developed the GeoSpring hybrid water heater, which uses heat pump technology to transfer heat from the surrounding air to the stored water. This design enables significant energy savings compared with typical electric water heaters, which generate heat using electric resistance elements. DOE testing for appliance EnergyGuide labeling confirmed that the GeoSpring heat pump uses 62% less energy than a standard 50-gallon electric water heater. The GeoSpring offers five different operating modes to adjust to changing hot water demand. For low-demand situations or when maximum energy efficiency is desired, the unit can operate entirely as a heat pump. For high-demand situations, backup resistive elements are used to boost the temperature recovery time to that of a standard electric water heater. The unit can also save energy by lowering the water temperature setpoint during extended periods of time in which a house is unoccupied (e.g., vacation) and returning to the previous setting shortly before the residents return. GE is currently focused on marketing the product to build consumer awareness of the advantages offered by heat pump water heaters. GeoSpring was the first ENERGY STAR qualified heat pump water heater, and also qualifies for the Federal 30% residential energy efficiency tax credit and numerous State and local utility rebates/incentives. The product is currently available through several national retailers, local independent retailers, and local plumbers and plumbing distributors.



GE's GeoSpring Hybrid Residential Water Heater

[1] *2010 Buildings Energy Data Book (Table 2.3.6)*, U.S. DOE, March 2011.
[2] *ENERGY STAR Water Heater Market Profile (pg. 4)*, U.S. DOE, September 2010.

Technology History

- Developed by General Electric Company and commercialized in 2009.
- First ENERGY STAR qualified heat pump water heater.

U.S. Energy Savings

(Billion Btu)

Cumulative through 2010	2010
341	273

U.S. Emissions Reductions

(Cumulative Tons)

Particulates	SO_x	NO_x	Carbon
1.53	73.7	54.9	6700

Applications

Can be used as an energy-efficient alternative to standard residential electric water heaters.

Capabilities

- Offers a capacity of 50 gallons, a first hour rating of 63 gallons, and an energy factor of 2.35 when in hybrid mode.
- Provides demand response readiness and communicates with a smart meter or power utility load controller.

Benefits

Compatibility

Retrofits easily by using the same utility connections as standard electric water heaters.

Cost Savings

Saves the average U.S. household $300 per year on its electric bills compared with a standard electric water heater.

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Vertex™ Residential Gas Condensing Water Heater

Improved Water Heater Design Increases Thermal Energy Efficiency and Reduces Costs

Water heating accounts for 13% of primary residential energy consumption.[1] High-efficiency water heaters tend to be much more expensive than traditional products and have lengthy payback periods. The higher cost arises from the use of complex designs that are difficult to manufacture and require expensive materials and components. Poor payback and reliability problems have made these products unappealing to consumers. A cost-optimized, high-efficiency water heater is needed.

With funding from the U.S. Department of Energy's Building Technologies Program, A.O. Smith Corporation has developed a high-efficiency water heater that addresses the concerns of cost and reliability. The design uses readily available components and materials that reduce the unit cost premium. In addition to the use of standard water heater parts, a glass-lined carbon steel heat exchanger was also developed. The cost savings realized from this choice of heat exchanger material versus stainless steel are significant and simplify manufacturing.

A.O. Smith refined the design specifications for this water heater based on numerous marketing studies and customer input. The design was then further modified to address ease of manufacturing concerns and weaknesses identified during reliability testing. A.O. Smith commercialized the technology in the second quarter of 2006 with the release of the Vertex product family. The first production model had 90% thermal efficiency and a second, with 96% efficiency, was released two years later. Known as the Vertex 100, this newer model has additional features such as on-board diagnostics and remote monitoring capabilities, as well as an upgraded temperature controller with a liquid crystal display user interface.



A.O. Smith's Vertex Product Line of Residential Gas Water Heaters

[1] *2010 Buildings Energy Data Book (Table 2.1.6)*, U.S. DOE, March 2011.

Technology History

- Available from A.O. Smith Corporation.
- Commercialized in 2006.

Applications

Can be used for residential or light commercial applications.

Capabilities

- Achieves up to 96% thermal efficiency with an input heating rate of up to 100,000 Btu/h.
- Operates as part of combination space heating/water heating systems.
- Offers a capacity of 50 gallons and a first hour rating of up to 164 gallons.
- Produces hot water at a rate that exceeds that of a standard 75 gallon unit.

Benefits

Compatibility

Installs easily using existing utility connections and can be vented using PVC pipe.

Durability

Provides reliable performance by using a field-tested design.

Energy Savings

Achieves up to 30% energy savings compared with a standard gas water heater.

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C.6 Windows Technologies

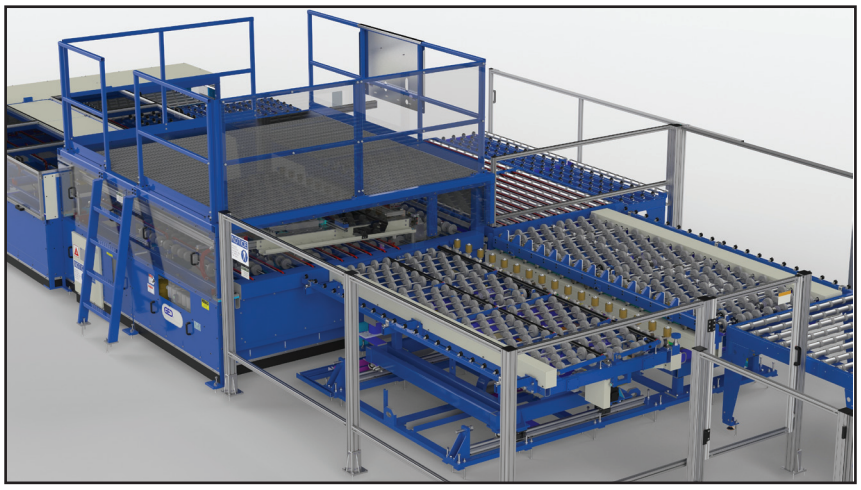
- ATLAS™: An Energy-Efficient Triple IG Window Manufacturing System C-28
- EnerLogic®: Low-Emissivity, Energy-Control Retrofit Window Film C-29
- OptiQ™: An Advanced Commercial Window Technology C-30
- SageGlass® Electrochromic Windows C-31
- Suntuitive™: Sunlight-Responsive Thermochromic Window Systems C-32

ATLAS™: An Energy-Efficient Triple IG Window Manufacturing System

High-Volume Manufacturing System Produces Windows Cost Effectively

Annually, commercial and residential buildings account for over 40% of U.S. energy consumption.[1] A considerable portion of the energy consumed, e.g. heating, cooling, lighting, and ventilation, is impacted by window performance (insulation and optical properties). The U.S. Department of Energy (DOE) identified that heat loss through windows is the largest single energy-related aspect of window performance. Technology developed in the form of low-emissivity coatings and inert gas fills has proved successful but opportunities remain to increase energy savings by addressing glazing properties and the sash/frame combination. Research efforts are in progress to develop and produce cost-effective window products with improved coefficient of heat transfer values or U-values of <0.20 (R-5). To provide homeowners with affordable and efficient residential windows that can reduce their energy bills, DOE has enabled research, design, and development of high-volume, efficient manufacturing to produce high-performance, energy-saving insulating glass units (IGUs).

With funding from DOE's Building Technologies Program, GED Integrated Solutions, Inc., developed and commercialized a high-volume and low-material and labor cost automated manufacturing system that produces high performance R-5 value IGUs. GED's revolutionary Automated Tri-Lite Assembly System (ATLAS) for insulating glass fabrication is a culmination of developing manufacturing processes for improved efficiency and throughput and design for manufacturability consideration of the end product. The ATLAS produces a triple-pane IGU in 20 seconds, improving on conventional methods that can take two minutes or longer. GED's ATLAS can be installed in most existing window manufacturing facilities and can produce a wide variety of IGU sizes for high thermal efficiency windows. PPG Industries, Inc., a major U.S.-based glass manufacturer and developer of advanced window technologies, assisted GED with unit design support and analytical testing and commissioned the first ATLAS to validate performance in an actual production environment. The ATLAS production process was awarded "Best in Show" September 2011 at GlassBuild America, a major glass and window industry event.



GED's ATLAS for Manufacturing Triple Pane IGUs

[1] *2010 Buildings Energy Data Book (Table 1.1.3)*, U.S. DOE, March 2011.

Technology History

- Developed by GED Integrated Solutions, Inc., in collaboration with PPG Industries.
- Commercialized in 2011.
- Available from GED Integrated Solutions, Inc.

Applications

Can be used for high-volume, low-cost manufacturing of triple-pane IGUs.

Capabilities

- Provides seamless integration into existing equipment and flexible, schedule-driven production.
- Processes units from 16" x 14" up to 100" x 72" at a rate of up to six IG dual units per minute.

Benefits

Cost Savings

Minimizes glass breakage, contamination, and damage using touch-less assembly and protects workers from injury and fatigue from handling glass.

Flexibility

Provides capability to handle small and large sized units, dual- and triple-glazed IGUs in any order or combination and still maintain optimum levels of production.

Product Quality

Uses vacuum lift mechanisms to lift and suspend the product without contact with the glass surfaces, ensuring contamination-free placement and alignment of triple IGUs.

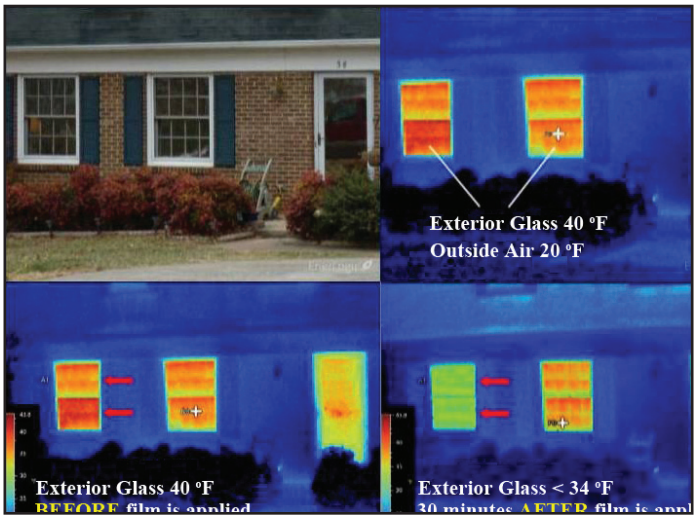
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EnerLogic®: Low-Emissivity, Energy-Control Retrofit Window Film

Low-Cost, Easily Installed Flexible Window Film Provides Short Payback Period

Approximately one third of the energy used for heating and cooling U.S. homes is lost through windows.[1] Research and development to improve energy conservation in windows have investigated fenestration, glazing, and glazing treatments, including active and passive window tinting. For a technology to become successful in the consumer marketplace, cost of ownership must have a perceived value and a short payback period. Also, a technology that can be easily retrofitted and cost effective is desirable. Currently, the best retrofit window film technology available has an emissivity >0.35. Suspended films have been used in the air gap of dual pane window units but proved to be uneconomical and a low-impact retrofit solution. Emissivity values as low as 0.02 are available in glass coatings found inside the air gap of sealed, dual-pane windows but cannot be a retrofitted and therefore are expensive. Low-emissivity coating technologies cannot be directly applied into an aftermarket window film due to processing issues as well as substrate flexibility, corrosion, and abrasion resistance.

Solutia Inc., with funding from the U.S. Department of Energy's Buildings Technologies Program (as part of the American Recovery and Reinvestment Act), developed a retrofit window film technology, Enerlogic, with improved emissivity. The technology uses sputter coating processes from a flexible touch panel and display manufacturing, preventing damage and maintaining the film's flexibility. To improve abrasion resistance, acrylic coatings cannot be used because they increase emissivity, cause iridescence, and are opaque in the far infrared (IR) spectrum. Solutia's new abrasion resistant technology is flexible, IR transmissive, and eco-lighting friendly. The products' low emissivity decreases the energy payback period, making them suitable for a wider range of climates. Solutia has several commercial building window and residential window products available with various light transmission and emissivity specifications, depending on the intended application. Solutia distributes their products through a national dealer/installer network and has successfully demonstrated their products at over 60 commercial and residential case study sites.



Solutia's Low E-Film Technology Before and After Installation

[1] *2010 Buildings Energy Data Book (Table 2.1.15)*, U.S. DOE, March 2011.

Technology History

- Available from Solutia Inc.
- Commercialized in 2011.
- Over one million square feet installed.

Applications

Can be used for commercial or residential windows.

Capabilities

- Can be installed in existing low-e commercial or residential windows(single or dual pane and tinted or clear).
- Improves energy efficiency of existing windows.
- Achieves a 3.5 times reduction of window emissivity to less than 0.1.

Benefits

Cost Savings

Reduces first cost by eliminating costly re-installation or replacement of existing windows.

Durability

Improves product durability and flexibility using flexible display manufacturing techniques combined with precious metal sputter coating.

Energy Efficiency

Improves window energy efficiency using reduced emissivity film coating and becomes energy neutral in less than two months of use.

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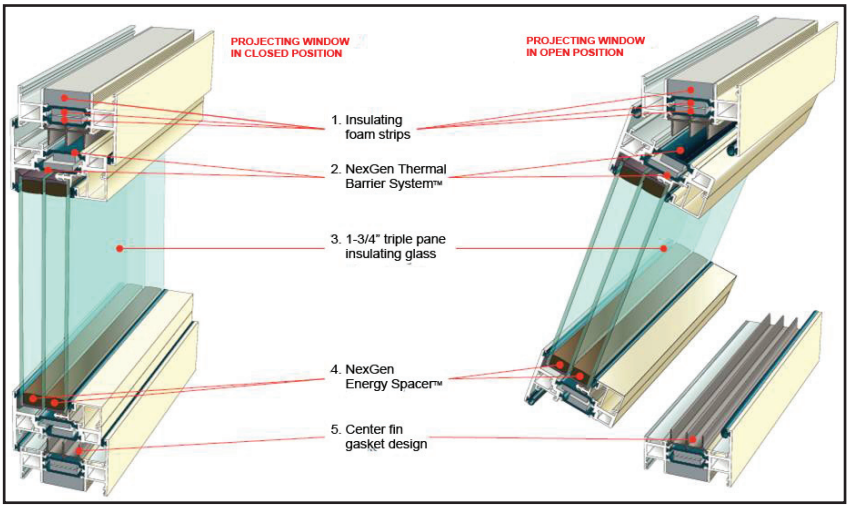
OptiQ™: An Advanced Commercial Window Technology

Highly-Insulating Commercial Window System Reduces Building Heating and Cooling Loads

Aluminum window framing systems are used in more than 80% of commercial buildings because of their inherently good structural properties and long service lifetime. Unfortunately, traditional aluminum window frames suffer from poor insulating performance, making windows one of the least effective parts of a building's envelope. Because nonmetal window frames do not have sufficient structural strength to meet the structural requirement, a cost-effective method is needed for improving the insulating capability of commercial-grade aluminum window frames.

With funding from the U.S. Department of Energy's (DOE's) Building Technologies Program and the American Recovery and Reinvestment Act, Traco developed and commercialized a window framing system that significantly increases the insulating ability of windows in commercial buildings. The new product, OptiQ Ultra Thermal Windows (AA4325), reduces energy loss by 40% compared with previously marketed and leading double-pane low-emissivity (low-E) windows. OptiQ has a coefficient of heat transfer value or U-value of 0.17 and 0.22 for fixed and operable windows respectively. This thermal performance was only previously attainable using nonmetal framing materials with reduced structural integrity. OptiQ's improved thermal performance and excellent moisture resistance are obtained by using an advanced framing design with a polyimide thermal break and a highly insulating glazing system. The technology's performance is LEED (Leadership in Energy and Environmental Design) certification enabling.

OptiQ also offers several enhanced aesthetic features, including 3.75-inch-depth frames with minimal sightlines and dual color options with the flexibility to vary interior and exterior finishes at reduced cost. Traco is also developing another low-E frame coating to further improve thermal performance. Currently, Traco is working on the process and manufacturing equipment to cost effectively apply the low-e coating to aluminum window frames. To demonstrate the performance advantages offered by the technology, low-e frame windows have been installed in a conference room at DOE's Forrestal Building.



Traco's OptiQ Ultra Thermal Window

Technology History

- Developed by Traco, a division of Kawneer Company, Inc.
- Commercialized in 2011.
- Available from Traco/Kawneer.

Applications

Can be used as an energy-saving replacement or alternative to conventional aluminum windows in commercial buildings.

Capabilities

- Improves the U-factor of commercial-grade aluminum windows by >40% compared with market leading commercial window systems.
- Reduces the emissivity value of the interior window frame surface from 0.90 to 0.65.
- Improves condensation resistance (CR>72, CRF>78) and reduces likelihood of mold.

Benefits

Comfort

Increases both window insulating capability, which improves occupants' thermal comfort, and condensation resistance, which reduces formation of mold.

Cost Savings

Reduces heating and air conditioning costs by inhibiting heat transfer through aluminum window frames.

Emissions Reductions

Reduces greenhouse gas emissions by decreasing energy consumption for heating and cooling buildings.

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SageGlass® Electrochromic Windows

Daylighting-Compatible, Electronically Tinting Glass Reduces HVAC Solar Loading

For centuries, buildings have had windows because people desire the natural daylight that windows provide. Unfortunately, windows permit heat to escape from a building in the winter and enter in the summer, and allow glare to penetrate into a building's interior. Buildings account for approximately 70% of U.S. electricity consumption and 40% of the nation's total energy use.[1] Technologies that reduce energy transmission through windows can therefore have a significant impact towards reducing the nation's energy consumption and greenhouse gas emissions. Many window treatments for reducing solar loading and glare, such as shades and blinds, also eliminate natural daylight and the building occupants' sense of connection to the outside, counteracting the purpose of the windows.

With funding from the U.S. Department of Energy's Building Technologies Program, SAGE Electrochromics, Inc., has developed a window glazing technology that overcomes conventional window insulation challenges and preserves the benefits of natural daylighting. SAGE's electrochromic glass technology consists of a series of ceramic layers on glass that can be either clear or tinted by applying low-voltage DC electricity. Clear SageGlass transmits 62% of visible light and has a solar heat gain coefficient (fraction of solar radiation admitted through a window) of 0.48. When the window is tinted, the light transmission drops to 3.5% with a solar heat gain coefficient of 0.09. The average SageGlass glazing energy consumption is only 0.04 W/ft^2. In relative terms, a single 60 W light bulb's electricity consumption would operate 1500 ft^2 of SageGlass.

In northern climates, the glazing technology has the potential to conserve energy by allowing passive solar irradiation to supplement heating and by harvesting daylight to augment (or replace) artificial lighting. For warmer climates, fully darkened SageGlass glazing can significantly reduce both air conditioning loads and peak power consumption. Even when in the tinted state, SAGE's glazing technology permits building occupants to view the outdoors, a feature that is beneficial to people's well-being and productivity.



SageGlass Glazing Installation Demonstrating Clear and Tinted States

[1] *Annual Energy Review 2010 (figs. 1.0 and 8.0)*, U.S. EIA, October 2011.

Technology History

- Developed and marketed by SAGE Electrochromics, Inc.
- Commercialized in 2007.

U.S. Energy Savings

(Billion Btu)

Cumulative through 2010	2010
3.91	1.69

U.S. Emissions Reductions

(Cumulative Tons)

Particulates	SO_x	NO_x	Carbon
0.018	0.845	0.630	76.8

Applications

Can be used to control transmission of the sun's light and heat through windows, thereby reducing building HVAC solar loading.

Capabilities

- Transitions between clear and tinted states within 3-5 minutes.
- Offers zone-based tinting control so that certain window panels block the sun's direct glare while others allow natural daylight to enter a room.

Benefits

Comfort

Blocks glare without compromising visibility and reduces sunlight fading damage to interior décor.

Versatility

Offers a variety of tint colors to suit consumer preferences for differing applications in both residential and commercial buildings.

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Suntuitive™: Sunlight-Responsive Thermochromic Window Systems

Window Technology Optimizes Daylighting and Reduces Solar Heat Gain

Fixed tint windows are a compromise between how much light and solar heat gain is allowed to enter a building. Research has focused on developing window technologies with additional features that reduce or enhance the effects of solar heat gain, prevent sunlight glare, and are compatible with daylighting schemes.

Pleotint, LLC, developed and commercialized a sunlight responsive thermochromic technology for windows and tested the technology's performance and viability with funding from the U.S. Department of Energy's Building Technologies Program. The product, known as the Suntuitive thermochromic interlayer, is marketed in North America through an alliance with PPG Industries. Windows with this interlayer technology have a dynamic change in visible transmission that is controlled by the amount of direct sunlight on the window. Throughout the day, the light transmission of the window changes and adapts based on the heat provided by the sun. This feature allows the windows to optimize the incoming brightness and heat load in both residences and commercial buildings. Every day of the year, every time of the day and on every orientation on a building, the windows tint simply based on the intensity of direct sun without using wires, power supplies, or controls.

The interlayer is made of the most common safety glass lamination polymer, polyvinyl butyral (PVB). The PVB is loaded with thermochromic materials discovered and developed by Pleotint. Rolls of the interlayer can be shipped to window fabricators throughout the world, allowing dynamic windows to be produced almost anywhere safety glass laminates are made. The Suntuitive thermochromic interlayer may be combined with suspended film technology and with almost any tinted or coated glass, including glass with the world's most efficient low-emissivity coatings. Pleotint's first commercial sale for a large commercial building installation took place 2011 and further confirmed the comfort and heat control benefits in this building as well as at other retrofit sites where Pleotint's technology was used.



Pleotint's Suntuitive Thermochromic Interlayer Combined with PPG's Azuria® Tinted Glass in the Dark and Light States

Technology History

- Developed and commercialized by Pleotint, LLC, through a marketing alliance with PPG Industries.
- Commercialized in 2011.
- Over 20,000 square feet installed.

Applications

Can be used to control daylighting and reduce energy consumption in residential and commercial buildings.

Capabilities

- Optimizes daylighting and provides visible light transmission between 50% and 10%.
- Achieves solar heat gain coefficient as low as 0.11.
- Provides dynamic window tinting without wires, power supplies, or controls.

Benefits

Comfort and Convenience

Provides sound reduction and impact resistance, decreases glare, and minimizes fading from solar ultraviolet radiation without compromising visibility.

Durability

Passed 2,500 hours accelerated aging test at the NREL using weatherometer conditions specified in ASTM E2141.

Installation

Installs like any conventional glazing without special requirements.

Manufacturability

Provides a thermochromic interlayer that can be supplied to laminators and window manufacturers worldwide.

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D.1 Building Controls

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Advanced Load Identification and Management for Buildings

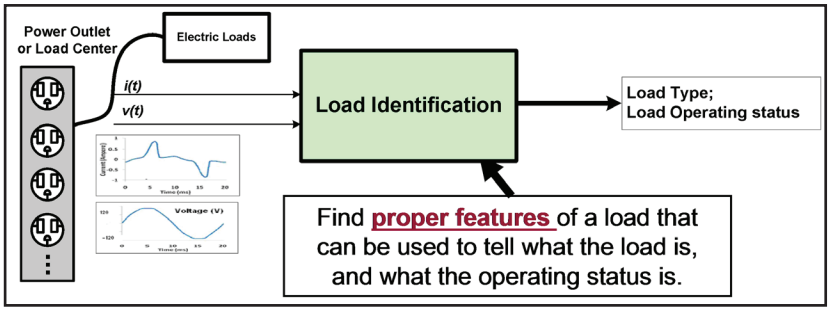
Emerging Technology

New Technology Identifies and Monitors the Performance of Individual MELs in Buildings

Commercial and residential buildings account for roughly 70% of end-use electricity consumption in the United States.[1] For this reason, an extensive amount of R&D has been directed at improving the energy efficiency of buildings. Most of this research has focused on technologies within the largest individual end-use categories of building energy consumption (e.g., space heating/cooling, water heating, lighting, and major appliances) or on improvements to envelope materials (e.g., insulation, roofs, and windows) that reduce a building's space conditioning load.

One important component of energy consumption in buildings that is often overlooked is miscellaneous electric loads (MELs), which include a wide variety of small devices such as microwaves, toasters, coffee makers, TVs, computers, and hairdryers. Developing widely applicable energy-saving strategies for MELs is difficult because of the diverse nature of MELs present in one building/home versus another (and the variability with which different people operate their devices). This difficulty is compounded by the fact that individual loads are not distinguished from one another on a building's electric bill. Detailed information about the energy consumption of individual electric loads is needed in order for building owners and homeowners to make energy-saving purchases and operating decisions with regard to MELs.

With funding from the U.S. Department of Energy's Building Technologies Program (as part of the American Recovery and Reinvestment Act), Eaton Corporation is developing advanced load identification and monitoring technologies that provide fine granular visibility of energy usage and safety protection information relating to MELs. The load identification intelligence will be embedded in an advanced power outlet/strip that can identify individual or multiple MELs connected to the same strip based on their current and voltage characteristics. Data from the Smart Power Strip will be delivered to building owners via low-cost communication methods (e.g., wireless sensor networks or Ethernet). The Smart Power Strip will also feature a remotely-controllable relay, a universal interface to building management systems, and advanced fault protection functions.



Eaton's Smart Power Strip for MEL Identification and Monitoring

Technology History

- Developed by Eaton Corporation, with assistance from the Georgia Institute of Technology.
- Currently developing a reference database of appliance load features and testing algorithms for identifying MELs.

Applications

Can be used to identify and monitor the energy consumption of MELs in commercial and residential buildings.

Capabilities

- Identifies electric loads based on their current/voltage characteristics.
- Automatically monitors load status and performance (e.g., energy consumption).
- Delivers information on electric loads to building owners via low-cost communication methods.

Benefits

Energy Savings

Enables building owners and homeowners to make energy-saving decisions with regard to MELs by providing them with detailed information about MEL energy consumption.

Safety

Uses advanced fault protection functions to protect equipment and building occupants.

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[1] *Annual Energy Review 2010 (fig. 8.0)*, U.S. EIA, October 2011.

Integrated Predictive Demand Response Control for Commercial Buildings

Emerging Technology

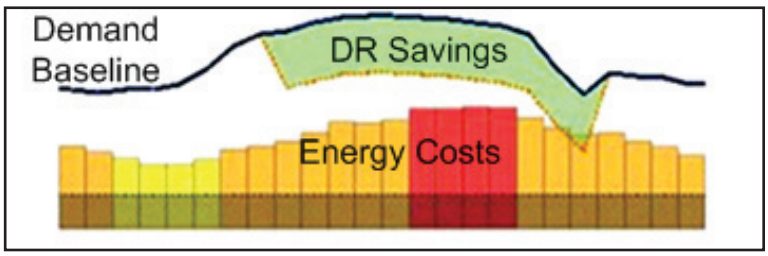
New Controls Reduce Peak Electricity Demand by 10%-15% Without Compromising Occupant Comfort, Safety, or Productivity

Demand response programs, which offer financial incentives to large consumers of electricity for reducing their consumption during periods of high stress on the electrical grid, are an important component of electric system planning. Commercial buildings, which account for roughly one-third of U.S. end-use electricity consumption,[1] are prime candidates for participation in demand response markets. When building owners consider incorporating demand response capability into their buildings, they want to reduce energy costs while still maintaining a safe, comfortable, and productive work environment for the building occupants. Control systems are needed that can balance these two facets of demand response participation.

With funding from the U.S. Department of Energy's Building Technologies Program (as part of the American Recovery and Reinvestment Act), Johnson Controls, Inc., is developing integrated predictive demand response (IPDR) control algorithms that enable commercial buildings to participate in a variety of demand response markets. The IPDR controls minimize building energy costs based on electric pricing or curtailment signals, while protecting equipment and ensuring occupant comfort and safety.

Prototype algorithms have been developed for Peak Pricing and Emergency Curtailment programs and are currently being tested at a 20,000-square-foot local government facility in a semi-arid climate. A third algorithm for Day Ahead pricing programs is also being developed. A 50,000-square-foot higher education building in a hot, humid climate will be used as a test site for the final algorithms.

Johnson Controls is also working to integrate a demand response market interface into the IPDR system. The market interface will provide building owners with information about demand response opportunities, historical participation, and revenue generated from participation. As the building owner opts into these demand response opportunities, the market interface communicates participation to the energy service provider, tracks the energy consumption against the building's baseline, and coordinates incentive settlement with the energy service provider.



Reduced Building Peak Energy Demand Achieved with Johnson Controls' IPDR Control Technology

[1] *Annual Energy Review 2010 (fig. 8.0)*, U.S. EIA, October 2011.

Technology History

- Developed by Johnson Controls, Inc.
- Currently testing prototype algorithms for Peak Pricing and Emergency Curtailment programs.
- Working to integrate a market interface platform into the IPDR system.

Applications

Can be used to enable commercial building participation in different demand response energy markets.

Capabilities

- Shifts a building's energy consumption from periods of high demand/costs to periods of low demand/costs.
- Automatically models a building's thermal responsiveness and controls the building's HVAC systems without customer interaction.
- Reduces occupant discomfort by using a building's thermal mass to store energy, ensuring that upper comfort limits are not exceeded during the curtailment period.

Benefits

Cost Savings

Reduces costs by providing the financial benefits of demand response without the need for new capital equipment purchases.

Grid Stability

Improves the reliability/efficiency of the electrical grid and reduces the occurrence of brownouts and rolling blackouts.

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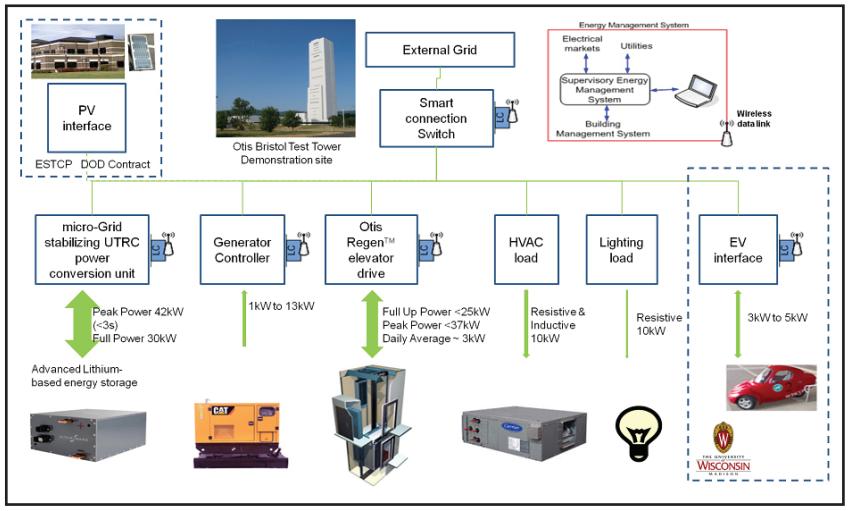
Plug-and-Play Distributed Power Systems for Smart-Grid-Connected Buildings

Emerging Technology

New Technology Reduces Electricity Costs and Improves Electric Grid Reliability

Electricity demand in buildings typically experiences a sharp peak during the afternoon and then decreases at night. This imbalance causes a number of problems for electric utilities and consumers. Utilities are forced to size their generation capacity to meet peak-hour demand, resulting in unused capacity at night when demand is low. Low nighttime demand can also make it difficult for utilities to make use of off-peak wind power generation. The daytime peak can cause power delivery/quality problems such as brownouts and blackouts (especially during summer afternoons when air conditioning loads are high) and is met using less-efficient peaking power plants. The increased cost of operating peaking plants is reflected in higher peak-hour electric rates for large electricity consumers (e.g., commercial and industrial customers). Technologies that enable communication between building electric loads and the grid are needed to help balance electricity supply and demand, improve power quality and reliability, and reduce electricity costs for consumers.

With funding from the U.S. Department of Energy's Building Technologies Program (as part of the American Recovery and Reinvestment Act), United Technologies Corporation (UTC) is developing a plug-and-play building energy microgrid that integrates building-level energy sources, storage, and loads with the external utility grid. The microgrid can operate in grid parallel or islanding modes, and seamlessly transition between these modes while monitoring energy usage and power quality levels. Individual microgrid components communicate with a central panel board via a wireless network. This design allows system components to be easily added or removed. The system is connected to a central data repository that contains status information from the microgrid, short-term weather forecasts (which help building management systems anticipate HVAC loads), and utility information such as electricity prices and grid demand levels. UTC is currently testing the microgrid technology in its laboratories, with field testing planned for the final stage of the project.



Eaton's Smart Power Strip for MEL Identification and Monitoring

Technology History

- Developed by UTC, with assistance from the University of Wisconsin.
- Currently integrating individual components into a full system and evaluating system performance.

Applications

Can be used to reduce electricity costs and improve power quality in residential and commercial buildings. Extensible to managing multiple buildings at the campus or district level.

Capabilities

- Coordinates multiple energy sources, energy storage technologies, and building electric loads via a wireless network.
- Increases energy supply security and power quality.
- Enables participation in electricity demand response markets.

Benefits

Cost Savings

Uses integrated energy storage to take advantage of opportunities such as shifting electric loads to off-peak hours (to avoid paying high-priced peak electricity rates) or curtailing loads on request from utilities or load aggregators under a contract.

Grid Stability

Improves grid stability by integrating onsite generation and storage to enable on-demand load reductions in response to high levels of stress on the grid. Provides local power factor correction, which increases the effective capacity of the external grid.

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Predictive Optimal Control of Active and Passive Building Thermal Storage Inventory

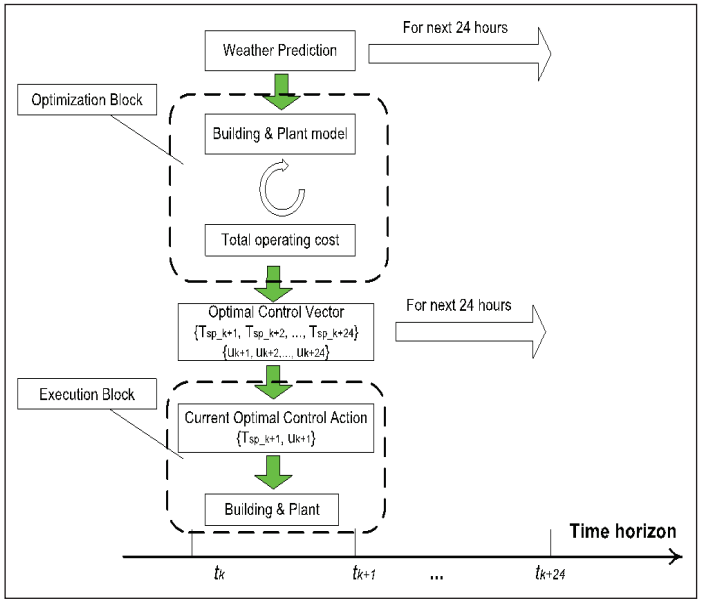
Emerging Technology

New Control Technology Reduces HVAC Energy Costs in Commercial Buildings

The cooling of commercial buildings contributes significantly to the peak demand for electricity experienced during mid-afternoon in the summer months of the year. Low electricity prices during off-peak hours (i.e., nights and early mornings) make the use of thermal energy storage (TES) technologies an attractive strategy for reducing HVAC energy costs. TES is typically employed via an active or a passive approach. Active systems use a building's cooling equipment to remove heat from an energy storage medium (e.g., ice or chilled water) and then use that medium to provide cooling during the day. Passive thermal storage involves night precooling of a building's structure and internal equipment, which serve as heat sinks during the day.

With funding from the U.S. Department of Energy's Building Technologies Program, the University of Colorado at Boulder has developed an improved form of predictive optimal control for optimizing the use of both active and passive TES strategies in commercial buildings. The technology uses information such as short-term weather forecasts, electricity price data, and a building's energy profile (e.g., size, structural materials, envelope characteristics, and occupancy) to devise an optimal TES control strategy, which it then delivers to a building's automated HVAC controls. Testing conducted during this project showed that the combined use of active and passive TES significantly increases cost savings compared with either method used on its own.

The control technology has been demonstrated by Clean Urban Energy, Inc. (CUE), in several large commercial buildings in downtown Chicago in anticipation of the technology entering the market. CUE has also developed a scalable, online version of the control software that can be expanded to simultaneously deliver control instructions to a large number of buildings.



Flow Diagram for the University of Colorado's Active and Passive TES Control Technology for Commercial Buildings

Technology History

- Developed by the University of Colorado at Boulder, in partnership with Clean Urban Energy, Inc.
- Currently being demonstrated in several large commercial buildings in the Chicago metropolitan area.

Applications

Can be used to predictively optimize thermal storage strategies in commercial buildings to shift HVAC electricity consumption from peak to non-peak hours in response to real-time pricing and demand response signals.

Capabilities

- Uses data such as short-term weather forecasts and energy prices to optimize thermal energy storage strategies for reducing HVAC power costs.
- Delivers hourly control instructions to a building's automation system.

Benefits

Cost Savings

Reduces HVAC operating costs by shifting electricity consumption from peak to off-peak (nighttime) hours.

Grid Efficiency

Increases grid efficiency by shifting consumption from peaking power plants to more efficient baseload plants.

Stability

Reduces daytime strain on the electrical grid and helps combat the problem of negative nighttime electricity prices due to an excess of generation capacity and a lack of demand.

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D.2 Envelope Technologies

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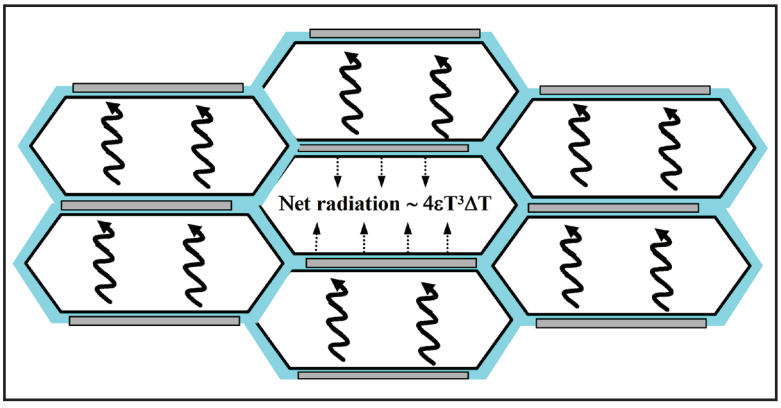
Advanced Building Insulation by Carbon Dioxide Foaming Process

Emerging Technology

New Process Produces Low-Cost, Environmentally Friendly Building Insulation

Rigid, closed-cell foam board materials (e.g., polystyrene, polyurethane, and polyisocyanurate) are widely used to insulate building roofs, walls, and foundations. A key contributor to the high thermal resistance (R-value) of these insulating materials is the low-thermal-conductivity blowing agent used in their production. (The blowing agent, which is dissolved in the polymer melt, expands as the melt exits an extruder and causes the melt to foam into a homogeneous, closed-cell structure in which the blowing agent is trapped.) Hydrochlorofluorocarbons (HCFCs) have historically been the dominant blowing agents, but their use is being phased out by the Montreal Protocol due to their ozone-depleting properties. Hydrofluorocarbons (HFCs), a common substitute for HCFCs, are not ozone-depleting but still have high global warming potential (GWP) values. (On a scale where CO_2 has a GWP of 1, common blowing agents HCFC-142b and HFC-134a have GWP values of 2000 and 1300, respectively.) Alternative blowing agents that do not contribute to ozone depletion and have reduced global warming impact are needed.

With funding from the U.S. Department of Energy's Building Technologies Program (as part of the American Recovery and Reinvestment Act), Industrial Science & Technology Network, Inc. (ISTN), is developing an improved foaming process for building insulation production that uses supercritical CO_2 as the blowing agent. ISTN's process will produce rigid polymer-clay nanocomposite foam that combines reduced pore sizes, an aligned oblate pore structure, and an embedded nanoscale secondary structure to increase its R-value. The project's primary objective is to produce insulation with an R-value that is similar to or better than current products without the use of ozone-depleting or high-GWP gases. Replacing HCFC blowing agent (15% by weight in building insulation produced with current methods) with CO_2 could also reduce the material cost of new insulation by up to 40%.



Oblate Pore Structure and Aligned Clay Reduce Net Radiation Transfer Across a Pore in ISTN's Advanced Building Insulation

Technology History

- Developed by Industrial Science & Technology Network, Inc.
- Currently conducting laboratory CO_2 foaming experiments and producing prototype foam insulation.

Applications

Can be used to produce high R-value, environmentally friendly building insulation by a foam extrusion process.

Capabilities

- Produces closed-cell insulation with a rapid foaming process, using supercritical CO_2 to minimize surface tension and create/preserve pores of substantially reduced size.
- Achieves R-values that are comparable to or better than existing insulation by using smaller pore sizes, an aligned oblate pore structure, and an embedded nanoscale secondary structure.

Benefits

Cost Savings

Reduces material costs of foam board insulation by up to 40% by replacing HCFC blowing agents with CO_2.

Environment

Eliminates the use of ozone-depleting and high-GWP gases in foam insulation without sacrificing insulating performance.

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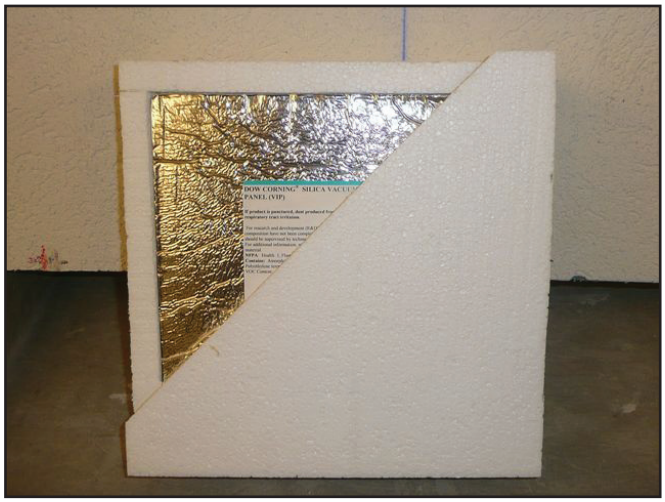
Energy-Efficient EIFS Wall Systems

Emerging Technology

New Technology Improves Envelope Insulating Performance

The insulating performance of a building's envelope plays a major role in determining the building's overall energy efficiency. Exterior insulation and finish systems (EIFS) can be used to increase the insulating value of a building's exterior walls, but are faced with barriers that prevent their widespread adoption (particularly in retrofit applications). Current retrofit solutions for improving envelope energy efficiency require the use of multiple components such as expanded polystyrene (EPS) insulation and siding. To achieve an R-30 wall, a minimum of eight inches of EPS foam is required. While this approach is technically feasible, it has poor aesthetics and typically requires roof flashings and overhangs to be extended (resulting in high labor and materials costs). A need exists for exterior insulation products that provide high R-values while minimizing additional wall thickness.

With funding from the U.S. Department of Energy's Building Technologies Program (as part of the American Recovery and Reinvestment Act), Dow Corning Corporation and Dryvit Systems, Inc., are incorporating vacuum-insulated panel (VIP) insulation into an improved EIFS design that increases the R-value of a typical wall to R-30 and is only three inches thick. This new technology offers an improved R-value per inch of insulation compared with current envelope systems. The VIP EIFS is adhesively attached to the building's outer walls and can be installed using existing application and finishing techniques. The design lends itself to fabrication in a shop for unitized or modular building construction. Field mechanics will be able to easily follow the project application guide to install the system, without needing to perform any onsite modifications. The thin cross-section of the VIP EIFS has a minimal impact on wall thickness/living space. Dow Corning and Dryvit plan to commercialize the technology once it has been validated for thermal performance and tested to meet industry standards for air/water infiltration, durability, structural performance, flammability, and ease of construction. To provide high-quality aesthetics, the product will be available in a number of different colors and finishes.



VIP Encapsulated in EPS for Use in a High-Performance EIFS Wall

Technology History

- Developed by Dow Corning Corporation, in partnership with Dryvit Systems, Inc.
- Currently optimizing the high-performance wall system for use in both new and retrofit commercial construction.

Applications

Can be used to improve the insulating performance of exterior walls in commercial or residential buildings to R-30. The system can be installed using existing application and finishing techniques during new construction or retrofit projects.

Capabilities

- Improves the insulating performance of exterior building walls to R-30 using only three inches of exterior insulation.
- Offers a wide variety of colors and finishes to provide an aesthetically pleasing look for building owners and homeowners.

Benefits

Ease of Installation

Simplifies installation by using encapsulated insulation panels that are shipped to the jobsite already made to the proper size. Field mechanics will be able to easily install the system without onsite modifications.

Energy Savings

Reduces HVAC energy consumption in buildings by improving the insulating performance of exterior walls. Includes air- and water-resistive barriers.

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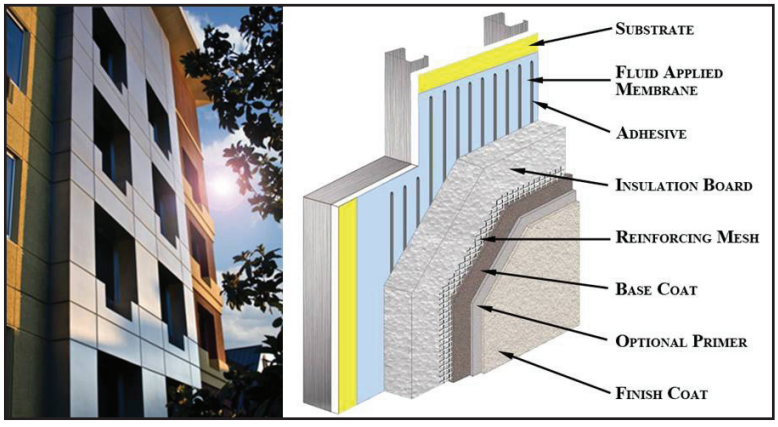
Exterior Insulation and Finish System (EIFS)

Emerging Technology

Weather-Resistant Wall Cladding Controls Moisture and Reduces Heat Loss and Gain

The U.S. Department of Energy (DOE) is targeting a 50% reduction in residential and commercial building energy consumption compared with baseline codes[1, 2] by 2014 and 2015 respectively, with further incremental reductions every 3 years starting in 2017 and 2018. Achieving these targets will require new building technologies, practices, and energy conservation strategies. Several solutions can be implemented almost immediately, e.g., deployment of higher efficiency lighting systems, HVAC usage control, and building or space occupancy detection strategies. The additional energy savings needed to meet DOE targets will require larger capital investment to install higher-efficiency building utility equipment and building construction and/or materials. One potential solution is using exterior insulation and finish systems (EIFS), which were developed in 1950s and 1960s and were first used in commercial buildings and then in residential applications.

The EIFS Industry Members Association (EIMA) and Oak Ridge National Laboratory (ORNL), with funding from DOE's Building Technologies Program, investigated EIFS susceptibility to moisture. Prior to completion of this study, a lack of real building data did not allow full understanding of the issues of moisture control capabilities of exterior wall materials and construction. EIMA and ORNL conducted extensive real building testing of the hygrothermal properties of various EIFS, stucco, and traditional brick and mortar external wall construction. The EIFS studied also had several product enhancements for moisture control, e.g., liquid-applied air/water-resistive barrier coatings, interior wall element moisture management, and ventilated exterior claddings. The results of the exterior wall configuration testing showed that EIFS absorbs less moisture and heat than other wall configurations, including brick and stucco. EIFS energy performance through use of continuous exterior insulation and design flexibility, limitless finish choices, cost, and ease of application make EIFS a viable choice in meeting the new building energy conservation standards.



EIFS Commercial Building Installation and Cross-Section

[1] *"International Energy Conservation Code"*, International Code Council, 2006.
[2] *"ANSI/ASHRAE/IESNA Standard 90.1"*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Technology History

- Researched by EIMA, ORNL, and industry collaborators.
- Continuing work on marketing strategy and consumer awareness programs.

Applications

Can be used for residential and commercial building applications.

Capabilities

- Improves exterior wall resistance to heat flow (R-value) using continuous exterior insulation.
- Provides superior hygrothermal performance compared with other exterior construction and materials.
- Provides flexible, durable, and maintenance free finish.
- Reduces air infiltration by up to 55% compared with standard brick or wood construction.

Benefits

Cost Savings

Reduces construction material through flexible design that accommodates complex architectural forms.

Product Quality

Provides product specification and performance that enables new building energy conservation standards to be attained.

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Insulating Form System for Concrete Foundation Edges

Innovative Technology Reduces Heat Loss Through Slab-on-Grade Foundations

Concrete slab-on-grade construction represents the primary foundation type of residential buildings throughout the southern and southwestern United States. Almost all of these homes have uninsulated slab perimeters that transfer heat from the warm interior of the house to the surrounding environment during the heating season. Builders currently have the opportunity to install slab edge insulation on new homes, but typically choose not to do so. Factors that influence their decision include added cost, installation difficulties, construction slowdown, and termite issues (in some parts of the country). A cost-effective, installer-friendly slab edge insulation system would offer multiple benefits to builders and homeowners, while reducing the energy consumption and greenhouse gas emissions associated with residential buildings.

With funding from the U.S. Department of Energy's Building Technologies Program, Davis Energy Group, Inc. (DEG), is developing Formsulate, a leave-in-place concrete slab form board. Formsulate consists of a PVC extrusion filled with two inches of Styrofoam™ insulation, along with specialized linear and corner couplers. Formsulate decreases construction labor by eliminating the need to strip form boards after the concrete has cured. The wooden form boards historically used in the slab-forming process end up as waste material and typically add an additional 400 pounds of construction waste per house. Formsulate eliminates this source of waste while allowing concrete subcontractors to continue using industry-standard forming practices. The insulation reduces heat loss through concrete slab edges, especially in homes with hydronic floor heating systems. In addition, the insulation is treated with approved termite-resistant chemicals to prevent termites from tunneling through the foam into the wall framing above.

DEG has conducted two field demonstrations using the Formsulate form boards to pour slab-on-grade foundations for custom homes in California. Future R&D work involves developing a Formsulate design that is compatible with post-tensioned concrete slabs.



Field Demonstration of DEG's Formsulate Technology

Technology History

- Developed by DEG, in partnership with The Dow Chemical Company and with support from the National Energy Technology Laboratory.
- Planning to develop a Formsulate design that can be used with post-tensioned concrete slabs.

Applications

Can be used as an energy-saving alternative to conventional wooden form boards in the process of forming concrete slabs for residential buildings.

Capabilities

- Reduces heat loss through concrete slab edges by more than 80% compared with uninsulated slab-on-grade foundations.
- Offers twelve-foot-long linear extrusions, linear couplers, and both internal and external corner couplers.

Benefits

Emissions Reductions

Reduces greenhouse gas emissions by lowering building heating loads.

Safety

Prevents termites from tunneling through the insulation and causing structural damage to the wall framing.

Waste Reduction

Reduces construction waste by eliminating the scrap wood resulting from use of traditional wooden form boards.

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Low-Cost Phase Change Materials for Building Envelopes

Emerging Technology

Phase Change Materials for Building Insulation Save Energy

The use of phase change materials (PCMs) in well-insulated buildings under certain climatic conditions has been shown to reduce building space conditioning energy consumption by up to 25%.[1, 2] Despite a number of studies that have shown that insulation enhanced with PCM in building envelopes can reduce energy consumption, widespread use of PCMs in construction products has been limited. High cost and product availability have been cited as the main barriers. The main price contributors include paraffin raw material and the cost of encapsulation.

With funding from DOE's Building Technologies Program (as part of the American Recovery and Reinvestment Act), Syntroleum Corporation and Oak Ridge National Laboratory (ORNL) are developing a low-cost process to produce form-stable PCMs. The on-purpose PCM paraffin technology converts fatty acid chains in canola and soybean oil to C16-C18 n-paraffins. Additionally, use of high-throughput continuous polymer pelletizing equipment instead of batch micro-encapsulation is also under development. Pelletizing is expected to provide much needed additional cost reduction in producing form-stable PCM products for building envelope applications.

Syntroleum has produced over 1 ton of PCM paraffin by hydrodeoxygenation of soybean and canola oils in a pilot plant. Product testing confirmed that PCM pellets meet preliminary performance targets (melting point = 22-23°C, heat of fusion ≥100 J/g). The PCM was used to produce gypsum wallboard prototypes for testing and compliance with the industry standard ASTM E84 flammability specification and for heating-cooling cycle studies. Once flammability code compliance and thermal cycling testing is completed, Syntroleum and ORNL will collaborate with a wallboard manufacturer to commercialize the product and launch field tests.



Syntroleum's PCM (wax/solid form T <22°C [L] and molten form T >23°C [R])

[1] *"PCM-Enhanced Building Envelope"*, Kosney et. al., ORNL, 2007.
[2] *"PCM-Enhanced Cellulose Insulation Thermal Mass in Lightweight Natural Fibers"*, Kosney et. al., ECOSTOC Conference, June 2006.

Technology History

- Developed by Syntroleum Corporation and ORNL.
- Continuing development to perform industry standard compliance testing and field testing of prototype product.

Applications

Can be used in building envelope products such as gypsum wallboards and attic insulation to enhance thermal efficiency.

Capabilities

- Produces PCM-range paraffins (e.g., octadecane and hexadecane) from low-cost bio oils.
- Uses high-density polyethylene encapsulation matrix instead of micro-encapsulation to form stable pellets that remain solid above the paraffin melting temperature.

Benefits

Energy Savings

Achieves reduced peak energy demand by providing passive heating and cooling from the stored solar thermal energy in the PCM.

Manufacturability

Uses hydrodeoxygenation to convert vegetable oil into PCM paraffin in a one-step process.

Sustainability

Uses biorenewable feed stocks, which effectively sequester CO_2 (carbon fixated in vegetable oils via photosynthesis) and further reduces green house gas emissions by enhancing energy efficiency of buildings.

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Nano-Enabled TiO_2 UV Protective Layer for Cool-Color Roofing Application

Emerging Technology

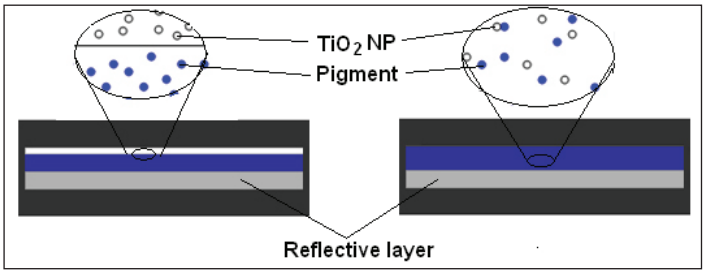
New Coating Reduces Building Cooling Costs

Cool color roofing—a simple and low-cost technology that uses solar reflective pigments to reduce a home's energy and peak electric demand for air conditioning—promises to provide a significant leap in energy efficiency. Typically, the cool roof has an infrared (IR) reflective bottom layer topped with organic or inorganic pigment layer for aesthetics.

For the cool roof to be effective for energy saving, the top pigment layer needs to be IR transparent and stable. However, neither organic nor inorganic pigment has both merits. To protect cool roof coating from ultraviolet (UV) damage and thus prolong its lifetime, UV-durable colored cool paints are needed. To date, cool roof coatings comprising fluorine-based resins and inorganic pigments have been produced to address the UV stabilities. However, fluorine-based resins are not cost effective compared with other industrial resins. Also, organic pigments have more color vividness, larger color selection, higher IR transparency, and lower cost than those of inorganic counterparts.

With funding from a U.S. Department of Energy Small Business Innovation Research grant (as part of the American Recovery and Reinvestment Act), Nanotrons Corporation is developing an innovative approach to use organic pigments and less costly nonfluorine resins that would add more value to the colored cool roofing industry. Phase I results have shown that titanium dioxide (TiO_2) nanoparticles in the paints can absorb UV radiation and increase the lifetime of colored cool roofs. Because of the nano-dimension and near infrared (NIR) transparency of TiO_2 particles, the color vividness and NIR reflectance of the color roofs will not be compromised. During Phase II, optimized nano-composite formulation will be scaled up to commercially viable levels for long-lasting cool roof coating applications.

The proposed waterborne clear TiO_2/acrylic nano-composite paint applied on organic pigment coated aluminum will fulfill commercially viable high solar IR reflective and architecturally acceptable cool roof coating. Cool white materials have been available for most roofing products. However, white residential roofing products sell poorly because homeowners prefer the aesthetics of dark-colored roofs. The proposed cool color roofing technology makes solar-reflective roofing available in any color (dark or light), which will significantly accelerate the cool roof program in the United States.



(Left) TiO_2 Layer Coated on Top of the Pigment Layer, and (Right) SiO_2 Shelled TiO_2 Nanoparticles Mixed with the Organic Pigments/Resin

Technology History

- Developed by Nanotrons Corporation.
- Focuses on optimizing of the coatings and their large-scale spray applications.

Applications

Can be used for advanced building cool-roof coatings applications.

Capabilities

- Absorbs UV radiation and prolongs the lifetime of colored cool roofs.
- Offers high IR reflectance and large color selection.
- Reduces costs using low-cost industrial resin and organic pigments.

Benefits

Cost Savings

Reduces the energy cost for building cooling.

Energy Efficiency

Provides commercially acceptable cool roof coating for both industrial and residential buildings.

Performance

Allows large color selection while maintaining a long operational lifetime and low cost.

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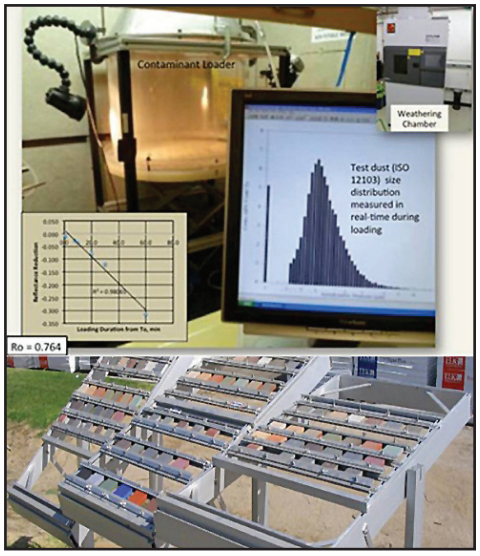
Reflective Elastomeric Roof Coating

Emerging Technology

Accelerated Testing Shortens Development Time for Energy-Saving Product

Space cooling accounts for 13% of buildings sector primary energy consumption, or about 5.4 quads.[1] One approach to reducing summer cooling loads in buildings is the "cool roof" concept, a roof that has both high solar reflectance and infrared emittance values. External weathering and soiling over time can degrade the effectiveness and reduce the solar reflectance of the roof finish. Unfortunately, the extent and nature of solar reflectance degradation can take several years, making development of new and improved cool roof finishes a lengthy and tedious process.

Oak Ridge National Laboratory (ORNL), in collaboration with DOW Chemical Company and Lawrence Berkely National Laboratory (LBNL), with funding from the U.S. Department of Energy's Building Technologies Program, is developing an accelerated testing protocol for expeditious development of cool roof finishes. ORNL has conducted extensive weathering testing of cool roof and other roofing products, testing that lasted over four years. Using these testing results, ORNL assessed the effects of solar exposure, climate conditions, weathering, and soiling. ORNL determined that several factors contributed to the degradation. Some factors were cyclic (e.g., soiling and amount of rain and wind exposure) and some were site related (e.g., presence of certain contaminants), but the primary contribution was from manmade pollutants such as soot and road dust. ORNL is using the environmental factor data to identify surface reflectance degradation parameters for an accelerated test that can be experimentally controlled and compared against current environmental test results. This model takes into account chemical or microbial effects as well as surface roughness and cyclic climatic effects. ORNL has begun constructing an on-purpose accelerated test facility that includes a contaminant loader module.



ORNL's Weathering and Contaminant Loading Test Facilities

[1] *2010 Buildings Energy Data Book (Table 1.1.5)*, U.S. DOE, March 2011.

Technology History

- Developed by ORNL in collaboration with Dow Chemical Company and LBNL.
- Continuing development and validation of the test protocol and collaboration with industry partners.

Applications

Can be used in building applications to improve the solar reflectance of roofs.

Capabilities

- Produces accurate test results that can be compared with and verified by actual field test data.
- Anticipated to reduce testing schedule from current requirement of 3 years and accelerate market push.

Benefits

Cost Savings

Reduces development costs of products where weather test performance and endurance are vital to market competitiveness.

Energy Savings

Enables market ready products that can contribute to meeting new building energy efficiency targets.

Product Quality

Enables the development of superior weather resistant and solar durable materials.

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Shape-Stable and Highly Conductive Nano-Phase Change Materials

Emerging Technology

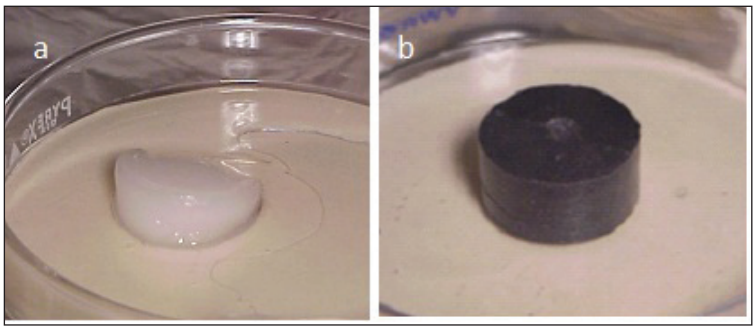
Highly Stable and Conductive Material Offers Diverse Energy Applications

Thermal energy storage systems overcome the discrepancies caused by the mismatch in the timing of energy supply and the demand in alternative energy systems. In the case of solar space heating, for example, the intermittent supply of solar radiation requires that the excess daytime supply be stored to meet the nighttime demand. Thermal energy storage improves building energy efficiency by controlling indoor temperature fluctuations and by shifting the energy demand away from peak hours.

With funding from a U.S. Department of Energy Small Business Innovation Research grant (as part of the American Recovery and Reinvestment Act), Technova Corporation is developing a new thermal energy storage material that complements large latent heat capacity with desired shape-stability, thermal conductivity, heat and fire resistance, scalability, economy, and versatility for use in diverse energy systems. The new hybrid nano-phase change material (nano-PCM) relies on the molecular interactions of PCM with functionalized nanomaterial surfaces as well as the support of PCM by a networked, thermally stable polymer to achieve a highly desired balance of qualities favoring their broad transition to energy-efficient buildings and solar energy markets. Hybrid nano-PCMs are produced by simple and low-cost processing techniques. High thermal conductivity is key to timely mobilization of the whole volume of nano-PCM towards latent heat storage in scaled-up building applications.

Phase I developed simple processing techniques for producing hybrid nano-PCMs and validated their ability to provide a distinct balance of latent heat capacity, thermal conductivity, and high-temperature stability of shape and mechanical performance. Building walls incorporating nano-PCM were also developed, and their value in controlling indoor temperature fluctuations and shifting of thermal load in building applications was demonstrated. Numerical analyses confirmed that nano-PCM building products can result in major energy savings and thermal load shifts.

Phase II is building on the Phase I accomplishments for (1) fully developing and thoroughly characterizing hybrid nano-PCMs and building products incorporating them; (2) theoretically and experimentally validatings the benefits of hybrid nano-PCMs in terms of energy efficiency, thermal comfort and shifting of thermal load in different building systems and climatic conditions; and (3) evaluating the competitive markets of the technology to identify priority applications.



Comparison of Paraffin Wax (a) and Technova's Nano-PCM Material (b) Heated Above Their Melting Temperatures.

Technology History

- Developed by Technova Corporation

Applications

Can be used to improve energy-efficient products for building construction.

Capabilities

- Significantly improves thermal conductivity and fire resistance
- Reliably and conveniently incorporates into energy-efficient buildings and solar energy systems for energy saving.

Benefits

Cost Savings

Eliminates the need for costly encapsulation measures. The use of low-cost nanomaterials and processing techniques further benefits the economy of nano-PCM.

Energy Efficiency

Achieves high levels of shape stability and thermal conductivity, which significantly improve heat transfer within the PCM, which is critical to successful scale up of the technology.

Performance

Benefits from long-term stability, because nano-PCM is not prone to liquefaction and leaching.

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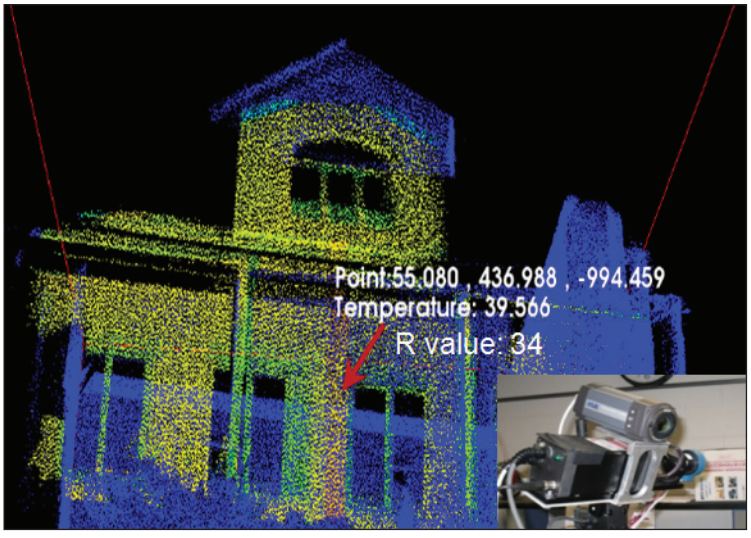
Three-Dimensional Building Energy Performance Measurement and Modeling System

New Technology Improves Building Envelope Retrofit Decision Making

Many homeowners or building owners trying to improve the energy performance of their building envelopes are faced with choosing from a large number of products and services with widely differing applications, initial costs, and payback periods. Making sense of this large amount of complex information can be difficult for individuals without any formal training or education regarding the energy performance of building components. A need exists for technologies and information dissemination methods that will help the general public make informed retrofit decisions that reduce energy losses through their walls, roofs, windows, and doors.

With funding from the U.S. Department of Energy's Building Technologies Program, the University of Nebraska-Lincoln's Durham School of Architectural Engineering and Construction is developing a technology that improves the measurement and modeling of building envelope energy performance. The system measures thermal radiation from envelope materials and uses light detection and ranging (LIDAR) technology to generate a three-dimensional (3D) model that stores thermal performance information at each point in space. After further analysis and information modeling, the University will deliver the final 3D model to building owners and homeowners via the internet.

Compared with numerical and graphical data, visual information about a building's energy performance is easier for nonexperts to understand. The ability to actually see thermal performance deficiencies in a building's envelope will help homeowners identify retrofit technologies that will have the greatest impact on reducing their energy consumption and monthly energy bills. The technology will also help the scientific community quickly and accurately gather building thermal performance data for use in additional modeling and analysis efforts.



3D Thermal Modeling of a House Performed by the University of Nebraska's Hybrid Thermal LIDAR System

Technology History

- Developed by the University of Nebraska-Lincoln's Durham School of Architectural Engineering and Construction.
- Currently conducting lab and field experiments to test an algorithm for estimating the thermal resistance of building envelope materials.

Applications

Can be used to rapidly and accurately measure building envelope thermal conditions for further analysis and modeling, the results of which can be disseminated to building owners and managers via the internet.

Capabilities

- Integrates 3D geometries of a building's envelope with thermal resistance information for the envelope materials (e.g., walls, roofs, windows, and doors).
- Stores thermal performance information at each point in 3D space.
- Delivers model results to homeowners and building owners via the internet.

Benefits

Energy Savings

Informs the public about techniques for improving the energy efficiency of their homes and buildings.

Simplicity

Offers visual information about a building's energy performance, which is easier for nonexperts (e.g., homeowners) to understand.

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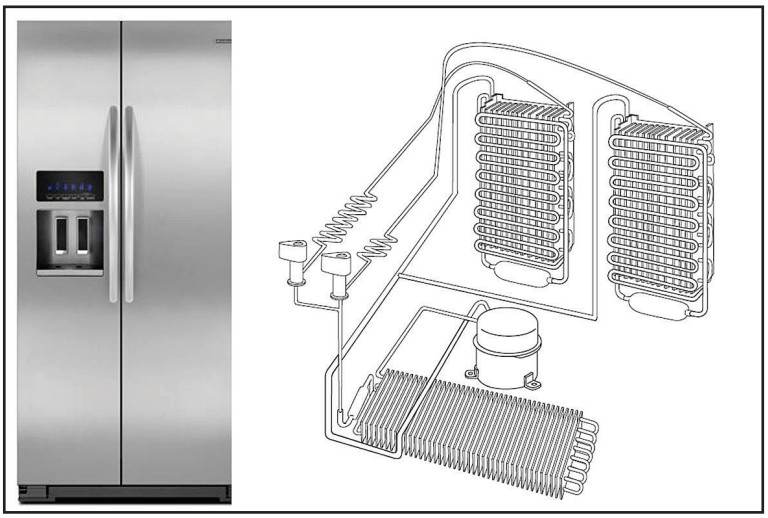
Advanced Sequential Dual Evaporator Cycle for Refrigerators

Emerging Technology

Refrigerator Technology Improves Product Performance and Saves Energy

The refrigerator is a major energy-consuming appliance in a typical home, accounting for ~6% of U.S. residential building energy usage.[1] Therefore, development efforts to increase refrigerator operating energy efficiency could contribute significantly in reducing total residential energy usage. Since the 1930s refrigerators have used a single vapor-compression cycle for both the fresh food and freezer compartments. Despite the cost and space advantages of using a single cycle, the overall coefficient of performance (COP) for refrigeration at freezer temperatures is below the COP for refrigeration required for fresh food temperatures. Single-cycle refrigeration exchanges air between the freezer and fresh food compartments and energy savings could be achieved if the majority of cooling was provided to meet the higher demands of the fresh food compartment. For this reason, the potential energy savings of adopting separate cycles for the freezer and fresh food compartments has been investigated.

Whirlpool Corporation, with funding from the U.S. Department of Energy's Building Technologies Program (as part of the American Recovery and Reinvestment Act), is developing a dual-cycle refrigerator to achieve breakthrough energy efficiency performance by using a number of technologies. These technologies include a sequential dual evaporator refrigeration cycle, variable capacity compressor, heat exchanger technology, vacuum insulation panels, thermal storage material, and advanced controls. Whirlpool, who first developed and patented a sequential dual cycle evaporator cycle in 1995 (U.S. Patent No. 5,465,591), will advance the technology for energy performance by initially using computer modeling and experimental investigation. Based on those results, a list of the most promising technology options for reducing energy and cost will be investigated further. Whirlpool will focus on how to apply the selected technology options to different refrigerator platforms and will develop refrigerator prototypes to demonstrate the targeted energy and food preservation benefits.



Whirlpool's Advanced Dual Evaporator Refrigerator Product

[1] *2010 Buildings Energy Data Book (Table 2.1.6)*, U.S. DOE, March 2011.

Technology History

- Developed by Whirlpool Corporation.
- Continuing performance development and prototype testing and evaluation.

Applications

Can be used in residential refrigeration applications.

Capabilities

- Provides individual cooling needs of freezer and fresh food compartments.
- Uses a single compressor and a three-way diverter valve to deliver refrigerant to dual evaporators.
- Improves refrigerator COP by operating the fresh food compartment evaporator at a higher temperature and pressure than the freezer compartment evaporator.

Benefits

Cost Savings

Reduces energy consumption with a cost premium <$100, shortening homeowner's payback period.

Energy Savings

Exceeds federal minimum energy standards by 20%-25% (ENERGY STAR specification) with a program goal of up to 50% below federal minimum energy consumption.

Performance

Improves performance using sequential dual-evaporator cooling to maintain high humidity in the fresh food compartment and a variable capacity compressor with fan control to minimize the temperature swings.

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Air Bearing Heat Exchanger

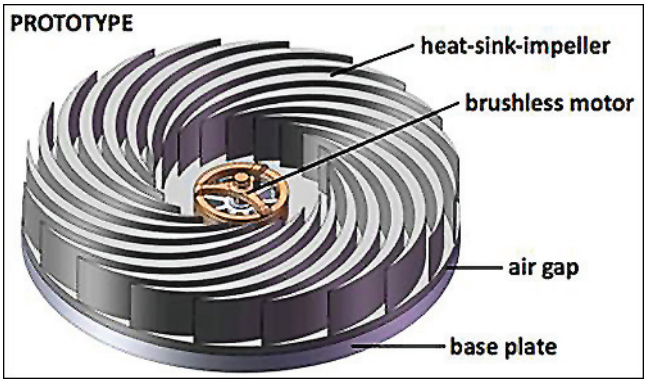
Emerging Technology

Novel Air-Cooled Heat Exchanger Improves Efficiency and Performance of HVAC Equipment

Air-cooled heat exchanger technology has changed so little in the past half century that its role in determining the efficiency, reliability, and net carbon footprint of the nation's energy infrastructure has largely been forgotten. Air conditioners, heat pumps, and refrigeration equipment comprise a significant portion of the load on our nation's electrical grid. The electricity demand spikes imposed by cooling loads are also very detrimental to grid reliability and operating margin. Advances in air-cooled heat exchanger technology should therefore be a central tenet of any grid-surety strategy.

With funding from the U.S. Department of Energy's Building Technologies Program, Sandia National Laboratories (SNL) is developing air bearing heat exchanger technology. In this novel device, heat is transferred across a narrow air gap from a stationary heat spreader to a rotating structure that is a hybrid of a finned heat sink and an impeller. This configuration places the heat sink boundary layer in an accelerating frame of reference, which at several thousand rpm, reduces the thickness of the boundary layer by up to 10 times, thereby greatly enhancing heat transfer.

The device's "direct drive" architecture generates relative motion between the finned heat sink and surrounding air by simply rotating the heat-sink-impeller through the air. This design significantly improves efficiency and reduces fan noise. While conventional fans suffer from limited aerodynamic efficiencies, all of the shaft work provided by the motor of the air bearing heat exchanger is used to create relative motion between the heat sink and the surrounding air. The rotating finned structure is also the first air-cooled heat exchanger device architecture with intrinsic immunity to heat sink fouling. Dust and other foreign matter entering the intake of conventional air-cooled heat exchangers cause severe performance degradation over time. In contrast, these particles do not adhere to the rapidly rotating heat-sink-impeller structure.



SNL's Prototype Air Bearing Heat Exchanger

Technology History

- Developed by SNL.
- Demonstrated Version 1.0 prototype in July 2009.
- Continuing to optimize fluid dynamics and determine device scaling laws.

Applications

Can be used to improve the efficiency and performance of HVAC equipment such as air conditioners, heat pumps, refrigerators, and computer processor fans.

Capabilities

- Increases volumetric cooling capacity by 10 times relative to conventional fan and finned heat sink systems.
- Reduces the amount of audible noise generated during cooling compared with fans.
- Eliminates the common problem of heat sink fouling through rapid rotation of the heat-sink-impeller.

Benefits

Efficiency

Maximizes productive translation of mechanical work into relative motion between the heat sink and the surrounding air, while simultaneously reducing audible noise.

Performance

Improves heat transfer by placing the thermal boundary layer in an accelerating reference frame.

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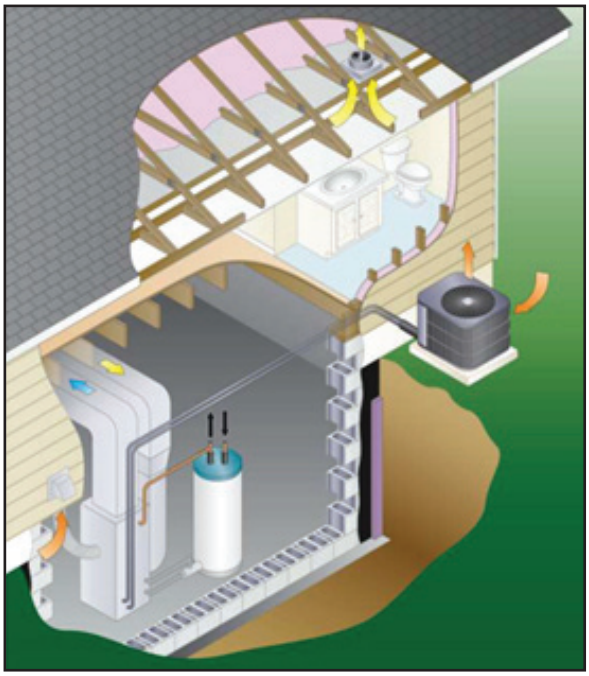
Air-Source Integrated Heat Pump

Emerging Technology

Multi-Function Heat Pump System Reduces Energy Consumption of Building HVAC

U.S. buildings account for 40% of carbon emissions and 75% of power grid capacity.[1] A large energy savings potential could be achieved by minimizing energy consumption for heating, cooling, water heating, and other energy service needs. Typically, separate systems (e.g., a heat pump, water heater, and in some locales a dehumidifier or humidifier) are used to provide these services. Integrating these functions into a single variable-capacity package, an integrated heat pump (IHP), can slash energy consumption and peak electric demand. High-efficiency air-source IHP (AS-IHP) technology has the potential to cut the energy bill for building energy services by 50% or more, depending on location.

With funding from the U.S. Department of Energy's Building Technologies Program, Oak Ridge National Laboratory (ORNL) has developed a variable-capacity AS-IHP concept and is working with a manufacturer under a CRADA (cooperative R&D agreement) to develop a prototype product for field demonstration. The IHP allows normally rejected heat from space cooling and dehumidification to be recovered for water heating, greatly reducing purchased energy requirements. The variable capacity feature of the AS-IHP also reduces purchased energy by allowing the system to operate at less than full capacity (and greatly increased efficiency) most of the time. ORNL and their CRADA partner are in the final stages of development of an initial prototype system. The prototype will be installed in a test residence to begin field trials in late 2011 or early 2012.



ORNL's AS-IHP System

[1] *2010 Buildings Energy Data Book (Tables 1.1.4 and 1.1.9)*, U.S. DOE, March 2011.

Technology History

- Developed by ORNL.
- Continuing development work, with the first prototype scheduled to be installed in late 2011 or early 2012.

Applications

Can be used in new or retrofit residential and small commercial building applications.

Capabilities

- Provides space heating and cooling amenities equivalent to conventional heat pump systems, in addition to water heating and dehumidification control.
- Uses variable-capacity design for improved efficient part load operation.
- Maximizes recovery of waste heat for water heating.

Benefits

Cost Savings

Reduces electricity usage and peak demand costs to the building owner.

Efficiency

Improves energy consumption efficiency by recovering HVAC waste heat and optimizing operation at less than full capacity.

Emissions Reductions

Reduces emissions of CO_2 and other gases (e.g., NO_x).

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Ammonia Absorption Technologies for HVAC Systems

Emerging Technology

Innovative Technologies Provide Energy-Efficient Absorption Space Conditioning

Absorption air conditioning systems, which use heat instead of an electric-motor-driven compressor to drive the refrigeration cycle, offer several advantages compared with conventional vapor-compression systems. Absorption systems use ammonia as the refrigerant, which has a higher heat of vaporization than fluorocarbons and does not have any ozone-depletion or global warming potential. Absorption systems also have fewer moving parts than vapor-compression systems, which increases product lifetime. Despite these advantages, the market penetration of absorption HVAC technologies has been limited by their low level of efficiency.

With funding from the U.S. Department of Energy's Building Technologies Program, Rocky Research is developing new technologies that will increase the efficiency of absorption systems. One important innovation is the use of generator-absorber heat exchange, which captures heat given off by the absorption of ammonia to help drive the distillation of ammonia from water in the generator. Rocky Research's generator uses a special construction to achieve high-efficiency vapor separation, and absorber performance is increased by a heat-transfer surface enhancement that provides good surface wetting at part-load conditions. Efficient operation at partial loads is also achieved by using a pulsing thermal expansion valve that allows for refrigerant flow control over a wide range of capacities and temperatures. These innovations significantly reduce the cycling losses of traditional gas-fired absorption systems. The initial technology developed with these innovations was a 5-ton absorption chiller. To enable the unit to operate as a heat pump at low outdoor temperatures, Rocky Research developed a solution pump with a positive return, which allows for lower solution operating pressures and temperatures. The heat pump will operate at temperatures as low as -22°F and does not require supplemental heating from an electric resistance heater until approximately 0°F. This capability will allow the Rocky Research heat pump to be used in most of the U.S. without any supplemental heating.



Rocky Research's 5-ton Absorption Chiller/Heat Pump

Technology History

- Developed by Rocky Research.
- Recently focused on integrating solar and exhaust heat recovery systems.
- Planning to offer a 5-ton chiller as initial product.

Applications

Can be used as an alternative to vapor-compression air conditioners and heat pumps in residential and light commercial applications.

Capabilities

- Offers variable-capacity operation and reduces cycling losses by using a high-turndown gas burner and a pulsing thermal expansion valve for refrigerant flow control.
- Achieves a cooling coefficient of performance (COP) of 0.7 at an ambient temperature of 95°F and a part-load COP of more than 0.8 at 85°F.
- Achieves a heating COP of 1.4 at 47°F and can provide heat pumping down to -22°F (with supplemental resistance heating beginning at 0°F).

Benefits

Safety

Reduces the chances of brownouts and blackouts during summer heat waves when stress on the electrical grid from air conditioning loads is exceptionally high.

Versatility

Can use natural gas, propane, captured solar heat, and exhaust heat from engines and turbines to power the generator.

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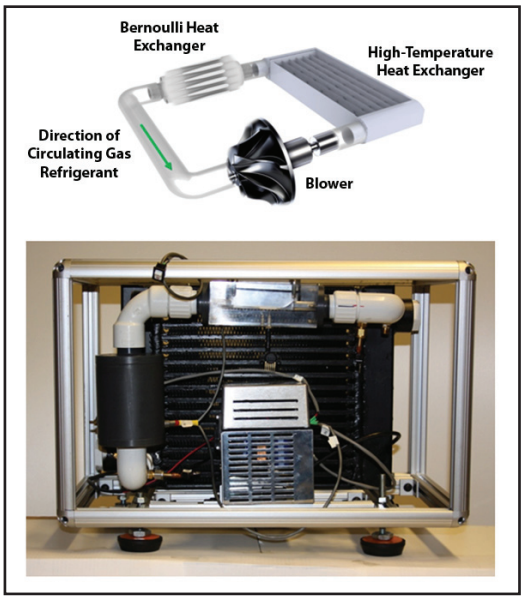
Bernoulli Principle Air Conditioning and Cooling System

Emerging Technology

New Cooling System is Lightweight and Environmentally Friendly

Traditional vapor-compression cooling systems move heat from a low-temperature source to a high-temperature sink by compressing a synthesized refrigerant gas in a compressor. Two drawbacks to this approach are the weight of the compressor (in applications where system weight is important) and the chemical nature of common refrigerants (e.g., R-134a), which are toxic and contribute to global warming. New cooling system designs are needed to overcome these barriers.

With funding from a U.S. Department of Energy Small Business Innovation Research grant (as part of the American Recovery and Reinvestment Act), Machflow Energy, Inc., is developing a new method of cooling that is based on Bernoulli's principle (for a volume of fluid in motion, the sum of all forms of that fluid's energy must remain constant). Machflow's system is driven by a high-speed blower, which circulates a mixture of noble gases (e.g., helium and argon) as the refrigerant. To absorb heat from the space to be cooled, the refrigerant passes through a bundle of Venturi tubes (labeled "Bernoulli Heat Exchanger" in the picture below). In the constricted section of the Venturi tube, an energy-conserving conversion occurs between random molecular motion (temperature and pressure) and directed motion (macroscopic fluid flow). As a result, the velocity of the refrigerant increases while its temperature and pressure decrease. The local decrease in the refrigerant's temperature to below that of the space to be cooled allows heat to be transferred to the refrigerant. The absorbed heat is rejected through a high-temperature heat exchanger after the refrigerant undergoes a relatively small increase in pressure (compared with a compressor) in the blower. Instead of requiring a large pressure change for a small refrigerant flowrate, Machflow's system cools with a smaller pressure change and a much higher refrigerant flowrate. The reduction in weight realized by using a blower instead of a compressor allows Machflow to build lightweight cooling systems with a similar efficiency as present-day vapor-compression heat pumps.



Machflow's Bernoulli Principle Cooling System

Technology History

- Developed by Machflow Energy, Inc.
- Currently building a series of demonstration prototypes to illustrate the technology's applicability in different marketplaces.
- Looking to develop partnerships with industry to help commercialize the technology.

Applications

Can be used in a variety of cooling applications. Anticipated initial uses include cooling for server farms and airborne electronics.

Capabilities

- Uses a lightweight, high-speed blower to circulate gaseous refrigerant. The blower can switch from a slow, low-energy cooling speed to a high-cooling flowrate of Mach 1 in seconds.
- Scales down to small sizes and can integrate well with computer chips and electronics.

Benefits

Environment

Uses inert, non-toxic refrigerants (noble gases) with no ozone-depletion or global warming potential. No documentation is needed if the refrigerant escapes.

Reduced Weight

Reduces the weight of cooling systems compared with conventional vapor-compression equipment.

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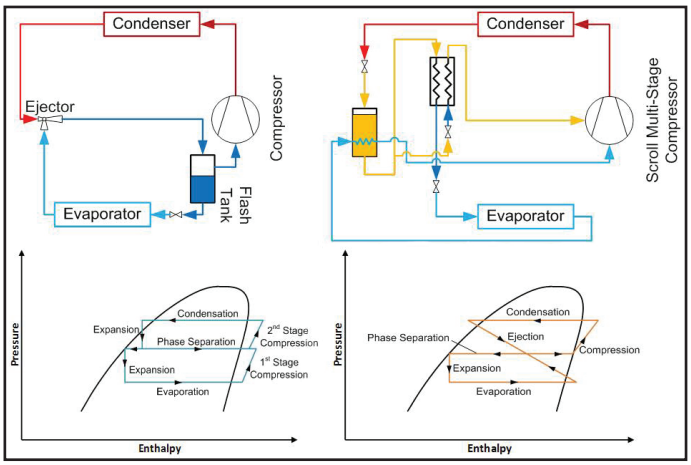
Cold Climate Multi-Stage Heat Pump

Emerging Technology

Heat Pump Technology Saves Energy for Building Heating Applications

About 10% of U.S. energy consumption is used for space heating in residential and commercial buildings.[1] Heat pumps provide significant energy savings compared with electric furnaces and provide a high-efficiency alternative to fossil-fuel-fired central heating systems. However, conventional heat pumps suffer from severe capacity and performance degradation at low ambient temperatures. Currently, heat pumps installed in cold and very cold climates rely on oversized components and require backup heating elements. Most of these direct resistive heating elements have a coefficient of performance (COP) of less than one and do not provide acceptable seasonal performance. The high-performance cold-climate heat pumps available on the market today are costly because of the additional compressor and sophisticated control systems required for operation. As a result, these systems have a higher first cost and longer payback period, which has slowed market penetration.

Oak Ridge National Laboratory (ORNL), with funding from the U.S. Department of Energy's Building Technologies Program, is developing a high-performance cold climate multi-stage heat pump using a single- or multi-speed vapor injected compressor. This setup improves the low ambient temperature performance and greatly increases the COP compared with conventional resistive heating units. The cold climate heat pump (CCHP) system can sustain acceptable heating capacity at low ambient conditions with almost twice the energy efficiency of direct resistive heating. The need for backup resistive heating is eliminated in ORNL's system, which increases the heating season COP. Using a single compressor with a fixed-cycle configuration provides a cost-effective system and is simpler to control. This technology is expected to have an acceptable payback and favorable market penetration. ORNL's CCHP system design and optimization is currently underway with initial prototypes being fabricated for experimental testing and development in a controlled environment. ORNL's goal is to further optimize the system design for the U.S. residential market in cold/very cold climate regions by identifying the most cost-effective system design with sustained performance. ORNL expects to complete the design and fabrication of an initial prototype in 2012.



Advanced CCHP Systems Under Investigation at ORNL

[1] *2010 Buildings Energy Data Book (Tables 1.1.3 and 1.1.5)*, U.S. DOE, March 2011.

Technology History

- Developed by ORNL and industry collaborators.
- Continuing work involves system design optimization, prototype fabrication, and performance testing.

Applications

Can be used for building heating in cold/very cold climate regions instead of inefficient technologies such as electric or natural gas furnaces.

Capabilities

- Provides high-efficiency heating in cold climates.
- Achieves a COP of 4.5 at 47°F ambient temperature with a maximum capacity degradation of 25% down to an ambient temperature of -13°F.
- Provides energy savings of up to 75% compared with electric furnaces and 25% compared with conventional air source heat pumps.

Benefits

Cost Savings

Reduces costs by reducing annual energy consumption and eliminating the need for backup heating.

Energy Security

Provides an energy-efficient alternative to natural gas furnaces, reducing dependence on imported natural gas.

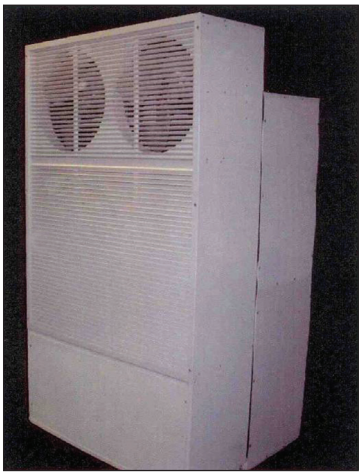
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Comboflair®: An Integrated HVAC and Water Heating System

Packaged System Provides Energy-Efficient Space Conditioning for Manufactured Homes

Manufactured housing is an important part of the U.S. residential market because it constitutes a major portion of affordable housing for low-to-moderate income American families. According to the U.S. Census Bureau, the average cost of a manufactured home in 2010 was $41.45/ft², whereas site-built homes averaged $84.07/ft² (excluding land).[1] While the structural quality of manufactured homes has been improving, few improvements have been made to the energy-related comfort or the efficiency of HVAC systems in these homes. The need for improved space conditioning systems has been identified by the manufactured housing industry and the U.S. Department of Energy's (DOE's) Building America Program.

With funding from DOE's Building Technologies Program, DeLima Associates and a team of project partners have developed the Comboflair, a space conditioning system that enhances energy-related comfort and reduces energy consumption in manufactured homes. The Comboflair combines a packaged air conditioning system with a small-duct, high-velocity air distribution system. A natural gas or propane water heater supplies both the hot water and space heating needs of the home, with space heating delivered via a hydronic coil in the air handler. This arrangement is more cost-effective than separate water heating and electric resistance space heating. Electric resistance heating is the most common heating technology offered with manufactured homes due to its low first cost. Unfortunately, such systems suffer from high operating costs. In the South, where most manufactured homes are sold, the 2009 average residential price of electricity ($31/MMBtu) was more than double that of natural gas ($14/MMBtu).[2] The Comboflair reduces heating costs by using natural gas instead of electricity and also eliminates the quality control problems associated with conventional on-site installation of air conditioners by local HVAC subcontractors. The self-contained packaged unit can be tested and installed at the manufactured home factory prior to shipping.



DeLima Associates' 4-ton Comboflair Unit

[1] *Manufactured Homes Survey*, U.S. Census Bureau and U.S. Department of Housing and Urban Development, November 2011.

[2] *Electric Sales, Revenue, and Average Price (Table 5A)* and *Natural Gas Annual 2009 (Table 23)*, U.S. EIA, November 2010 and December 2010, respectively.

Technology History

- Developed by DeLima Associates, with assistance from a team of project partners from the HVAC, manufactured home, and propane/natural gas industries.
- Currently focused on bringing the completed technology to the market.

Applications

Can be used to improve HVAC energy efficiency and indoor air quality in manufactured homes.

Capabilities

- Provides 2-4 tons of cooling via a vapor-compression system and uses either gas hydronic heating or an electric heat pump with gas hydronic auxiliary heating.
- Achieves a cooling seasonal energy efficiency ratio (SEER) of 13.
- Provides sufficient hot water to maintain a shower temperature of 105°F for more than 20 minutes while maintaining an indoor temperature of 70°F during a peak winter day in the southern U.S.
- Maintains indoor relative humidity between 25%-35%.

Benefits

Ease of Installation

Installs as a single packaged unit at the manufactured home facility. Offers a small footprint (30" x 42" 4-ton unit) for minimal space consumption.

Energy Savings

Uses a small-duct, high-velocity air distribution system to minimize the loss of conditioned air via duct leakage.

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Energy-Efficient Façades for Green Buildings

Solar Heat and Power System Generates and Conserves Energy for Building Utility Loads

Solar energy systems on building façades can provide multiple benefits from both energy conservation and occupant quality perspectives. A high-quality system should reduce the heat and glare of direct sunlight while allowing diffuse natural daylight to flood the interior of a building. The façade should maximize the amount of solar energy captured for conversion or storage so that electricity and heat can be optimally redistributed among a building's multiple utility systems to conserve energy. The design should also be aesthetically attractive for architectural markets.

An integrated, concentrating (IC) solar façade that meets all of these requirements has been developed by the Rensselaer Polytechnic Institute (RPI) Center for Architecture Science and Ecology, with funding from the U.S. Department of Energy's Building Technologies Program, the New York State Energy Research and Development Authority, and the New York State Foundation for Science, Technology and Innovation. The system is architecturally integrated into the façades, clerestories, roofs and atria of buildings while still providing outside views and diffuse daylight for the building's occupants. These benefits are accomplished by miniaturizing and distributing the essential components of concentrating photovoltaic (PV) technology within the weather-sealed building envelopes. The IC system produces electricity with PV cells and captures the remaining solar energy via coolant flow through the receiver on which the cells are mounted. This coolant can be directed through heat exchangers to provide thermal energy for domestic hot water, space heating applications or absorption/adsorption cooling cycles. Solar-tracking technology is used to adjust the angle of the optics and PV cells throughout the day. The direct light from the sun is captured by the optics and directed onto the PV cell and heat sink. The diffuse incident sunlight passes through the translucent components of the system and enters the building to provide the benefits of natural daylighting.

The IC solar façade system has been demonstrated in several "proof of concept" lab and building-scale prototypes. Performance approaching the theoretical optical efficiency has been demonstrated. The first large-scale demonstration will be a retrofit and addition to a New York City midtown atrium, where a 25-ft-high and 260-ft-long daylighting system will be installed in the south-facing façade.



Prototype Installation of RPI's Energy-Efficient Façade at the Syracuse Center of Excellence

Technology History

- Developed by the Rensselaer Polytechnic Institute Center for Architecture Science and Ecology.
- Licensed by HeliOptix, LLC.
- Preparing for large-scale deployment on commercial buildings.

Applications

Can be integrated into façades, clerestories, roofs, and atria of commercial buildings to provide electrical power, thermal energy, enhanced daylighting, and reduced solar gain.

Capabilities

- Produces electricity (peak >2.72 kW/m^2) and hot water (peak >3.93 kW/m^2).
- Provides diffuse daylighting at 3.2 klux.
- Reduces heat gain and glare from direct sunlight.

Benefits

Cost Savings

Reduces building cooling and lighting equipment requirements and operating costs.

Ease of Integration

Modular design easily attaches to a variety of existing building structures or can be implemented during new construction.

Emissions Reductions

Reduces emissions from fossil fuel consumption by using renewable solar energy to meet building electrical and thermal loads.

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Ground-Source Integrated Heat Pump

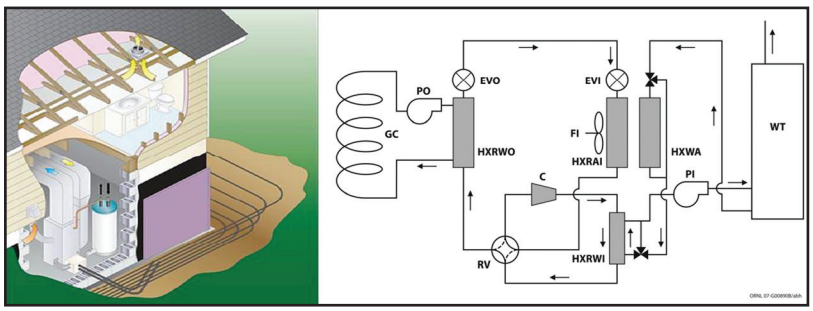
Emerging Technology

Multi-Function Heat Pump System Reduces Energy Consumption of Building HVAC

Maximizing commercial and residential building energy efficiency will contribute greatly to achieving the U.S. Department of Energy's (DOE's) 2020 energy savings targets. Achieving these objectives will require cost-effective, energy-efficient technologies to minimize energy consumption for heating, cooling, water heating, and other energy service needs. Typically, separate systems (e.g., a heat pump, water heater, and in some locales a dehumidifier or humidifier) are used to provide these services. Integrating these functions into a single variable-capacity package, an integrated heat pump (IHP), can slash energy consumption and peak electric demand. High-efficiency ground source IHP (GS-IHP) technology has the potential to cut the energy bill for building energy services by 60% or more, depending on location.

With funding from DOE's Building Technologies Program, Oak Ridge National Laboratory (ORNL) has developed a variable-capacity GS-IHP concept and is working with a manufacturer under a cooperative research and development agreement (CRADA) to demonstrate a first-generation prototype GS-IHP product. The GS-IHP allows normally rejected heat from space cooling and dehumidification to be recovered for water heating, greatly reducing purchased energy requirements. This feature can also reduce the load on the GS-IHP's ground heat exchanger (vertical or horizontal loop or foundation heat exchanger, etc.), allowing the size and cost to be reduced. The variable capacity feature of the GS-IHP also reduces purchased energy by allowing the system to operate at less than full capacity (and greatly increased efficiency) most of the time.

ORNL has installed two of the first-generation prototype products in test houses and has been field testing them in collaboration with the CRADA partner. The CRADA partner is currently working on a second-generation prototype, incorporating lessons learned from the ongoing field tests. These prototypes are expected to begin field trials in late 2011.



ORNL's GS-IHP for Space Conditioning and On-Demand Water Heating

Technology History

- Developed by ORNL.
- Continuing development work to further improve system performance and cost.

Applications

Can be used in new or retrofit residential and small commercial building applications.

Capabilities

- Provides the same space heating and cooling capacity as conventional heat pump systems, in addition to water heating and humidity control.
- Uses variable-capacity design for improved, efficient part load operation.
- Maximizes recovery of waste heat for water heating.
- Uses renewable low-temperature geothermal energy for building energy needs.

Benefits

Cost Savings

Reduces electricity usage and peak demand costs to building owners.

Efficiency

Reduces electricity consumption and peak demand by recovering waste heat and by operating at less than full capacity, which significantly improves energy efficiency.

Emissions

Reduces emissions of CO_2 and other gases (e.g., NO_x).

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HyPak: A High-Efficiency Rooftop Packaged HVAC System

New Technology Provides Low-Cost, Energy-Efficient Space Conditioning

More than half of U.S. commercial building space is cooled by packaged HVAC equipment, most of which are rooftop units (RTUs). RTUs are popular because they are inexpensive, provide zonal control, are easy to install, can be serviced without disrupting building occupants, and are familiar to the HVAC industry. Unfortunately, existing RTUs are also very inefficient. Conventional RTUs often have single-speed motors for their supply and exhaust blowers, which consume the same amount of power regardless of changes in airflow requirements. In addition, the air-cooled condensers found in many RTUs struggle to reject heat at high outdoor temperatures, which increases the workload of the unit's compressor. An improved RTU design is needed that offers the advantages of conventional RTUs and energy-efficient operation.

With funding from the U.S. Department of Energy's Building Technologies Program, Davis Energy Group, Inc. (DEG), is developing the HyPak, an RTU that combines several innovative features to reduce HVAC energy consumption. The design uses a novel cooling tower (known as the "counterflow evaporative water cooler" or CEWC) to cool condenser water and simultaneously pre-cool outdoor ventilation air. Evaporative cooling allows the condenser to operate near the ambient wet-bulb temperature instead of dry-bulb, which significantly improves performance in hot, dry conditions. The HyPak uses an oversized evaporator coil relative to conventional RTUs, which allows for a higher evaporative temperature and therefore reduces the power consumption of the compressor. A wide fin spacing (8 fins per inch versus 15 in a conventional RTU) is used on the evaporator coil to minimize pressure drop and reduce the chance of bacterial growth across the fins.

Additional energy-saving features of the HyPak include variable-speed blowers to maximize efficiency in partial-load conditions and a variable-capacity tankless gas water heater (coupled to a hydronic air coil) for heating. DEG plans to develop a unit that can deliver up to 100% outdoor air (for nights when the outdoor air temperature is less than that of the return air) and an automated process to reduce the cost of assembling the CEWC.



Prototype Installation of DEG's HyPak Rooftop HVAC System

Technology History

- Developed by DEG, in partnership with Munters Corporation and with support from the National Energy Technology Laboratory.
- Planning to develop a unit that can deliver up to 100% outdoor air and an automated process for assembly of the unit's CEWC.

Applications

Can be used to provide energy-efficient space conditioning in commercial buildings.

Capabilities

- Provides 10-30 tons of cooling capacity with an energy efficiency ratio of 16-20, depending on outdoor conditions.
- Cools condenser inlet water to 75°F and pre-cools outdoor air from 105°F to 80°F at a wet-bulb temperature of 70°F.
- Delivers up to 40% ventilation air using variable-speed supply and exhaust blowers to match airflow requirements.

Benefits

Cost Savings

Reduces peak HVAC electricity consumption by using evaporative cooling, which is most effective at high outdoor temperatures.

Indoor Air Quality

Improves indoor air quality by using a high-efficiency air filter and ultraviolet light disinfection system, which prevents any biological contaminants in the supply air stream from entering the building.

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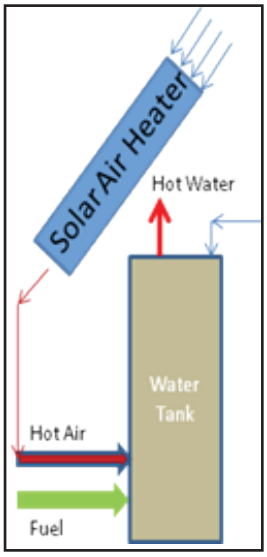
Improving Efficiency of Fuel-Fired Furnaces for Space and Water Heating Systems

Emerging Technology

Combustion Air Pre-Heating System Uses Solar Power to Save Energy

Residential and commercial buildings account for 41% of annual U.S. energy consumption; about 30% of this consumption is used for space heating and water heating.[1] One potential solution to reduce fossil fuel consumption in all types of furnaces is to preheat combustion air. Commercial and industrial customers would benefit more from this method than residential customers because of differences in the end-use patterns. Another solution is to use solar energy, which can preheat air up to 170°F in several U.S. climates. Fuel savings are proportional to the temperature and volume of preheated air supplied for combustion in the furnace. Using solar technology in this way enables meaningful improvement in fuel savings with small, inexpensive collectors.

Oak Ridge National Laboratory (ORNL), with funding from DOE's Building Technologies Program, is investigating the use of inexpensive solar air heaters for preheating air fed to furnaces for space conditioning and for water heating. Simulations show that a solar air heater as small as 2 m^2 can produce 8 cubic feet per minute (cfm) of preheated air at a temperature of >95°F. This output is independent of cold or hot climates, such as Chicago or Miami, with the only difference being the annual usability, 2,500 hours versus 3,700 hours, respectively. When combined with water heating, the technology may potentially reduce fuel consumption by 7%-13%. The solar technology also has the advantage that it can be retrofitted into existing furnace systems, which addresses a large market sector in commercial, industrial, and residential applications. The simplicity of this technology will enable a quick time to market and large-scale implementation.



ORNL's Solar Air Heating System

[1] *2010 Buildings Energy Data Book (Tables 1.1.3 and 1.1.5)*, U.S. DOE, March 2011.

Technology History

- Developed by ORNL.
- Continuing development to improve performance, reduce costs, and design for manufacturability.

Applications

Can be used as a standalone system in commercial and industrial applications.

Capabilities

- Reduces fuel consumption by up to 7% and improves fuel efficiency.
- Reduces fuel costs by using energy in preheated air and reduces fuel requirements for same capacity throughput.
- Produces 8 cfm of pre-heated air (≥95°F) in cold and hot climates.

Benefits

Cost Savings

Reduces the cost of fuel by taking advantage of the energy in preheated air and the need for less fuel for same capacity throughput.

Durability

Improves product efficiency over its lifetime.

Installation

Easily retrofits into existing heating systems.

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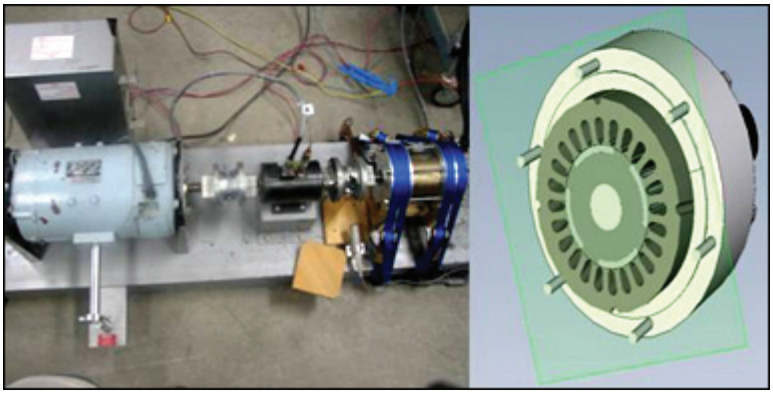
Improving Electric Motor Efficiency

Testing and Simulation Process Evaluates Motor Materials, Design, and Performance

Electric motors in the commercial and residential sectors account for roughly 38% of annual U.S. electricity consumption, or about 1430 TWh.[1] Improvements in electric motor efficiency can therefore contribute significantly to the U.S. Department of Energy's (DOE's) 2015 energy conservation goals. Motor efficiency can be improved by characterizing and understanding the magnetic properties of the materials used in motor components. A comprehensive testing method is needed to characterize losses during motor operation and to evaluate the effects of material lamination thickness, annealing, and processing.

With funding from DOE's Building Technologies Program, SMMA - The Motor and Motion Association, and a consortium of industry partners are developing test methods, equipment, and software simulation models to improve the efficiency of electric motors used in commercial and residential applications. The project is investigating current design conventions, materials, and manufacturing processes. SMMA's testing methods examine a greater number of motor operating parameters across a wider range of conditions than current procedures, and do so in a reduced amount of time. The expanded test parameter dataset reduces errors arising from extrapolation of motor behavior to conditions not included in conventional tests. A computer-controlled system is being developed that will facilitate flexible, customizable, multi-parameter testing (including Epstein, Toroid, and Single Strip tests) in accordance with the ASTM A343 industry standard.

Data from the new testing method were used to improve the validity and accuracy of existing electric motor simulation models. The simulation results have been compared with conventional design results, allowing the differences to be analyzed for potential motor efficiency gains. An enhanced computer modeling motor design package was also developed and tested by an industry partner. This computer aided design (CAD) package was used in the assembly of a new motor prototype, resulting in improved efficiency and performance behavior that matched predictions by the computer simulation. Further evaluation and research will be performed with the goal of building upon the demonstrated improvements.



SMMA's Motor Characterization Test Bed and CAD Output

[1] *Energy-Efficiency Policy Opportunities for Electric Motor-Driven Systems (pg. 36, Table 14)*, International Energy Agency, 2011.

Technology History

- Developed by SMMA, with assistance from Clarkson University, the Electric Motor Education and Research Foundation, and industry partners.
- Seeking research funding opportunities to develop materials and components for improving motor efficiency.

Applications

Can be used to improve electric motor efficiency in commercial and residential applications.

Capabilities

- Improves the throughput of testing and material characterization.
- Enhances product development and enables motor components to be designed for manufacturability.

Benefits

Cost Savings

Automates testing procedures and streamlines the motor design and development process.

Efficiency

Reduces electric motor losses, thereby providing performance and efficiency gains.

Productivity

Extends battery life and reduces downtime from motor failure or maintenance.

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Multi-Zone HVAC Options for Residential Applications

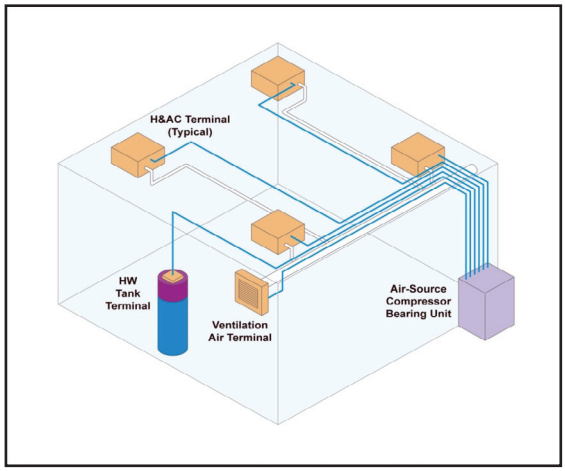
Emerging Technology

System Uses Advanced, Integrated HVAC and Water Heating to Reduce Energy Consumption

One option for achieving greater energy savings in providing space conditioning (temperature and humidity control) and hot water for buildings is to integrate these functions. This integration can be accomplished by using an integrated heat pump (IHP), which is being developed by multiple manufacturers. Conventional, centrally ducted HVAC systems, the most common U.S. configuration, provides space conditioning to both unoccupied and occupied portions of a dwelling, despite space-conditioning only being needed in the occupied portion of the dwelling. The space conditioning of unoccupied areas of a building wastes energy. Zoned HVAC systems can provide full space conditioning to select portions of the building; unused or less-used areas are not fully conditioned, except when needed. Such systems exist in the market today.

Oak Ridge National Laboratory (ORNL), with funding from the U.S. Department of Energy's Building Technologies Program, is developing HVAC systems that would use an IHP in a zoned HVAC configuration. Such a system would add the energy savings from an IHP to those achieved by zoning the HVAC, improving energy efficiency levels. Energy savings are gained from reducing delivered loads and/or running more efficiently at lower compressor and fan speeds, in variable-speed zoned systems, for longer periods. Achievable space conditioning energy savings are estimated to be 15%-25%, depending on the climate and degree of zoning setback used.

ORNL is examining what level of additional energy savings can reasonably be expected and if those savings more than offset the additional cost to install the system (which varies between various configurations). State-of-the-art calculations are being performed to compare the projected energy savings of four, different, zoned, integrated appliance options with a baseline system using a central heat pump without zoning and a conventional electric water heater. These calculations are being performed for a relatively large 5-zone house (2,600 ft^2) because larger houses are more likely to benefit from zoning. The ultimate objective is to provide a reliable basis for judging whether integrated, zoned HVAC systems warrant further development.



ORNL's IHP-Multi-Zone HVAC System

Technology History

- Developed by ORNL.
- Continuing work developing energy-saving zoned HVAC for residential applications.

Applications

Can be used for residential HVAC systems in larger homes >2500 ft^2.

Capabilities

- Reduces electricity consumption for space conditioning by 15%-25%.
- Uses variable refrigerant flow to provide economical and efficient zoned space conditioning to meet demand.

Benefits

Cost Savings

Reduces electricity costs (which must be compared with the first cost of a zoned HVAC system).

Efficiency

Increases electric energy savings by not fully conditioning unoccupied space (adding to that which has already been achieved by IHPs).

Installation

Easily retrofits into existing homes, depending on the configuration.

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Nanographitic Additive for Enhanced Heat Transfer and Lubricity of Refrigerant Systems

Emerging Technology

Refrigerant Additive Improves HVAC Energy Efficiency

HVAC systems account for 38% of primary energy consumption in the U.S. buildings sector, or 15.3 quads per year.[1] Improving the efficiency of HVAC systems can therefore significantly reduce U.S. energy consumption. The key attributes of an air-conditioning system are the compressor's mechanical efficiency and the thermal efficiency (heat transfer) of the refrigerant. Unfortunately, refrigerant lubricants that improve compressor performance (by reducing friction) often have a negative impact on the heat transfer properties of the refrigerant.

To overcome this technical challenge, Oak Ridge National Laboratory (ORNL), with funding from the U.S. Department of Energy's Building Technologies Program, is developing an HVAC refrigerant and lubricant nanographene additive (NGA) to increase operational thermal efficiency and thereby reduce overall energy consumption. Nanographene is exfoliated graphite and light weight, with a thermal conductivity >1000 W/mK, two and half times that of copper. These characteristics underlie the reduced friction and improved heat transfer capabilities for reducing HVAC system energy consumption. ORNL has focused on functionalizing the NGA within the refrigerant for HVAC systems and quantifying the thermal energy efficiency improvements obtained by using NGA in the refrigerant.

To achieve its objectives, ORNL developed two thermal efficiency characterization platforms. The first system is a thermosyphon, which is a thermal efficiency characterization system modeled on that of power plants and provides a means to investigate energy transfer from a heater to a working fluid and to moderate the effects of a nanoadditive. This system is being used to optimize the boiling process enhancement effect of NGA in a HVAC thermal cycling system. The second system uses portable window HVAC units modified for evacuation and charging of refrigerant and lubricant and for external control and operation. These modifications enable known quantities of a nanoadditive to be loaded into a working HVAC unit and then operated continuously or in pulsed mode. This platform is being used to quantify the impact of NGA on HVAC energy use.



ORNL's Refrigerant Thermal Characterization and HVAC Energy Use Test Facility

[1] *2010 Buildings Energy Data Book (Table 1.1.5)*, U.S. DOE, March 2011.

Technology History

- Developed by ORNL.
- Continuing nanoadditive development, testing, and optimization for use in HVAC systems.

Applications

Can be used in residential, commercial, and industrial HVAC systems and boiler-based power plant energy generation applications.

Capabilities

- Improves overall HVAC operational power consumption by 4%-11%.
- Reduces electric power consumption and enhances lubrication of moving parts in HVAC systems.
- Enables thermal energy utilization and efficiency characterization of thermosyphon based nanoaddidtives.
- Enables energy utilization profiling of HVAC test platform by programmable control.

Benefits

Cost Savings

Reduces compressor frictional loading on startup, reducing startup torque and the likelihood for premature failure.

Emissions

Reduces global warming emissions by reducing utility load demand, thereby reducing power generation emissions.

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Next-Generation Refrigerant Lubricants

Emerging Technology

Low-GWP Refrigerant Lubricants Optimize Performance of HVAC and Refrigeration Systems

Polyol esters (POEs) have been the lubricant of choice for hydrofluorocarbon (HFC)-refrigerant-based stationary refrigeration and air conditioning systems since the early 1990s. Because many HFCs have high global warming potential (GWP) values, efforts are underway to commercialize alternatives with significantly lower impact on the environment. Alternatives under consideration include low-GWP HFCs like difluoromethane (R-32), hydrofluoroolefins (HFOs), and natural refrigerants such as hydrocarbons or CO_2. (On a scale where CO_2 has a GWP of 1, the common HFC refrigerant R-134a has a GWP of 1300. R-32, HFOs, and hydrocarbons have approximate GWP values of 600, 5, and 3, respectively.) To minimize friction and wear in the compressor, optimized compatibility of the refrigerant with the lubricant is critical and will reduce energy consumption, increase the compressor's service life, and maintain high-efficiency heat transfer in the refrigeration system. In general, the molecular structure characteristics of POEs that contribute to the best efficiency in the refrigeration circuit are inversely related to those characteristics that improve lubricity and performance of the lubricant in the compressor.

Chemtura Corporation, with funding from the U.S. Department of Energy's Building Technologies Program (as part of the American Recovery and Reinvestment Act), patented POE technology that has potential application in developing synthetic refrigeration lubricants with the best possible balance of both lubricity and refrigerant compatibility. Chemtura has optimized synthetic lubricants for several different refrigerants and applications such as low GWP HFCs (e.g., R-32, HFOs, and HFO/HFC blends), hydrocarbons, and CO_2. One advantage of this synthetic ester technology is that the structure of the molecules can be tailored and/or optimized for a specific refrigerant. These products are currently being tested by several compressor manufacturers and refrigeration system builders. Transfer of the laboratory-scale process to manufacturing is underway.



Chemtura's Synthetic Refrigerant Lubricant Lab-Scale Manufacturing Process

Technology History

- Developed by Chemtura Corporation.
- Continuing development of large-scale manufacturing process for next-generation synthetic lubricants and lubricant-refrigerant system testing and evaluation.

Applications

Can be used in refrigeration and air-conditioning equipment applications.

Capabilities

- Improves balance of frictional properties and refrigerant compatibility compared with current commercial synthetic lubricants.
- Provides synthetic ester lubricants for refrigeration applications using R-410A, hydrocarbons (R-290, R-600), and CO_2 (R-744) refrigerants.
- Optimized for use with next-generation, ultralow GWP refrigerants.

Benefits

Environment

Maximizes energy efficiency of zero ozone depleting and low GWP refrigerants in refrigeration and air conditioning systems.

Performance

Provides optimized balance between lubricity and refrigerant compatibility to achieve the best lubrication performance and heat exchanger efficiency.

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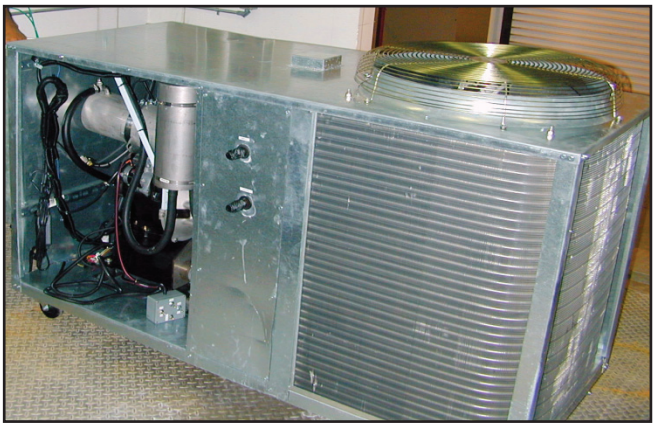
Residential Fuel-Fired, Multifunction Heat Pump

Emerging Technology

New Heat Pump Saves Primary Energy and Reduces Greenhouse Gas Emissions

HVAC equipment for residential and commercial buildings consumes approximately 38% of the total energy used in buildings, a total of 15.34 quads.[1] Water heating and electric heating and cooling are important contributors to peak electricity demand. In residential buildings, space heating is the dominant component of energy consumption, accounting for 26.5%, followed by space cooling at 15.8%.[1] Natural-gas-fired furnaces and boilers are the most common heating systems. Water heating constitutes the next largest element of primary residential energy consumption after space conditioning, accounting for 13.2% of energy consumption.[1] Energy efficiency of HVAC and water heating technology could be significantly increased with improved coefficient of performance (COP), e.g., cooling COP = 1.3 and heating COP = 1.5, and reducing it's primary energy usage by over 30%.

With funding from DOE's Building Technologies Program, Oak Ridge National Laboratory (ORNL) and Southwest Gas are developing a residential, fuel-fired, multifunction heat pump that achieves high source energy efficiency for space conditioning and water heating. The proposed technology is similar to traditional heat pump units but with two main differences. First, the primary energy savings are higher, based on a site versus source comparison, as the result of using natural gas to supply shaft power to the compressor rather than an electric motor. Second, waste heat is recovered from the engine to supplement space and water heating and to reduce the energy input. The recovered waste heat will be applied to the refrigerant during the heating season and to water during the cooling season. The system is controlled by a programmable logic controller (PLC) that determines how much waste heat is allocated when both space and water heating are required, based on the predetermined settings stored in the PLC's memory. The PLC controls the compressor and fan speeds and allows the multifunction HVAC system and building demand to be monitored.



ORNL's Prototype Fuel-Fired, Multifunction Heat Pump

[1] *2010 Buildings Energy Data Book (Tables 1.1.5 and 2.1.6)*, U.S. DOE, March 2011.

Technology History

- Developed by ORNL and industry partner, Southwest Gas.
- Continuing development work to improve performance and cost prior to market introduction.

Applications

Can be used as alternative to electric heat pump and gas furnaces in residential applications.

Capabilities

- Provides 2 to 5 tons of cooling capacity.
- Achieves a cooling COP of 1.3 at an ambient temperature of 95°F and a heating COP of 1.5 at 47°F.
- Provides low ambient heating by recovering waste heat from fuel combustion.
- Provides 60 gallon per day domestic hot water at 140°F from waste heat recovery.
- Provides variable-capacity operation to meet user demand.

Benefits

Cost Savings

Reduces primary energy usage by recovering waste heat to supplement heating and produce hot water.

Installation

Easily retrofits into existing residential applications or new residential installations.

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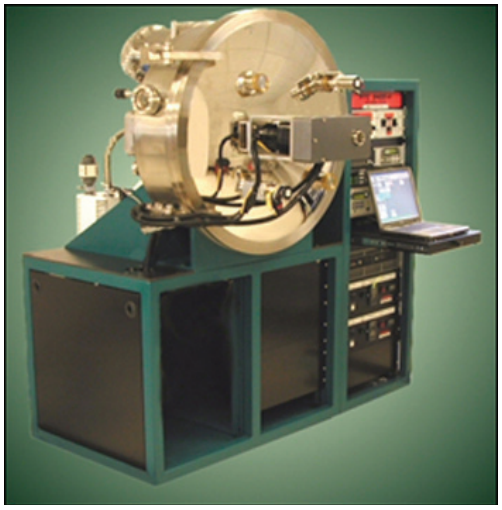
Thermoelectric Materials for Waste Heat Recovery

Emerging Technology

Nanoscale, Multilayer Film Deposition Process Increases Efficiency of TE Materials

The thermoelectric (TE) effect is the direct conversion of a thermal gradient (temperature difference, ΔT) into an electrical potential difference (voltage) and vice versa. The ideal application of TE technology is in buildings, where waste heat from furnaces, water heaters, and concentrated solar energy systems could be recovered. TE devices operated in reverse could potentially compete with and eventually exceed the performance of commercial vapor compression cooling systems used in refrigeration and air conditioning units. The cost, efficiency, and performance of TE devices must be improved if TE-based systems are to become alternatives to conventional building technologies. TE material efficiency is expressed as a value of ZT, the material's "figure of merit", Z, times its average absolute operating temperature, T. Historically, ZT values for TE devices have been around 1.0, which is insufficient to compete with vapor compression cooling systems. TE coolers in use today have a coefficient of performance (COP) of about 0.5, whereas most air conditioners and refrigerators have COP values of 3-5.

With funding from the U.S. Department of Energy's Building Technologies Program, Hi-Z Technology, Inc., is developing a unique nanoscale materials approach to overcome the cost and efficiency limitations that have prevented TE systems from being deployed in large markets. This technique produces a quantum well thermoelectric (QWTE) device, which has an in-plane film topology to control heat and current flow. Alternating layers of semiconductors having different electronic properties are deposited and yield a ZT >2.0 and superior electrical performance compared with bulk alloys. The process can be automated to enable affordable, high-volume fabrication and uses readily available, abundant, nontoxic materials. Hi-Z is continuing to develop the technology, and early results have demonstrated ZT >3.0 at room temperature and ZT >6.0 at 325°C. Research is being conducted to fabricate these materials into modules, reduce heat losses within the devices, and improve the electrical contacts on the thin films. Hi-Z expects to produce the first high-efficiency device within the next two years.



Hi-Z's Sputter Coating System for Producing QWTE Devices

Technology History

- Developed by Hi-Z Technology, Inc.
- Currently improving device technology and seeking manufacturing partnerships.

Applications

Can be used to convert waste heat from furnaces, water heaters, and solar panels into electricity, or act as a heat pump for refrigeration and air conditioning if supplied with an electric current.

Capabilities

- Achieves up to 50 W output at 15% efficiency; Hi-Z's current module produces 14 W at 5% efficiency.
- Achieves a COP of 3.0, which is comparable to conventional mechanical vapor compression cooling systems.

Benefits

Cost Savings

Reduces manufacturing costs using automated process and readily available Si, C, B, and N.

Durability

Uses solid-state, high-temperature-compatible materials that require less maintenance than conventional systems.

Environmental

Avoids using toxic and expensive materials such as Te, Co, As, Ir, and Pb. Reduces emissions by reducing energy consumption.

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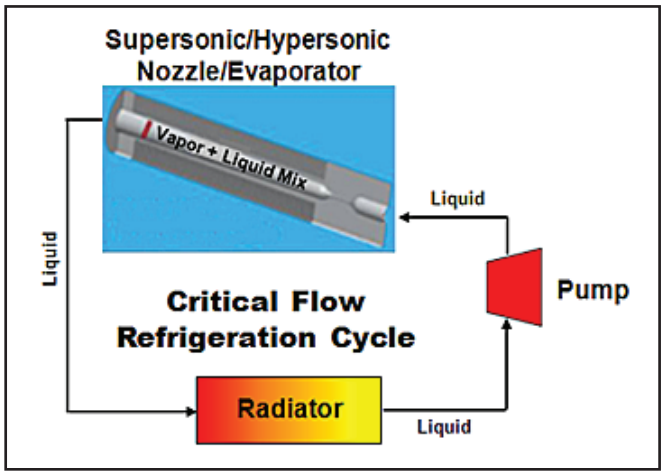
Water-Based, Critical Flow, Non-Vapor-Compression Cooling System

Emerging Technology

New Technology Provides Energy-Efficient Alternative to Vapor Compression Cooling

Vapor-compression cooling systems are commonly used to provide air conditioning, refrigeration, and chilled water in the commercial and residential sectors. These systems typically operate with a coefficient of performance (COP) between 2 and 5, which is significantly lower than their theoretically achievable efficiency. The efficiency-limiting factor for these systems is the work required to compress a vaporized refrigerant to the pressure/temperature required for it to be condensed into a liquid by ambient air blown across the unit's condenser coils. A need exists for improved cooling systems that can overcome the barriers related to compressor performance.

With funding from the U.S. Department of Energy's Building Technologies Program (as part of the American Recovery and Reinvestment Act), Caitin, Inc., is developing a new refrigeration cycle that operates by pumping a liquid refrigerant to high pressures instead of compressing a vapor. It takes less work to pressurize a liquid than it does to compress a gas, so a liquid-pump-based system with the same cooling capacity as a vapor compression system can operate with significantly higher efficiency (i.e., a higher COP). In Caitin's system, a pump is used to pressurize liquid water from ambient conditions (about 15 psi) to more than 100 psi. The water is then forced through a nozzle, which causes its pressure to drop to about 5 psi. This abrupt pressure drop causes some of the liquid to flash vaporize and lowers the temperature of the liquid/vapor mix to the point where it can absorb heat from the space to be conditioned (causing more of the liquid to boil in the evaporator tube). Passage through the nozzle also increases the velocity of the refrigerant to greater than or equal to the speed of sound, a condition known as critical flow. Under critical flow conditions, a compression wave is generated that "shocks" the refrigerant up to the ambient pressure (about 15 psi) as it exits the evaporator tube, resulting in condensation of the vaporized portion of the vapor/liquid mix. The heat that was absorbed by the circulating refrigerant is then rejected to the environment via a radiator.



Caitin's Critical Flow Refrigeration Cycle

Technology History

- Developed by Caitin, Inc., with assistance from Kansas State University.
- Currently optimizing cooling nozzle and developing system for commercial HVAC applications.

Applications

Can be used to provide chilled process water for a variety of applications (e.g., electronics cooling or central air conditioning in commercial buildings).

Capabilities

- Offers a scalable cooling capacity from 1 to 25 kW.
- Operates with a COP of up to 10.
- Improves heat transfer by using a refrigerant with a high enthalpy of vaporization. Heat transfer coefficients in excess of 100,000 W/(m^2-K) have been achieved.

Benefits

Energy Savings

Saves energy by pumping a liquid refrigerant to high pressures instead of compressing a vapor.

Environment

Provides an environmentally friendly alternative to hydrofluorocarbon refrigerants (e.g., R-134a), which contribute to global warming and can be harmful to building occupants if released in a confined space.

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Wireless Remote Monitoring System for Residential Air Conditioners and Heat Pumps

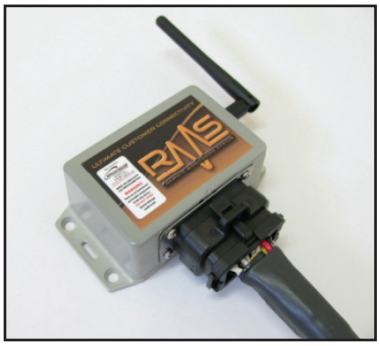
Emerging Technology

New Technology Reduces Air Conditioning Energy Consumption and Expenses

In a typical home, one of the largest sources of energy consumption is the air conditioning (AC) or heat pump system. If the AC is operating at degraded efficiency, a homeowner can be unaware of the equipment problem because the house is still cool (even though the AC is running continuously to keep up). Degraded AC efficiency results in wasted energy, reduced system life, and a tendency for units to fail on hot days. AC units that break have usually been operating with reduced cooling capacity (and for longer periods without cycling) for some time, but the reduced capacity only becomes apparent on the first hot day when the unit can't keep up anymore. Conventional systems capable of monitoring the "operational health" of AC units are typically expensive and only report raw data from sensor outputs. New technologies capable of analyzing AC performance and identifying the likely cause of the problem are needed so that homeowners can take preventative action before their AC units fail entirely.

With funding from a U.S. Department of Energy Small Business Innovation Research grant (as part of the American Recovery and Reinvestment Act), Mainstream Engineering Corporation is developing an innovative, low-cost device to detect AC problems and identify their causes. The Remote Monitoring System continuously and automatically monitors an AC unit and detects possible maintenance issues (e.g., clogged air filter or dirty condenser coils) and service issues (e.g., low refrigerant charge, failed start or run capacitors for the compressor motor, faulty fans/blowers, compressor short cycling, or a clogged expansion valve). When a problem is detected, the system automatically sends a notification with problem-specific information to the homeowner and the AC service company that installed the unit. This information enables the service company to send a technician with the proper supplies, avoiding multiple trips. The homeowner or technician can log on to a secure website to investigate the unit's energy consumption, compare its current performance with that of prior years, and carry out "what if" calculations to determine the economic feasibility of replacing the current unit with a more efficient one.

Mainstream is currently developing the technical and marketing aspects of the technology in preparation for field testing of a preproduction prototype in homes during the summer of 2012. If the field tests are successful, Mainstream will commercialize the technology through HVAC/R service contractors.



Mainstream's Remote Monitoring System

Technology History

- Developed by Mainstream Engineering Corporation.
- Currently developing the technical and marketing/sales aspects of the technology in preparation for field testing in homes.

Applications

Can be used to automatically monitor and detect problems in residential air conditioning systems.

Capabilities

- Diagnoses common AC problems that waste energy and shorten equipment life.
- Transmits information on system welfare to the homeowner and repair technician via a wireless internet signal.
- Records equipment operating history to allow for energy consumption analysis and comparisons.
- Uses three temperature sensors, a current sensor, and three voltage sensors placed on the outdoor condenser unit to detect AC or heat pump performance issues.

Benefits

Cost Savings

Alerts homeowners to simple AC maintenance issues that can be fixed with a minimum of time and expense, preventing the costly replacement of a failed unit.

Energy Savings

Saves energy (and money) by enabling rapid detection and resolution of problems that degrade AC efficiency (e.g., low refrigerant charge).

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D.4 LED Devices

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Advanced Manufacturing Methods for Warm-White LEDs for General Lighting

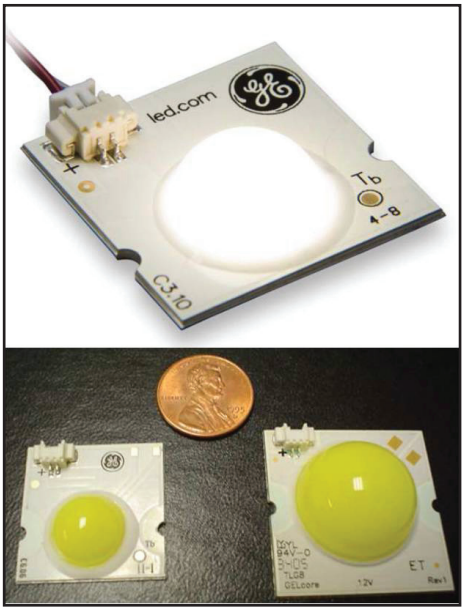
Emerging Technology

Illumination-Grade LED Manufacturing Process Reduces Costs

Over the next two decades, solid-state lighting (SSL) could reduce U.S. lighting electricity consumption by 25%.[1] For widespread adoption to occur, SSL product performance, quality, and value proposition need to improve as well as the knowledge and awareness of the consumer and the lighting community. Most SSL products rely on the phosphor down conversion of the light radiating from a blue LED to produce a white-light-like spectrum. Typically, the phosphor is mixed with an epoxy encapsulant and placed in contact with an LED chip. The remote phosphor approach is the exact opposite: the phosphor is not in contact with the emitter chip. This approach has been shown to improve light extraction and provide stable and consistent color and light output. Thermal degradation of the phosphor and the LED emitter's dependency on wavelength to produce the desired white light are also reduced.

General Electric (GE) Lighting Solutions, LLC, with funding from the U.S. Department of Energy's Building Technologies Program (as part of the American Recovery and Reinvestment Act), is designing and developing specialized manufacturing techniques to improve the consistency, productivity, and cost of remote phosphor components. A manufacturing process is being redesigned for improved throughput by adopting automation and using electronic industry assembly standards. These improvements will help achieve cost savings goals and enable GE to offer an LED platform that is more accessible for widespread general lighting systems.

GE manufactures a remote-phosphor-based LED product, the Vio™, at its Nela Park facility in Cleveland, Ohio. This facility will be the pilot manufacturing line for GE's development work.



GE Lighting Solutions's Remote Phosphor LED Product

[1] *Energy Savings Potential of Solid-State Lighting in General Illumination Applications 2010 to 2030*, U.S. DOE, February 2010.

Technology History

- Developed by GE Lighting Solutions, LLC.
- Continuing work on reliability testing, scale up of laboratory process, and adaptation to high-volume manufacturing lines.

Applications

Can be used to manufacture LED products used in lighting applications.

Capabilities

- Produces 300 lm light output with a color rendering index >85 in warm-white.
- Reduces labor and materials capital costs by up to 53%.
- Achieves coating consistency using a remote phosphor molding process.

Benefits

Cost Savings

Reduces materials and labor costs using industry assembly standards and automation.

Performance

Can reach the efficacy target of >75 lm/W with <30% lumen depreciation and color shift of less than two-step MacAdam ellipse over 50,000 hours.

Product Quality

Provides color binning characteristics within a four-step MacAdam ellipse of the black body curve.

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Affordable, High-Efficiency Solid-State Downlight Luminaires with Novel Cooling

Emerging Technology

High-Efficiency LED Replacement Lamp Saves Energy and Reduces Costs for Lighting Applications

Light-emitting diode (LED) lamps are rapidly gaining acceptance in commercial and residential lighting applications. However, thermal management and high system cost remain key barriers to broad market penetration. Passive heat sinks are often unable to manage the large heat fluxes generated by the LEDs, compromising the system efficacy and lifetime. In addition, these lamps often require high LED chip counts to meet overall lumen targets, thereby increasing the initial system cost.

To overcome these limitations, GE Global Research, with funding from the Department of Energy's Building Technologies Program, has developed an LED-based 1500 lumen lamp that uses revolutionary cooling technology to improve performance and reduce lighting energy costs. GE synthetic jets are very small micro-fluidic, bellows-type devices that provide high-velocity jets of air that impinge on the LED heat sink. These jets of air increase the heat transfer rate to more than ten times that of natural convection. The improved cooling enables LED operation at high drive currents without losses in efficiency or lifetime. For a given lumen output, the synthetic jets' improved thermal management reduces the necessary LED chip count by 40%, dramatically lowering the cost of the lamp. In addition to performance and cost advantages, the synthetic jet cooling reduces LED lamp size and weight.

GE and its project partner, the University of Maryland, are currently developing physics-of-failure-based models to accurately predict product reliability and any potential failure modes. This work will lead to LED lighting systems with optimized reliability to guarantee a 50,000 hour product lifetime. The current program strategy is independent of chip-level technology. Therefore, any advances in LED chip-level performance will be additive to the technologies developed in this program. The multiple benefits offered by this improved LED technology will enable these lamps to significantly penetrate the general lighting markets.



Prototype GE Synthetic Jet Cooled LED Lamp

Technology History

- Developed by GE Global Research in partnership with GE Lighting Systems and the University of Maryland.
- Continuing work to optimize the design for manufacturing and reliability.

Applications

Can be used as a high-efficiency replacement for conventional 1500 lumen incandescent and compact fluorescent light bulbs in both residential and commercial applications.

Capabilities

- Produces 1500 lumens at a color rendering index (CRI) of 81 and a correlated color temperature (CCT) of 3100 K.
- Achieves efficacies exceeding 50 lumens per watt (LPW) for warm white light and 75 LPW for cool white light.
- Maintains high performance over its installed lifetime through optional 180, 50, and 20 degree full width half maximum beam angle control.

Benefits

Cost Savings

Reduces initial system cost by using synthetic jet cooling, which lowers the LED chip count necessary to meet lumen output targets.

Product Quality

Offers a compact design that is half the size and weight of a 600 lumen, passively cooled lamp.

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Epitaxy Tools for Manufacturing Light-Emitting Diode Devices

Emerging Technology

Automated Manufacturing Process Improves Quality and Reduces Manufacturing Costs

Lighting accounts for about 13% of primary energy consumption in the U.S. buildings sector.[1] Light-emitting diodes (LEDs) and solid-state lighting (SSL) show great promise for improving energy efficiency and reducing energy consumption. SSL technologies offer much higher efficacy than traditional lighting technologies such as incandescent and halogen lighting, but widespread adoption of SSLs is hampered by LED performance, durability, and cost. Reducing costs will drive LED demand, and metal-organic chemical vapor deposition (MOCVD) wafer growth is one of the highest cost steps in the LED device manufacturing process.

Applied Materials, Inc., with funding from the U.S. Department of Energy's Building Technologies Program (as part of the American Recovery and Reinvestment Act), developing an advanced epitaxial growth system for manufacturing high-brightness LEDs. The system is built on the Centura™ platform and consists of a multi-chambered epi-system with MOVCD and hydride vapor phase epitaxy chambers, lamp heating, and automated in-situ cleaning. The resulting wafer growth process has been optimized for manufacturing high-brightness LED devices, increasing the internal quantum efficiency of LEDs, and improving production yield to reduce overall operating costs.



Applied Materials' Centura Fully Automated Epitaxy Tool

[1] *2010 Buildings Energy Data Book (Table 1.1.5)*, U.S. DOE, March 2011.

Technology History

- Developed by Applied Materials, Inc.
- Continuing development of the system and exploring marketing strategies in LED device manufacturing.

Applications

Can be used for manufacturing high-brightness LED devices.

Capabilities

- Increases manufacturing throughput via faster growth rate of high-quality gallium nitride with an automated process.
- Decreases cycle time and improves production yields.
- Produces LEDs with high internal quantum efficiency and consistent device parameters in each wafer, wafer to wafer, and run to run.
- Increases throughput by developing a novel automated in-situ cleaning process.

Benefits

Energy Savings

Enables market penetration of SSLs, which will reduce the nation's energy usage for lighting.

Manufacturability

Lowers manufacturing costs and improves LED device quality and performance.

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High Flux Commercial Illumination Solution with Intelligent Controls

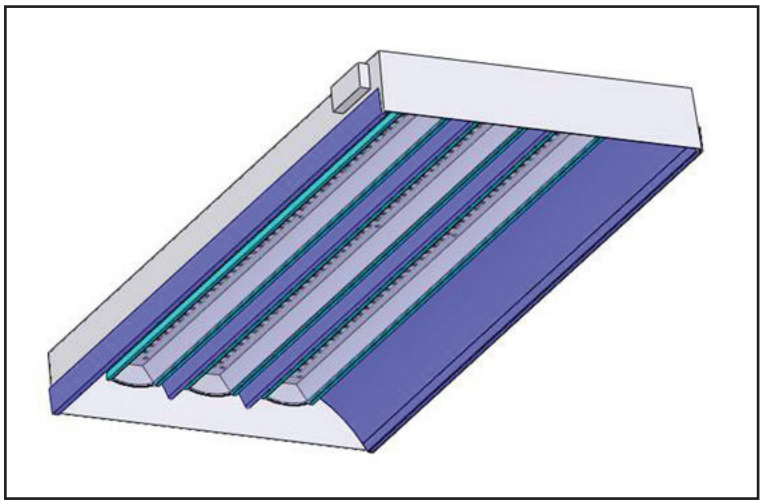
Emerging Technology

LED-Based Linear Fluorescent Replacement Delivers Better Lighting and Saves Energy

The U.S. Department of Energy (DOE) is fully supporting the energy and environment agenda to deploy energy efficient technologies. Last year, lighting consumed about 5 quads of energy.[1] Solid-state lighting (SSL) for residential and commercial building applications could potentially save a total of 16 quads over the next two decades.[2] Barriers that are stalling widespread adoption of SSL technologies are cost and poor quality (durability, color consistency, and uniformity).

Osram Sylvania Inc., with funding from DOE's Building Technologies Program, is developing an LED-based replacement for linear fluorescent lights that offers longer lifetime and improved steady-state system efficacy. The system will contain a high-efficiency light engine module designed to reduce cost and improve fixture-to-fixture color uniformity. The light engine, power supply, and control system will be integrated into a complete luminaire suitable for commercial production. The light engine will be driven by an ultra-high efficiency, class 2 power supply. Further energy savings will be achieved by using an intelligent control system with occupancy sensing and compatibility with daylight harvesting schemes. The system is designed to take advantage of LED dimming capability while providing a pleasant lighting experience for the user. The overall cost of ownership is reduced over incumbent technologies by extending the life of the system to 100,000 hours compared with 12,000 hours of conventional linear lighting technologies.

System design and optimization has been completed and a prototype is currently being tested. Planning and scheduling are underway to fully develop the product and obtain agency qualification and approval.



Sylvania's SSL Linear Fluorescent Replacement Concept

[1] *2010 Buildings Energy Data Book (Table 1.1.5)*, U.S. DOE, March 2011.
[2] *Solid State Lighting R&D: Multi Year Program Plan,* U.S. DOE, March 2011.

Technology History

- Developed by Osram Sylvania Inc.
- Continuing work to further develop the hardware design and evaluate prototype test data.

Applications

Can be used in commercial (office, retail) and industrial environments.

Capabilities

- Achieves 92 lumens per watt in steady state system efficacy.
- Produces 3200 lm luminous flux.
- Provides additional energy savings using an intelligent lighting control system.

Benefits

Durability

Achieves 100,000 hours system lifetime using optimized package design.

Flexibility

Provides easy connection between the luminaire and an intelligent control network.

Product Performance

Provides high light output with high efficacy and a 3500 K correlated color temperature with a color rendering index of 85.

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LECD Technology for Lighting and Signage

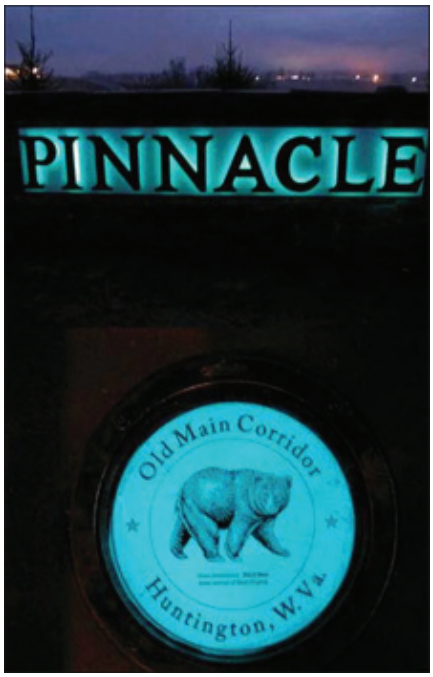
Emerging Technology

Durable, Electro-Ceramescent, Light-Emitting Device Operates on Low-Power Requirements

A large demand exists for a new type of artificial lighting that is highly visible in darkened conditions, energy efficient, and environmentally stable. Such a light source should also be nonglaring in response to the expanding dark-sky initiative, which strives to reduce the prevalence of light pollution around major urban areas. Developing more energy-efficient lighting sources is a growing trend; alternative technologies currently on the market meet some of these demands, but not all.

With funding from the U.S. Department of Energy's Building Technologies Program, Meadow River Enterprises, Inc., Ecer Technologies, LLC, and their research partners are developing an electro-ceramescent lighting technology. The product is made by applying several layers of ceramics on a thin piece of steel. Encapsulated in one of these layers is a mixture of phosphors, which emit photons when electrically energized. The electron-to-photon conversion is very efficient and does not depend on heating a filament to generate light. This new light source is referred to as a light-emitting-ceramic device (LECD).

LECD technology is very durable, with an expected lifetime of 50,000 hours. Unless a mechanical defect occurs, the LECD will not fail catastrophically but will fade slowly over time. The technology operates on either an AC or DC supply, and its low power requirement allows signs to be powered by solar panels. LECDs have improved visibility at night and during inclement weather, and do not have a "halo" effect in fog, rain, or snow. These features are excellent safety benefits for the transportation sector. LECD lighting has many potential uses including industrial, commercial and highway signage, directional markers, and residential landscaping products.



Ecer Technologies' LECD Signs

Technology History

- Developed by Meadow River Enterprises, Inc., and Ecer Technologies, LLC.
- Focusing on investment and marketing strategies for commercialization and manufacturing process improvement and development.

Applications

Can be used in a variety of signage and lighting applications.

Capabilities

- Produces clear, nonglaring light with a power consumption of less than 0.2 W per square foot.
- Operates over a wide temperature range (-40°F to over 190°F).
- Allows signs to be powered by solar panels.

Benefits

Cost Savings

Enables increased material utilization and lower costs through use of a continuous flow manufacturing process.

Durability

Offers a life expectancy of over 50,000 hours. Produces a negligibly small amount of heat and does not de-laminate over time.

Efficiency

Requires one-tenth of the energy consumed by similar light-emitting diode applications.

Environmental

Provides nonglaring light in response to the dark-sky initiative.

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Scaling Up: Kilo-Lumen SSL Exceeding 100 Lumens per Watt

Remote Phosphor, Thermal Management, and Driver Technologies Provide High Efficacy SSL

Currently, very few reasonably priced, high-performance solid state A19 lamps can replace existing 60-watt incandescent lamps with an output of 900 lumens, a color rendering index (CRI) above 90, and uniform "spherical" output. The traditional approach of phosphor-coated, blue light-emitting diodes (LEDs) results in reduced system efficiency due to light being reflected back into the LED, where it heats up the chip and the phosphor. This phenomenon, known as Stokes Shift Loss, reduces the lumen output and lifetime of LEDs. A new packaging design is needed that will improve the thermal management and efficacy of A19 LED lamps.

With funding from the U.S. Department of Energy's (DOE's) Building Technologies Program, Light Prescriptions Innovators (LPI), LLC, and their technology partners are developing technologies that will address the efficiency issues associated with conventional phosphor-coated LEDs. LPI's design places the phosphor at a distance from the LED itself and uses advanced focusing lenses to direct blue light from the LED chip(s) to the phosphor. White light from the excited phosphor is prevented from returning to its source by special optics, which increases efficacy and prevents the LED chip(s) from overheating. The design also protects the phosphor itself from heat given off by blue light production in the LEDs. A cooler phosphor temperature improves light output uniformity and quality over a wide variety of operating conditions. To improve the lamp's thermal management, LPI has developed a passive cooling method that creates an air vortex that works in either vertical or horizontal lamp orientations. LPI has also developed a new LED electronic driver technology that reduces the size and loads of several key components (capacitors), positively impacting the reliability of the driver. These new technologies will extend the lifetime of the prototype lamps that are currently under development.



LPI's Remote Phosphor in an A19 LED Lamp

Technology History

- Developed by LPI, with assistance from Osram Opto Semiconductors.
- Pursuing a commercialization agreement with an industrial partner.

Applications

Can be used as an energy-efficient alternative to incandescent and compact fluorescent lighting, especially for applications that require high-quality color rendering and lamp durability.

Capabilities

- Achieves an efficacy >90 lm/W.
- Adjusts device output automatically to prevent overheating.
- Achieves a CRI >90 in a color temperature range of 2700-3100 K.
- Dims down to 20% of maximum output.

Benefits

Durability

Achieves 25,000 hours of operating lifetime.

Manufacturability

Provides compatibility with high-volume manufacturing processes.

Product Quality

Improves the quality and efficacy of light using patented phosphor, thermal management, and dimming technologies.

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D.5 LED Materials

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Automated Defect Detection, Inspection, Analysis and Yield Management for LED Manufacturing

Emerging Technology

Automated LED Wafer Process Control Improves Yield and Reduces Material Costs

Solid-state lighting (SSL) is expected to play a significant role in achieving the U.S. Department of Energy's (DOE's) energy cost savings within the next several years. However, manufacturing cost reductions are critical to widespread adoption of SSL. Costs can be reduced via wafer size transitions, improved tool productivity, and process yield. Process yields can be improved by enhanced killer (catastrophic failure) defect detection on the wafer substrates during the wafer epitaxy, die fabrication, and device packaging processes. Currently, increased yield targets for 2015 for light-emitting diode (LED) manufacturing have about a 50% cost savings potential.

KLA-Tencor Corporation, with funding from DOE's Building Technologies Program (as part of the American Recovery and Reinvestment Act), is developing a yield management system that will enable automated process control of the front-end LED manufacturing process, e.g., wafer substrate inspection, wafer epitaxy processing, and die fabrication. The Candela 8620 system for substrate and epitaxy processing improves detection of yield-relevant defects such as micro-pits and micro-cracks, which are known to cause electrical failure and reduced reliability. The Klarity-LED YMS software enables statistical process control (SPC) with seamless transfer of inspection data to wafer fab and die fab processing. Determining root causes of process deviations is accelerated by the Klarity software's defect source analysis (DSA) algorithms and interconnectivity capability to transmit inspection results back to the processing equipment.

KLA-Tencor is currently field testing and evaluating the new hardware and software systems. Initial results have demonstrated benefits in accelerating process ramp, improving baseline yield, and detecting process deviations excursions in high-volume LED production. These improvements in process control capabilities are in line with the SSL roadmap targets for DOE's cost savings' targets.[1]



KLA-Tencor's Candela 8620 Inspection System and Klarity LED Yield Management Platform

[1] *Solid State Lighting R&D: Manufacturing Roadmap,* U.S. DOE, July 2011.

Technology History

- Developed by KLA-Tencor Corporation.
- Continuing work on field testing and evaluation and commercialization.

Applications

Can be used in LED manufacturing for defect detection and classification at wafer level.

Capabilities

- Provides automatic process control, defect detection, and instrument connectivity.
- Achieves consistent submicron defect detection.
- Provides real-time process monitoring, DSA, SPC, and yield-limiting defect alerts.

Benefits

Cost Savings

Reduces process yield losses, thereby improving material and time utilization.

Flexibility

Can be used on a variety of semiconductor materials and wafer substrates, sizes, and types.

Manufacturability

Provides seamless data integration and connectivity for automating process control.

Product Quality

Reduces device defect density for improved performance and durability.

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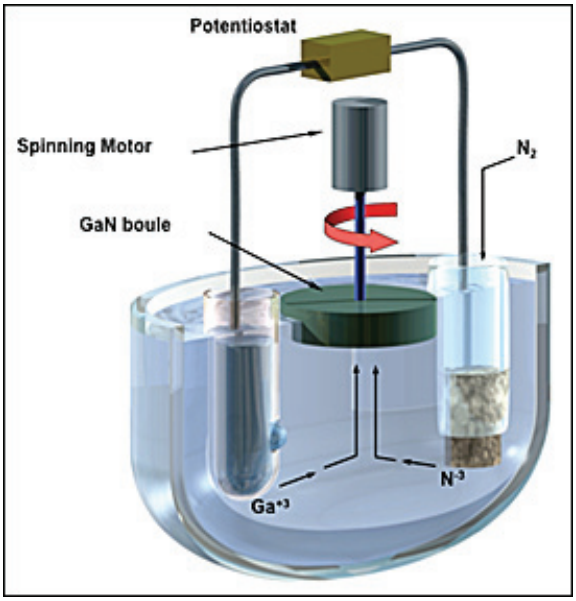
Bulk GaN Substrate Growth Technique

Emerging Technology

Novel Process Enables Production of High-Quality Solid-State Devices

Gallium nitride (GaN)-based semiconductor devices are gaining wider market acceptance in solid-state lighting, laser diode, and power electronics applications. The final performance characteristics of these devices are heavily influenced by the quality of the substrate on which the devices are grown. Conventional wafer epitaxy is constrained by the crystalline quality of the substrate material, which is typically silicon carbide, sapphire, or silicon. This heteroepitaxial growth method often results in an increased defect density in the final product wafer due to slight mismatches in the crystal lattices and thermal expansion properties of the substrate and the wafer. These defects in turn lead to poor electrical and thermal performance in the resulting solid-state devices. The quality of the devices can be improved via homoepitaxial growth, whereby GaN-based devices are grown on GaN substrates. Large quantities of high-quality GaN crystal substrate are therefore needed.

With funding from the U.S. Department of Energy's Building Technologies Program and Office of Electricity, Sandia National Laboratories (SNL) is developing a new crystal growth technology, called Electrochemical Solution Growth (ESG), to produce bulk GaN substrates for fabricating thin film optoelectronic devices. The ESG process is cost-effective and can be scaled to meet industry-desired diameters for the product GaN boules (and the resulting substrate wafers). Bulk GaN crystal growth is currently limited by the difficulties in producing adequate conditions for a reaction between nitrogen and gallium. The ESG method addresses this challenge by producing a reactive form of nitrogen at atmospheric pressure in a solution. The process builds on well-developed concepts from rotating disk reactor metal-organic chemical vapor deposition (MOCVD) technology. Using a rotating crystal seed surface, ions diffuse across a fluid boundary layer near the surface and deposit on the surface to form a single-crystal GaN boule. The technique produces high-quality material (10^2 dislocations/cm^2), resulting in improved performance and durability for GaN-based devices grown from the substrates.



SNL's ESG Process for Producing Bulk GaN Substrates

Technology History

- Developed by SNL.
- Continuing R&D involves optimization of the experimental conditions for GaN crystal formation.

Applications

Can be used to grow improved crystalline GaN substrates for subsequent epitaxial manufacturing of high-quality solid-state optoelectronic devices.

Capabilities

- Produces high-quality bulk GaN containing only 10^2 dislocations/cm^2.
- Enables improved solid-state device performance and durability.

Benefits

Reliability

Uses proven concepts from existing crystal growth applications, such as rotating disk reactor MOCVD technology.

Scalability

Enables the GaN boules to reach industry-desired diameters for the resulting substrate wafers.

Versatility

Can be applied to produce many different types of solid-state devices across multiple markets.

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Enhancing Quantum Efficiency of InGaN-Based LEDs

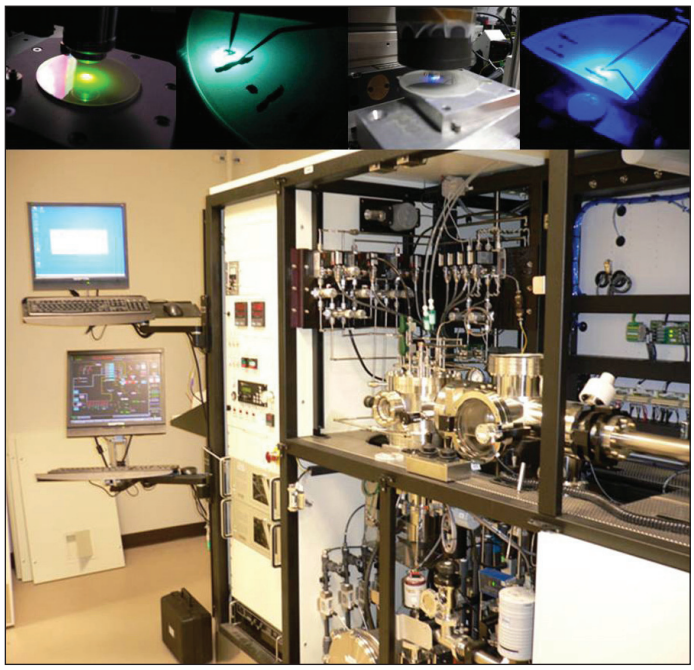
Emerging Technology

Staggered Growth of InGaN Quantum Wells Improves Quantum Efficiency of Nitride LEDs

Concerns over the rising cost of oil and the environmental impact of carbon emissions have prompted a national discussion about energy conservation and renewable sources of energy. Solid-state lighting (SSL) could significantly reduce the amount of energy consumed to produce light for residential, commercial, and industrial applications. High-performance visible-light emitters are crucial for widespread adoption of SSL. Conventional III-Nitride light-emitting-diode (LED) devices must overcome major challenges to achieve the high performance required for SSL. Polarization fields within indium gallium nitride (InGaN) quantum wells (QWs) lead to charge separation, which in turn reduces the radiative efficiency and internal quantum efficiency of nitride LEDs (green and blue).

With funding from the U.S. Department of Energy's Building Technologies Program, Lehigh University is developing staggered InGaN QWs to address charge separation constraints in nitride LEDs. Staggered InGaN QWs combined with high and low indium composition InGaN layers improves the radiative recombination rate in the QW active region, resulting in increased radiative and internal quantum efficiency. The prototype nitride LEDs were produced by a newly developed process that used a graded growth temperature profiling technique and metal-organic chemical vapor deposition (MOCVD). The process has potential for development in commercial applications.

Prototype nitride LEDs, whose nanostructure was first optimized by computer simulation, were fabricated and achieved three times the output power and efficiency compared with a conventional device. Lehigh is currently applying for patents on these optimized nanostructures and the MOCVD fabrication process. New funding opportunities and partnerships are being investigated to apply the process commercially.



Lehigh's MOCVD Process and InGaN LEDs

Technology History

- Developed by Lehigh University.
- Applying for patents and seeking funding and commercial partnership opportunities.

Applications

Can be used to improve the internal quantum efficiency of InGaN-based LEDs.

Capabilities

- Reduces charge separation effects.
- Increases output power and efficiency of InGaN LEDs by two to three times.
- Uses standard MOCVD equipment for device fabrication and can be easily commercialized.
- Uses computer simulation of device nanostructure to optimize device design and improve performance.

Benefits

Cost Savings

Reduces the cost of final LED products by increasing the production yield and efficiency of InGaN LEDs.

Durability

Enhances device structure, which decreases lattice defects and increases device lifetime.

Efficiency

Enables higher efficiency LEDs for SSL.

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Growth Technique for Large-Diameter AlN Single Crystal

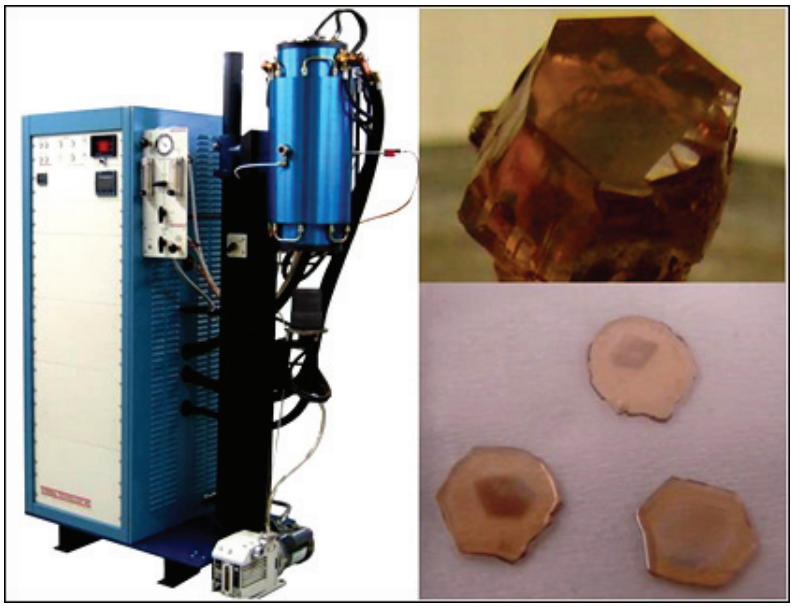
Emerging Technology

Epitaxial Process Improves Lattice-Matched Substrates Used for Manufacturing LEDs

Superior energy savings potential, longer lifetime, and higher efficacy make nitride-based light-emitting diodes (LEDs) the key devices to replace incandescent and fluorescent lighting. A primary issue preventing higher efficacies in LEDs is poor crystalline quality of their nitride epitaxial layers (epilayers). Lattice mismatching and differences in the substrate crystal structure often lead to defects in the LED devices. High-quality nitride epilayers can be grown on aluminum nitride (AlN) substrates and enable high brightness LEDs to be fabricated. The increased efficacy of these LEDs would be sufficient for general lighting applications.

With funding from a U.S. Department of Energy Small Business Innovation Research grant, Fairfield Crystal Technology, LLC, is developing a process for AlN substrate growth that will enable fabrication of highly efficient LEDs for solid-state lighting. The reproducibility of the process has been demonstrated for AlN growth for multi-grain AlN crystal boules up to 2 inches in diameter and up to 25 mm in length. A specially designed crucible successfully produced standalone AlN single-crystal boules up to 9 mm in diameter. Polished AlN crystal wafers have also been used to fabricate epi-ready AlN single crystal samples for group III-nitride epitaxy.

In addition to LEDs, the high-quality AlN substrates can be used to fabricate other types of nitride-based devices, such as blue laser diodes for optical recording, high-frequency devices for telecommunications, and ultraviolet detectors for analytical and homeland security applications. Other possible applications for the devices produced by this technology include medical, dental, and industrial imaging.



Fairfield's AlN Fabrication System, AlN Crystal, and Substrates

Technology History

- Developed by Fairfield Crystal Technology, LLC.
- Currently demonstrating the technology to solid-state device manufacturers for potential applications, licensing, and partnership.

Applications

Can be used to fabricate AlN substrates for manufacturing LEDs and other solid-state devices.

Capabilities

- Produces AlN crystal boules of up to 2 inches in diameter and 25 mm in length.
- Enables production of high-performance LEDs for solid-state lighting applications.

Benefits

Durability

Extends product lifetime, which results in a lower cost of ownership for device end-users.

Product Quality

Produces substrates with fewer defects, resulting in a reduced number of scrap devices and improved device performance.

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Heterointerfaces for High-Power LEDs

Emerging Technology

Process Produces Structured InGaN Device for High-Efficacy LED Fabrication

The introduction of the Edison lamp significantly changed lighting technology, and the light-emitting diode (LED) appears to be creating a similar effect. Existing lighting technologies consume about 22% of U.S. electricity per year, and solid-state lighting (SSL) is expected to reduce energy consumption for lighting by a factor of three to six.[1] LEDs and SSL offer potential energy savings and perform better than less energy-efficient conventional lighting technologies. For widespread adoption, LED technology must have high luminous efficacy and longevity. Two major technical barriers exist. First, as LED current density increases, the light input peaks and further increases in current, causing the LED to self-dim. Second, as the LED current density increases, more heat is generated and thermal management becomes vitally important.

To overcome these challenges, the U.S. Army Research Laboratory (ARL), with funding from the U.S. Department of Energy's Building Technologies Program, is developing III-nitride semiconductor materials, which can be used for SSL technology. ARL's research efforts have focused on the device structure and physics of III-nitrides to improve LED performance. III-nitride LEDs suffer from efficiency droop at high current densities, carrier leakage, and poor hole injection as a result of positive polarization charges at the heterointerfaces within these devices. ARL is investigating the negative charged polarization properties of indium gallium nitride/gallium nitride (InGaN/GaN) heterostructures, specifically, the detrimental effects of the spontaneous positively charged and piezoelectric polarization within these materials. Minimizing or eliminating these polarization effects can resolve the LED efficacy limit at high current densities.

ARL's design, growth, characterization, fabrication, and device physics of III-nitride optoelectronic devices was patented in 2011 (No. 7,956,369). The design represents a significant breakthrough for InGaN-based light sources and enables previously unattainable high current densities. ARL has fabricated devices that reach peak efficiency at current densities five times larger than conventional devices and with only one-eighth the efficiency droop.



ARL's III-Nitride Etching and Device Fabrication

[1] *Energy Savings Potential of Solid-State Lighting in General Illumination Applications 2010 to 2030*, U.S. DOE, February 2010.

Technology History

- Developed by the U.S. Army Research Laboratory.
- Continuing process development to improve device performance and process yields.

Applications

Can be used for high-power LED devices required for SSL applications.

Capabilities

- Achieves improved LED durability, efficacy, and internal quantum efficiency.
- Reduces efficiency droop by over 85% at high current densities (5 times) compared with conventional LED devices.

Benefits

Energy Savings

Improves LED efficacy, reducing energy consumed by SSL applications using the technology.

Product Quality

Produces high product quality and performance with a low-defect-density heterostructure.

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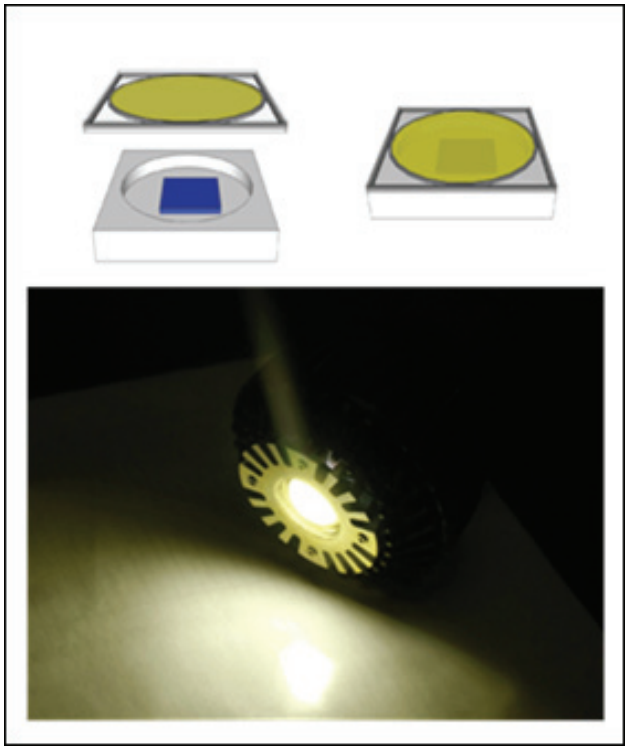
High-Efficiency, Nanocomposite White Light Phosphors

Emerging Technology

New Phosphors Provide High-Quality Color Rendering and Tunable Color Temperature

Solid-state lighting (SSL) technology has long held tremendous potential as a means to improve energy efficiency and reduce waste with long-lasting, high-efficiency light fixtures. Widespread use of SSL in businesses and homes could significantly reduce overall electricity consumption in the United States. However, adoption of SSL has been slow due to the high upfront cost of replacing existing lights and the poor color rendering provided by many early SSL products. Currently available SSL lights often emit a 'cool', blue-yellow light with a correlated color temperature (CCT) of ≥5000 K, which many consumers are not partial to. For household lighting, most consumers are accustomed to incandescent light, which has a 'warm' CCT of around 2700 K. Current SSL solutions for providing consumer-satisfactory white light, such as discrete RGB (red-green-blue) LEDs and doped yttrium aluminum garnet (YAG) phosphors, are costly and inefficient.

With funding from a U.S. Department of Energy Small Business Innovation Research grant, Nanosys, Inc., is developing remote phosphor components based on proprietary quantum dot technology that address the cost, efficiency, and color quality issues of traditional LED phosphor systems. This solution enables the energy savings of the best high-efficiency SSL to be attained in applications where a CCT of 2700 K and a high color rendering index (CRI) are critical, such as the residential and hospitality markets. In addition, Nanosys' remote phosphor components are designed to be process-ready devices that can be incorporated into existing luminaire manufacturing processes and thereby reduce the cost of retooling and scale-up.



Nanosys' Remote Phosphor Affixed to Blue LED (top) and Emitting Warm White Light (bottom)

Technology History

- Developed by Nanosys, Inc.
- Continuing to improve the internal quantum efficiency and reliability of remote phosphors in preparation for manufacturing scale-up.

Applications

Can be used in lighting applications where high-quality color rendering across a range of color temperatures is desired.

Capabilities

- Produces custom white light with an efficiency ≥80 lm/W.
- Achieves a CRI ≥92 with a customizable CCT in the range of 2700-6500 K.
- Provides light output independent of input blue wavelength variation.

Benefits

Cost Savings

Reduces production costs by providing a process-engineered component that integrates easily into existing manufacturing processes.

Durability

Provides color stability throughout the product lifetime.

Versatility

Allows manufacturers to pursue differentiation in spectrum branding to serve markets and applications around the world with differing CCT preferences.

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High-Efficiency Nitride-Based Solid-State Lighting

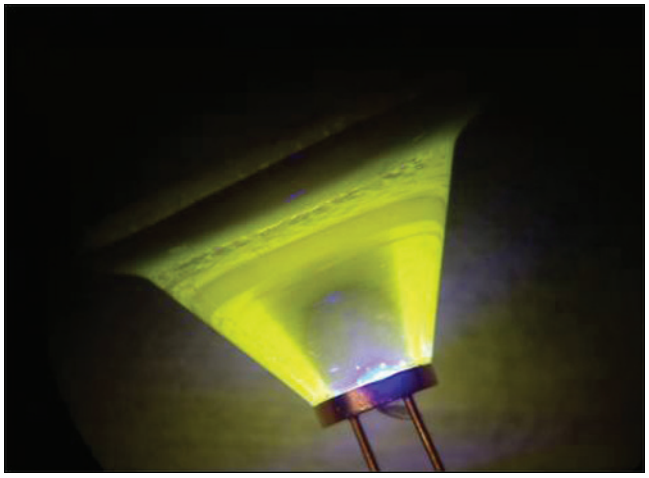
Emerging Technology

Nonpolar and Semipolar Gallium Nitride Substrates Enable Superior Solid-State Lighting

Conventional incandescent lamps, which currently are used in the majority of residential and commercial lighting applications, are very inefficient. Fluorescent lamps, including compact versions, are more efficient but contain toxic mercury and must be disposed of carefully. Solid-state lamps based on gallium nitride (GaN) light-emitting diodes (LEDs) are much more efficient than the best tungsten halogen incandescent lamps and already have efficiencies comparable to fluorescent lamps. In addition, solid-state lamps do not contain the toxic mercury present in fluorescent lighting products.

The use of nonpolar or semipolar bulk GaN substrates for fabricating LEDs provides several key advantages for the resulting lighting products. The low-defect-density substrates ensure that most of the current injected into an LED contributes to light output, which increases the lamp's lifetime. The nonpolar or semipolar orientation further improves the radiative efficiency and eliminates the wavelength shift that accompanies increasing current in conventional polar GaN LEDs. In addition, the nonpolar or semipolar orientation maintains high efficiency at high current density, thereby reducing the "efficiency droop" seen in polar LEDs.

With funding from the U.S. Department of Energy's Building Technologies Program, the University of California, Santa Barbara (UCSB), conducted research focused on epitaxial growth of nonpolar or semipolar templates, along with the subsequent growth and fabrication of LEDs. The experimental results confirmed theoretical predictions and spurred the efforts towards the future commercialization of bulk nonpolar or semipolar GaN substrates. Additional work has focused on light extraction methods. Coupled with nonpolar or semipolar substrates, this work has significantly improved LED light output and efficiency. Continuing improvements to both internal and external efficiency will soon enable cost effective replacement of all incandescent and most fluorescent lighting. Future commercialization of the nonpolar or semipolar GaN-based LEDs will be performed by industrial members of the UCSB Solid State Lighting and Energy Center.



UCSB's High Efficiency Nonpolar LED for Solid-State Lighting

Technology History

- Developed by UCSB, with contributions from the Rensselaer Polytechnic Institute.
- Continuing R&D is achieving white lighting efficiencies superior to tungsten halogen lamps and comparable to fluorescent lamps.

Applications

Can be used in a variety of commercial and residential illumination applications, including automotive and specialty lighting.

Capabilities

- Achieves external quantum efficiency of >40% at 35A/cm^2 (350 mA on a 1 mm x 1 mm chip).
- Reduces wavelength shift below 2 nm from 50-350 mA on a 1 mm x 1 mm chip.
- Increases high-power lifetime of LEDs to >5 years.

Benefits

Durability

Reduces replacement frequency and cost by using all-solid-state construction.

Energy Savings

Reduces air conditioning loads through high-efficiency operation with minimal heat generation.

Environmental

Uses non-toxic material in manufacturing, without the mercury present in fluorescent lamps.

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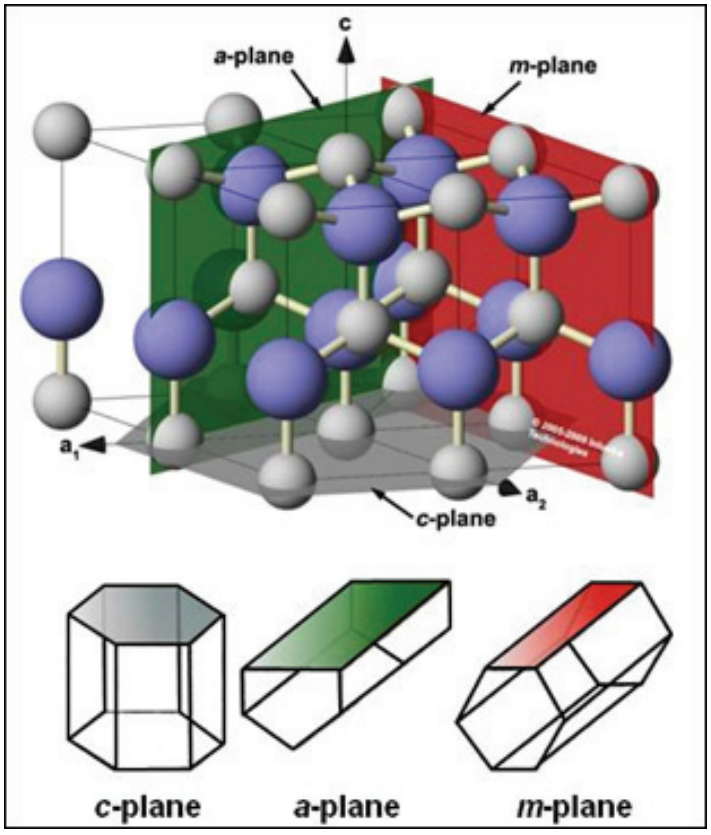
High-Efficiency, Non-Polar, GaN-Based LEDs

Emerging Technology

Low-Defect, Custom-Oriented GaN Substrates Produce Brighter LEDs

The quality of light-emitting diodes (LEDs) for solid-state lighting depends heavily on the device fabrication step, in which thin gallium nitride (GaN) semiconductor layers are deposited on a crystalline substrate material. Traditionally, GaN devices have been grown on foreign substrates such as sapphire or silicon carbide. Crystal lattice mismatches between the two materials cause the resulting solid-state devices to have high defect densities. These defects have a negative impact on device durability and key performance properties such as thermal conductivity. The growth of GaN devices on 'native' GaN substrates minimizes defect formation, but GaN substrate prices must fall significantly from their current level ($2000-$4000 per 2-inch diameter wafer) in order for widespread adoption to occur.

With funding from the U.S. Department of Energy's Building Technologies Program, Inlustra Technologies, Inc., is developing scalable, cost-effective processes for manufacturing GaN substrates from which high-performance GaN devices can be fabricated. In addition to the advantages offered by native substrate growth, Inlustra's substrates enable LED performance enhancements by manipulation of a device's structure in relation to its atomic lattice structure. As opposed to traditional GaN devices, which are cut in the polar *c*-plane, Inlustra's GaN materials are oriented in the non-polar *a*- and *m*-planes (see figure below). In this manner, a high electrical-to-optical efficiency can be obtained at elevated drive currents, thereby yielding more light output per LED chip.



GaN Crystal Structure and c-, a-, and m-Planes

Technology History

- Developed by Inlustra Technologies, Inc.
- Currently developing low-cost, high-volume manufacturing techniques and increasing substrate wafer diameter.

Applications

Can be used for fabricating low-defect GaN-based LEDs and laser devices.

Capabilities

- Enables stable LED light output with no color shifting at elevated drive currents.
- Improves photon conversion efficiency at high drive currents (reduces LED droop).
- Maximizes device optical performance by optimizing GaN crystal plane orientation.

Benefits

Cost Savings

Reduces the cost of producing GaN-based devices by shortening device layer deposition time and enabling simplified fabrication schemes.

Energy Savings

Increases LED efficiency, thereby achieving an equivalent lumen output with reduced electricity consumption.

Performance

Reduces internal defects and increases the high-current performance and durability of LEDs.

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High-Performance Green LEDs

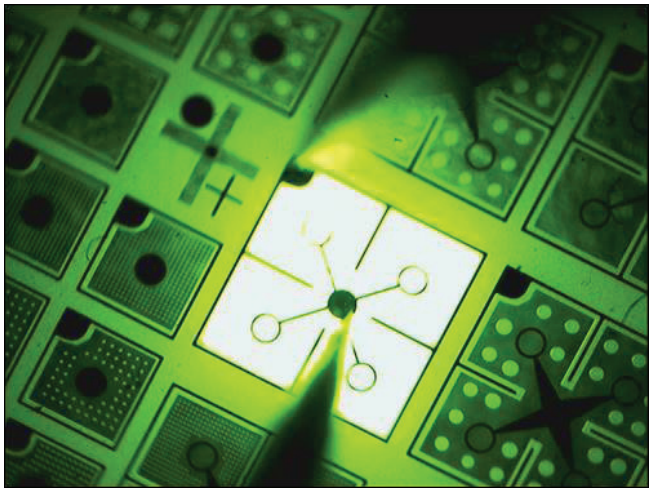
Emerging Technology

Direct-Emitting Green LEDs Increase Energy Efficiency of Solid-State Lighting Devices

Traditional incandescent lighting is highly inefficient in using electricity. Light-emitting diodes (LEDs) based on aluminum gallium indium nitrides (AlGaInN) are now at the cusp of revolutionizing the worldwide lighting market by providing significantly higher reliability and energy efficiency. However, current approaches use a combination of a single, narrow-band, blue LED and a broader yellow-emitting phosphor material that receives its excitation from the same blue LED. The result is a somewhat fractured spectrum that many consumers perceive as a harsh bluish white. This existing technology also suffers from a particularly poor color rendering in the red and green parts of the spectrum.

Rensselaer Polytechnic Institute (RPI), with funding from the U.S. Department of Energy's Building Technologies Program, is developing novel AlGaInN LED dies that improve performance in the green spectral region. RPI's approach uses the advantage of higher efficiency by direct emission of the desired wavelengths, bypassing the optical transformation step inside the phosphor materials. This particular implementation aims at the green spectral region which, in combination with red and blue emitters, forms a highly pleasing white that can be even further enhanced with additional colors in between. By using homoepitaxial growth on high quality bulk gallium nitride (GaN), RPI substantially enhances the green light generation efficiency and directly controls the material-inherent piezoelectric polarization. By rotating the crystal growth plane, scientists can also achieve a color-stable green emission independent of the operating current.

Expanding on these approaches offers the potential to overcome the well-known performance drop at high injection currents and to progressively deliver LED light sources at any desired wavelength throughout the visible spectrum, possibly even into the deep green and yellow colors. RPI has developed advanced prototypes and will be evaluating a demonstration unit of this technology.



RPI's High-Efficiency Green LED

Technology History

- Developed by RPI in partnership with Kyma Technologies, Inc.
- Continuing work to commercialize the technology in the next year.

Applications

Can be used in all solid-state lighting devices as a more energy-efficient substitute for incandescent light bulbs and fluorescent lighting.

Capabilities

- Increases light output per LED chip.
- Enables optimized color mixing and easier cooling in solid-state lighting devices.

Benefits

Cost Savings

Reduces costs by using large-scale bulk GaN substrates.

Durability

Eliminates phosphor aging issues and maintains a constant wavelength that is independent of operating current for stabilized emission color.

Energy Savings

Increases energy efficiency by directly emitting desired wavelengths, which eliminates phosphor-excitation losses associated with conventional LED technology.

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High-Performance Structured OLEDs and LEDs

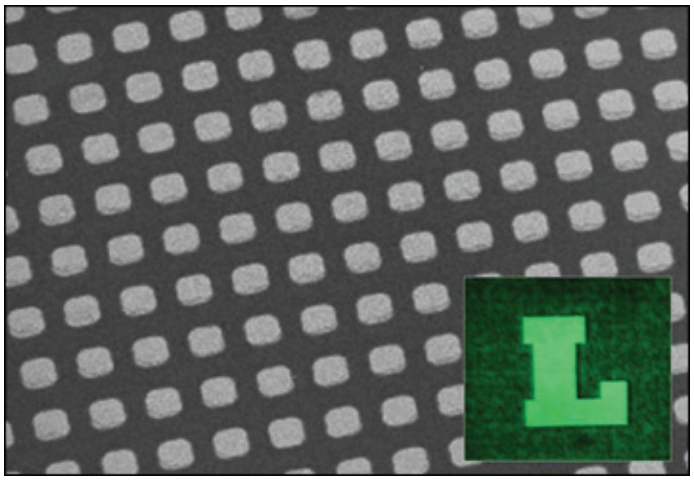
Emerging Technology

New Fabrication Process Improves Performance of OLED and LED Devices

Traditional organic light-emitting diode (OLED) devices use unstructured, multilayer films that present light extraction, charge injection, and reliability difficulties. On the other hand, the performance of light-emitting-diode (LED) devices is sensitive to lattice defects and stresses, which are known to contribute to high resistance and structural instability. Low efficacy and unstable materials are preventing OLEDs from being widely adopted and deployed. Adoption of LEDs is hindered by defective wide bandgap semiconductor layers, which keep LED efficacy much lower than its theoretical limit. Using structured OLEDs and LEDs would alleviate these difficulties and improve device efficacy and reliability.

With funding from the U.S. Department of Energy's Building Technologies Program, Lawrence Berkeley National Laboratory (LBNL) is developing micro- and nano-structuring processes for fabricating OLEDs and LEDs. This structured approach to OLED architecture is an alternative to conventional, multilayer film fabrication. This process uses less-reactive electrode materials that are easier to manufacture and are more durable and reliable than conventional materials. OLED efficiency is improved by increasing charge injection and using nano-structured materials at the electrode-organic interface. The structured materials are insensitive to air or water and have improved charge balance and a low refractive-index microstructure. These features also improve light out-coupling in the organic light-emitting layer, thereby producing higher OLED efficacy.

A similar process can be applied to LED fabrication, where the micro- and nano-scale heteroepitaxy process reduces structural defects in wide bandgap semiconductor layers. The resulting high-quality crystalline structure provides current confinement, which reduces heat generation and improves efficacy. The structure also forms an internal light-guide, which further improves device efficiency. LBNL is currently seeking potential industrial partners to commercialize the technology.



LBNL's OLED Material and Prototype Sample Display (inset)

Technology History

- Developed by LBNL.
- Seeking potential industrial partners to commercialize the technology.

Applications

Can be used to provide energy-efficient area lighting and information displays.

Capabilities

- Uses a scalable micro- and nano-fabrication process to produce structured OLEDs and LEDs.
- Enhances charge injection and light extraction for increased efficacy.
- Improves device performance to levels suitable for widespread deployment.

Benefits

Durability

Increases product lifetime by using low-defect, stable materials.

Performance

Enhances device efficiency by improving electrical and optical output.

Productivity

Uses imprint-based fabrication and vapor deposition steps to simplify the manufacturing process.

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Key Technologies for White Lighting Based on LEDs: Precise Temperature Measurement

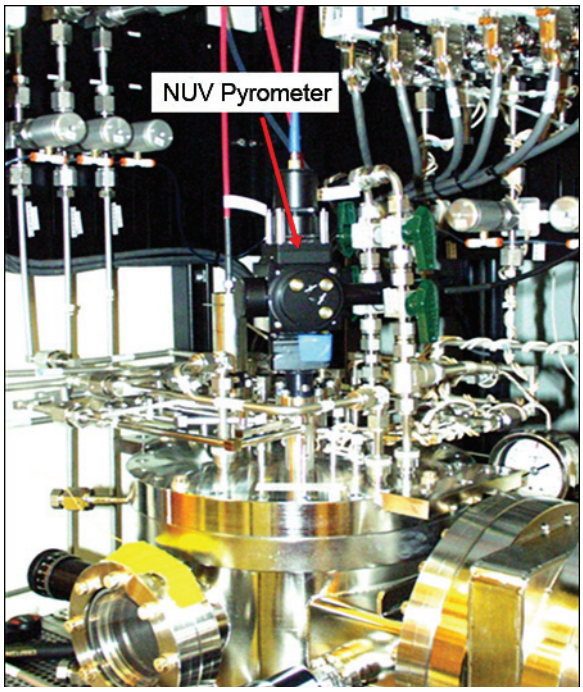
Emerging Technology

Novel Pyrometer Enables Precise Temperature Measurement During Growth of InGaN LEDs

Temperature measurement during indium gallium nitride (InGaN) metal-organic chemical vapor deposition (MOCVD) is very difficult due to the transparency of the substrates (e.g., sapphire) and epilayers at the near-IR wavelengths (e.g., 900-1000 nm) normally used for pyrometry. Until recently, no method has been readily available to measure the true wafer surface temperature during deposition. The problem is particularly severe because the InGaN composition (and therefore emission wavelength) is extremely sensitive to temperatures from 700-800°C. Because of errors in existing temperature measurement techniques, process drifts of 10-20°C are common, leading to InGaN devices that emit light outside of the target wavelength window.

With funding from the U.S. Department of Energy's Building Technologies Program, Sandia National Laboratories (SNL) is developing a new type of pyrometer to accurately and precisely measure the temperature during the MOCVD process. Unlike existing equipment, this pyrometer was developed based on high-temperature GaN opacity in the near-ultraviolet (NUV) wavelength range of approximately 400 nm. The ability to measure thermal radiation at wavelengths where the wafer and/or epilayer are opaque greatly enhances temperature control, which will increase the yield of InGaN epitaxial material and significantly lower the cost of the final LED products.

SNL is currently collaborating with Veeco Instruments, Inc., to further develop an in-situ pyrometer for accurate substrate temperature measurement. The next-generation NUV pyrometer will measure the wafer temperature distribution with both high-temperature resolution and spatial resolution during growth of the active region of InGaN LEDs.



SNL's NUV Pyrometer for Temperature Measurement During InGaN LED Growth

Technology History

- Developed by SNL.
- Continuing work involves collaboration with Veeco Instruments, Inc., to further develop an in-situ pyrometer that accurately measures substrate temperatures.
- Testing of several prototypes of the near-UV pyrometer in a production setting are taking place with the evaluation of pyrometer performance being measured.

Applications

Can be used to improve the temperature control of the MOCVD process during the growth of InGaN LEDs.

Capabilities

- Accurately and precisely measures the GaN/sapphire wafer temperature during the growth of InGaN LEDs.
- Achieves temperature-reporting accuracy to within 1°C.
- Enables narrower emission wavelength range for LEDs.

Benefits

Cost Savings

Reduces the cost of final LED products by increasing the production yield of InGaN epitaxial material.

Product Quality

Produces InGaN devices that emit light within a target wavelength window by eliminating process temperature drifts associated with conventional measurement techniques.

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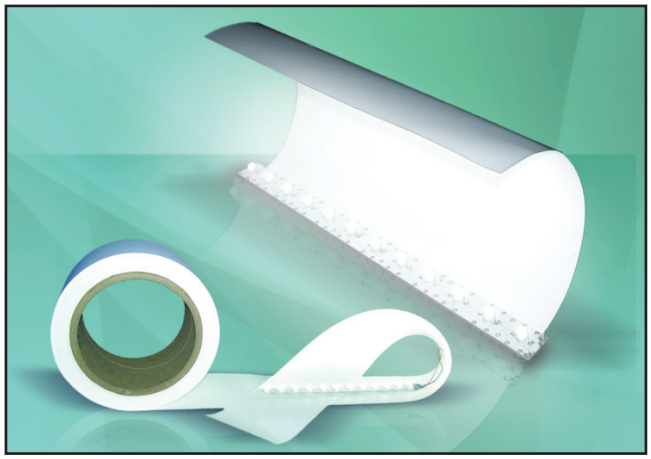
Low-Cost, Highly Lambertian Reflector Composite for Improved LED Fixture Efficiency and Lifetime

Emerging Technology

Polymeric Material Improves Light Output Quality of SSL Fixtures

The energy-saving potential of solid-state lighting (SSL) sources (compared with conventional lighting sources) could reduce U.S. lighting electricity consumption by 25% over the next 20 years.[1] For SSL products to be widely adopted, they must become cost competive with conventional technologies and improve their quality and performance. These shortcomings manifest themselves as products that do not deliver the expected lumen output, operational lifetime, and quality of light. Quality of light metrics, light uniformity, glare, color, color consistency, and color rendering are important because they contribute to the net effect and visual experience of lighting fixtures and systems. High-performance SSL products typically use reflectors combined with diffusers to produce a uniform, nonglare light distribution from the discrete light-emitting diode (LED) light source(s) within the fixture. However, the specular nature of reflectors can sometimes produce unnecessary glare, and the LED source or array can be very visible as "hot spots" to the end user.

With funding from the U.S. Department of Energy's Building Technologies Program (as part of the American Recovery and Reinvestment Act), WhiteOptics, LLC, and their project partners are developing a polymer microfiber with highly effective light scattering and reflective properties. WhiteOptics' approach to this technology consists of transforming these fibers into a composite material that maximizes visible light reflection and can be used effectively in SSL systems to optimize light output. The focus of polymer microfiber processes is high-volume manufacturability so it can be produced cost effectively and can be used in general LED illumination fixtures, lowering overall LED system cost. The objective is to demonstrate a 98% or greater reflective, highly diffuse, low-cost composite material that can withstand 50,000 hours or greater luminaire operation under expected LED system thermal and environmental operating extremes.



WhiteOptics' Diffuse Reflector for LED Lighting Fixtures

[1] *Energy Savings Potential of Solid-State Lighting in General Illumination Applications 2010 to 2030*, U.S. DOE, February 2010.

Technology History

- Developed by WhiteOptics, LLC, in partnership with the University of Delaware Center for Composite Materials.
- Currently scaling up the technology for full-scale field demonstration and accelerated durability testing.

Applications

Can be used in LED luminaires to improve overall system efficiency and provide well-mixed, uniform light distribution.

Capabilities

- Achieves 97% reflectance in a commercially scaleable process.
- Improves luminaire optical efficiency by 15%-20% over existing finishes.

Benefits

Cost Savings

Reduces overall system cost by reducing the number of LEDs needed for uniform light output.

Durability

Contributes to system durability by reducing the LED thermal density.

Flexibility

Improves luminaire design because high, diffuse reflectance allows efficient light mixing while reducing hotspots.

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Low-Cost Illumination-Grade LEDs

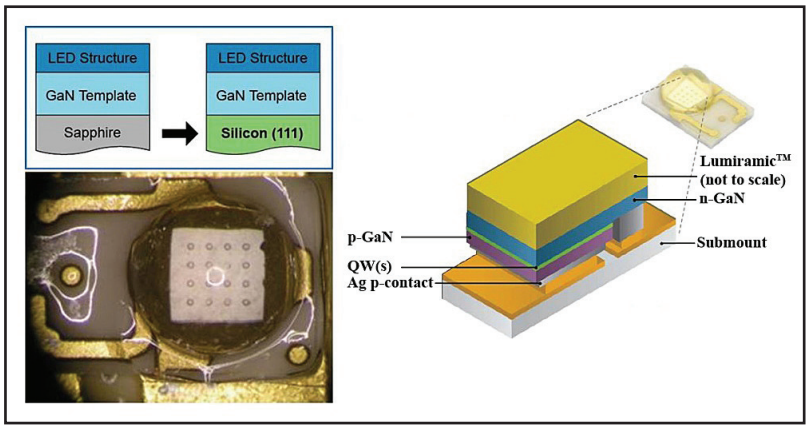
Emerging Technology

Silicon Wafer Epitaxy Process Reduces Manufacturing Costs

Lighting residential and commercial buildings consumes about 13% of the total U.S. annual energy usage.[1] Solid-state lighting (SSL) technologies offer great potential for increasing energy efficiency and reducing energy consumption. SSL technologies offer much higher efficacy (lumens per watt) than conventional incandescent and halogen lighting technologies. However, SSL market penetration has been hampered by poor light emitting diode (LED) performance, durability, and high cost, which subsequently have lowered consumer confidence. Manufacturing LED devices using wafer epitaxial growth of gallium nitride (GaN) represents a significant portion of LED manufacturing costs. Reducing epitaxy manufacturing costs of illumination-grade LEDs will enable market adoption and a reduction in the energy used for lighting.

Philips Lumileds Lighting, with funding from the U.S. Department of Energy's (DOE's) Building Technologies Program (as part of the American Recovery and Reinvestment Act), is developing processes and techniques to reduce the epitaxy manufacturing costs for illumination-grade, high-power LEDs. In part, costs will be reduced by using epitaxial deposition of GaN on silicon (Si) substrates. Replacing standard 75 mm diameter sapphire substrates with larger 150 mm diameter silicon substrates will enable a higher yielding epitaxy process. Higher yields are obtained from the superior material quality of silicon substrates, including improved thermal conductivity.

Philips is using their Luxeon Rebel® LED device fabrication process as the pilot manufacturing line for this program because of the availability of solid benchmarks to compare 150 mm substrate GaN on Si with the standard GaN on sapphire epitaxy process. Before scaleup and development of a 150 mm Si substrate epitaxy and wafer fab manufacturing process, Philips will need to conduct a comprehensive comparison of characterization data from the entire process (epitaxy through final illumination grading).



Philips' Low-Cost GaN-on-Si Illumination LED

[1] *2010 Buildings Energy Data Book (Table 1.1.5)*, U.S. DOE, March 2011.

Technology History

- Developed by Philips Lumileds Lighting Company.
- Developing and scaling up epitaxy process on larger-diameter Si wafer substrates.

Applications

Can be used for commercial-scale manufacturing of illumination-grade LED devices.

Capabilities

- Targets >60% reduction of epitaxy manufacturing costs for illumination-grade LEDs.
- Targets DOE goals for illumination-grade LED performance using 150 mm GaN-on-Si substrates.
- Targets device performance with equivalent or better performance compared with devices fabricated using current processing methods.

Benefits

Cost Savings

Reduces epitaxy cost per growth run per wafer by 40% and existing epitaxy and wafer manufacturing costs by 50%.

Product Quality

Optimizes process parameters, leading to consistent device characteristics and performance.

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Website: http://www.philipslumileds.com

Low-Cost Lithography for High-Brightness LED Manufacturing

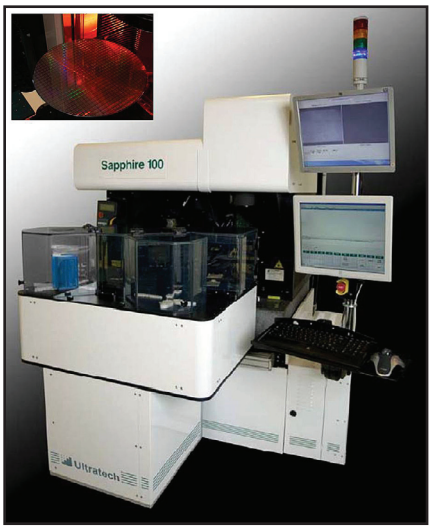
Emerging Technology

Automated Lithography Tool Allows Low-Cost, High-Yield, LED Manufacturing

National energy policy calls for energy-efficiency improvement in commercial and residential buildings, and the U.S. Department of Energy (DOE) has targeted more efficient, cost-effective lighting as one of several significant contributing factors to meet future building energy-efficiency goals. In particular, solid-state lighting (SSL) has significant energy-saving potential, but manufacturing costs needs to be reduced for widespread adoption. Over the last decade, high brightness light-emitting diodes (HBLEDs) used in most SSL applications have improved in efficiency by a factor of 20 and decreased in cost by a factor of 10. The 2015 efficacy targets are within reach, but the HBLED cost target of $1-2 per kilolumen will require a further factor of 20 decrease. HBLED manufacturing can take advantage of the extensive knowledge and techniques used in the semiconductor industry to improve processes, throughput, and yield.

Ultratech, Inc., with funding from DOE's Building Technologies Program (as part of the American Recovery and Reinvestment Act), is developing a reduced cost-of-ownership (CoO) projection lithography system for manufacturing HBLEDs. Typically, the LED fabrication process involves four or more lithography steps. HBLED manufacturers use contact or proximity printing processes, which are prone to yield losses because mask contamination occurs from contact with warped or bowed wafers. Projection lithography accommodates wafer topography variation and eliminates contact contamination issues and mask alignment overlay errors arising from warped wafer substrates, improving yields and HBLED device quality.

Ultratech's projection based lithography system aims to reduce lithography cost by 50% using an LED-based illuminator, auto-focusing light source, automated material handling, and process control. These features combine to increase throughput and decrease operating costs and maintenance downtime. The autofocus feature can process extremely warped wafers without operator intervention. Ultratech is approaching its 50% CoO reduction goal and is currently testing and characterizing the lithography system and expect completion in 2012.



Ultratech's Sapphire 100 Lithography System

Technology History

- Developed by Ultratech, Inc.
- Continuing development work, field testing, and system evaluation.

Applications

Can be used for manufacturing high-quality, durable HBLEDs for SSL applications.

Capabilities

- Reduces the cost of ownership by 50%.
- Increases lithography process throughput.
- Provides flexible, automated, material-handling capabilities, including warped or bowed wafer substrates.

Benefits

Cost Savings

Reduces capital equipment costs by 38% and operating cost over 5 years by 46%.

Manufacturability

Provides a turnkey, purpose-built lithography mask alignment and exposure system for HBLED manufacturing.

Product Quality

Reduces lithography alignment errors and contamination, resulting in improved device durability and performance.

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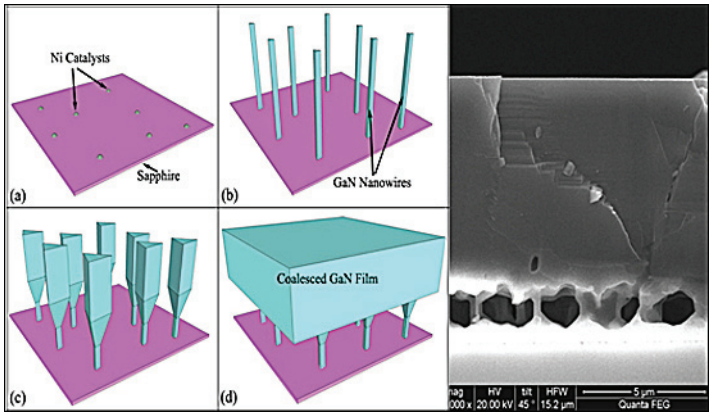
Nanowire-Templated Lateral Epitaxy of Low-Dislocation-Density GaN

Emerging Technology

New Technique Enables Inexpensive Production of High-Quality GaN Substrates

Solid-state lighting (SSL) has the potential to provide light that is much more efficient and longer-lasting than conventional technologies, resulting in significant energy savings and reduced carbon emissions. The basis of most SSL devices is the light-emitting diode (LED), which typically consists of a sandwich of gallium nitride (GaN)-based semiconductor layers. LEDs are typically grown on sapphire substrates because of the lack of bulk GaN crystal. Large lattice mismatch, or difference in atomic spacing, between GaN and the sapphire substrate results in defects forming in the GaN layers. These defects significantly reduce device efficiency and lifetime, hindering the development of higher performance SSL.

With funding from the U.S. Department of Energy's Building Technologies Program, Sandia National Laboratories (SNL) is developing an innovative and inexpensive GaN crystal growth technique called nanowire-templated lateral epitaxial growth (NTLEG). The process uses aligned arrays of single-crystalline GaN nanowires as templates for the growth of high-quality GaN on sapphire substrates. The single-step process results in lateral GaN film formation that bridges the substrate and the nanowire array. The nanowire's small dimensions (typically <100 nm diameter) provide lateral strain relief and reduce lattice mismatch. The strain relaxation effect reduces defect density by 50 times compared with GaN films grown by conventional multi-step techniques. SNL will continue to optimize the process to achieve higher quality GaN films and plans to extend the technique to grow indium gallium nitride (InGaN) and other semiconductors.



SNL's Nanowire-Templated GaN Film Growth Process

Technology History

- Developed by SNL.
- Planning to extend the technique to grow InGaN and other semiconductors.

Applications

Can be used to produce LEDs for SSL devices with a reduced number of defects, which improves device efficiency and durability.

Capabilities

- Reduces defect density by 50 times compared with conventional sapphire-GaN growth techniques.
- Offers high-quality film growth.
- Can be applied to other types of semiconductor material growth.

Benefits

Cost Savings

Provides a single-step process that reduces costs and complexity compared with other defect reduction methods.

Product Quality

Improves quality, leading to increased device output and lifetime.

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Nitride- and Oxynitride-Based Phosphors for Solid-State Lighting

Emerging Technology

Highly Durable and Efficient Phosphors Improve Blue LED Down Conversion

The expectations of solid-state light (SSL) reducing U.S. lighting energy usage and significantly contributing to climate change are well known. However, achieving R&D breakthroughs in efficiency and performance is needed as is informing buyers and specifiers how to successfully apply SSL lighting. Improving SSL performance has technological challenges, especially in the area of phosphors. Blue light-emitting diodes (LEDs) produce white light using phosphor down conversion (Stokes Conversion). Currently, many phosphor systems need improved quantum yield, thermal stability, and chemical stability. Overcoming these technological challenges would result in a phosphor capable of providing the required efficiency and lumen performance of illumination-grade LEDs.

Lightscape Materials, Inc, with funding from the U.S. Department of Energy's Building Technologies Program (as part of the American Recovery and Reinvestment Act), is developing nitride- (red) and oxynitride- (green) based phosphor materials for SSL applications. These materials have improved quantum yield, thermal stability, lumen maintenance, and internal scattering losses. Lightscape also is developing a commercially viable preparation process for mass producing these enhanced phosphor materials.

Lightscape has successfully developed red and green phosphor formulations ahead of schedule. Development continues on producing other phosphor compositions for SSL applications that offer more flexibility on the type of white light (color correlated temperature) and higher color rendering index. Strategic planning and marketing efforts are under way to supply the phosphor products.



Lightscape's Phosphor Technology for SSL Applications

Technology History

- Developed by Lightscape Materials, Inc.
- Continuing development work and investigation of marketing and commercialization strategies.

Applications

Can be used for producing illumination-grade LEDs for SSL applications.

Capabilities

- Achieves quantum yield of ≥90%, approaching DOE's 2020 target of 95%.
- Provides reduced thermal quenching of <10% at 300°F, exceeding DOE's 2020 target of 10%.
- Achieves a lumen maintenance of <10% loss after 5,000 hours at 185°F and 85% relative humidity.

Benefits

Cost Savings

Provides superior performing phosphor materials using a cost-effective production process.

Flexibility

Provides a wider range of lighting capabilities and options, enabling more opportunities for lighting designers to specify SSL.

Product Quality

Increases LED product quality through improved lumen output, stability, durability, and increased quality of light.

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Optimized Phosphors for Warm-White LEDs

Emerging Technology

Phosphor Materials and LED Light Engines Provide High CRI, Warm-White Light Sources

With widespread deployment, solid-state lighting's (SSL's) rapid ongoing improvements and superior energy-saving potential could save $120 billion in U.S. energy costs over the next two decades.[1] Typically, SSL technology produces white light using phosphor down conversion (Stokes Conversion) of the narrow band of blue wavelengths radiated by a light-emitting diode (LED) into a broad band of wavelengths. LEDs with current phosphor systems experience efficacy losses when trying to achieve either low correlated color temperatures (CCTs) or a high color rendering index (CRI). To overcome these deficiencies, research and development are needed to optimize the phosphor materials and their performance in LED systems.

GE Global Research, with funding from the U.S. Department of Energy's Building Technologies Program (as part of the American Recovery and Reinvestment Act), is developing phosphor materials that potentially can reduce the efficacy losses encountered producing low CCT (warm white light) and high CRI LEDs. GE is working on optimizing phosphor compositions and synthesis to maximize phosphor efficiency and minimize scattering losses within the LED light engines. The phosphor synthesis processing has been modified to remove the fine particles that disproportionately back-scatter light into the LED light engine. Removing the fine particles also improves phosphor quantum efficiency because many secondary phase particles are also removed. GE is also designing light engines that further minimize losses by removing parasitic absorptions. Advanced light engine efficacy prototypes will be developed that maximize light engine efficacy, which will establish design rules to use these optimized phosphors.

Currently, GE's phosphor efficiency (including package losses) is greater than 80% compared with 68% to 70% at the start of the materials' development. The phosphor syntheses and compositions are being scaled up, and potential product lines that can take full advantage of these materials and light engine designs are being investigated.



GE's Optimized Phosphors and LED Light Engine

[1] *Energy Savings Potential of Solid-State Lighting in General Illumination Applications 2010 to 2030*, U.S. DOE, February 2010.

Technology History

- Developed by GE Global Research, GE Lighting Solutions, and the University of Georgia.
- Continuing development and optimization of phosphor compositions, phosphor synthesis, and light engine design.

Applications

Can be used in manufacturing energy-efficient SSL lighting products.

Capabilities

- Produces 2700-3200 K CCT white light with >100 lm/W efficacy and CRI>90 using only phosphor down conversion.
- Achieves a 30% improved phosphor & package efficiency of ~195 lm/W compared with unoptimized phosphor efficiencies.
- Targets combined improvement with total phosphor efficiency of 200 lm/W.

Benefits

Cost Savings

Potentially reduces overall LED and SSL system costs for high CRI lamps by using high efficiency phosphors rather than red LEDs and by reducing the overall LED count.

Efficiency

Optimizes LED system efficacy using high efficiency phosphor down conversion to achieve 150 lm/W efficacy and 75% wall-plug efficiency.

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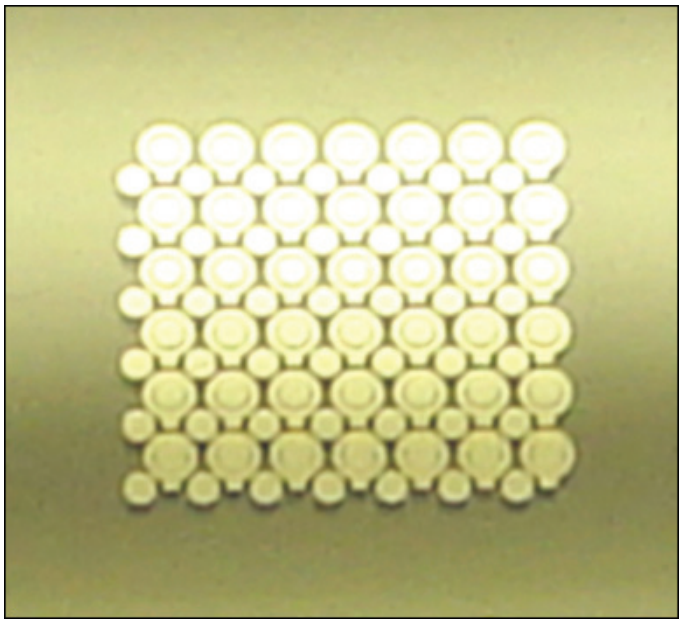
Phosphor-Free Solid-State Lighting Sources

New LEDs Generate White Light Without Using Phosphors

Typical white light-emitting diode (LED) sources consist of a blue LED plus a phosphor material, which is used to convert the LED emission wavelength into a broad spectrum, creating white light. Although high-power LEDs have been produced with this technique, problems exist with device lifetime, efficacy, and color temperature. A need exists for solid-state lighting (SSL) devices that can produce high-efficacy white light without the drawbacks of phosphor-based designs.

With funding from the U.S. Department of Energy's Building Technologies Program, Cermet Inc., is developing a phosphor-free technology that incorporates a blue LED and dopants within a substrate material. The blue LED emissions excite the dopants, which then emit red and green wavelengths to produce white light. This approach addresses several of the limitations present in a typical white LED source. One key advantage comes from integrating the red and green components in the substrate, which provides a more efficient process for photon conversion. In addition, the use of low-defect-density device structures improves the device's optical performance and durability.

Cermet has developed advanced LED prototypes and has demonstrated a device that provides warm white light. Future development will focus on increasing the total lumen output and efficacy of the prototype device. Cermet continues to seek out and explore possible collaboration and investment partnership opportunities as they prepare to release the technology into the marketplace.



Cermet's Phosphor-Free SSL Technology

Technology History

- Developed by Cermet Inc., with assistance from the Georgia Institute of Technology.
- Currently focusing on increasing the total lumen output and efficacy of the device and exploring partnership opportunities.

Applications

Can be used as an alternative to phosphor-based SSL technologies in the general illumination marketplace.

Capabilities

- Produces white light by color mixing emissions from a blue LED with red and green light from within the substrate.
- Enables white LEDs to be fabricated in vertical current geometries.
- Allows white LEDs to be produced without phosphors.

Benefits

Cost Savings

Reduces the cost of fabricating white LEDs by combining the substrate and phosphor functions in a single stage.

Efficiency

Increases white LED efficacy to the levels required for general illumination applications.

Manufacturability

Uses typical commercial approaches for substrate growth and LED epitaxial growth.

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Photoluminescent Nanofibers for High-Efficiency Solid-State Lighting Phosphors

Emerging Technology

Advanced Nanoscale Materials Enable High-Quality Color Rendering

Polymer nanofibers are nanoscale materials whose properties can be adjusted to manage the lighting performance of high-efficiency solid-state lighting (SSL) luminaires. By controlling fiber diameter, fiber packing, and fiber morphology, a low-cost, high-performance optical material can be fabricated. When used in SSL devices, nanofibers can take the form of either diffuse reflectors or photoluminescent materials that promote high-efficiency light output and provide color blending to desired chromaticity.

With funding from the U.S. Department of Energy's Building Technologies Program, Research Triangle Institute (RTI) International is developing advanced nanofiber materials for SSL applications. RTI developed nanofiber reflectors (NFRs) that displayed high diffuse reflectance with reflectance values in excess of 95%. In contrast, traditional reflector materials such as aluminum and paint typically possess reflectance values below 80% and absorb a larger fraction of light, reducing luminaire output efficiency. Incorporating the NFR technology into reflectors, troffers, and beam formers present in SSL luminaires provides better reflectance and lower light loss than is possible with conventional materials.

RTI's photoluminescent nanofibers (PLNs) were formed by combining nanofibers with photoluminescent materials such as phosphors and quantum dots. Forming the PLNs with the proper combination of green and red luminescent materials and exciting the nanocomposite with a blue light-emitting diode were demonstrated to produce high-efficiency (>55 lumens per watt) white light with excellent color rendering properties. Incorporating quantum dots in the PLNs is particularly advantageous because this approach enables any color deficiencies in the light source to be corrected without creating unnecessary radiation in the near-infrared part of the spectrum. Cost models developed during this project have demonstrated that both the NFR and PLN materials can be mass produced at a manufacturing cost that makes them commercially attractive.



High-Quality Color Rendering Provided by an LED Luminaire Using RTI's PLN and NFR Technology

Technology History

- Developed by RTI International, in partnership with Dimatix, Inc., Evident Technologies, Donaldson Company, and Elmarco, Inc.
- Tested advanced lighting designs containing photoluminescent nanofibers and nanofiber reflectors.
- Currently seeking to license the technology.

Applications

Can be used to improve the light output quality of phosphor-converted LEDs.

Capabilities

- Achieves a luminous efficacy in excess of 55 lumens per watt and a color rendering index of 90 for both neutral and warm white illumination. Light output is color tunable and diffuse.
- Enables high quantum efficiency down-conversion of LED wavelengths to produce full-spectrum white light.

Benefits

Cost Savings

Enables cost-effective solutions for diffuse, high-reflectance light management across the visible spectrum.

Versatility

Can be conformed to various geometries imposed by light fixtures, thus enabling new lighting designs.

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Wafer Fabrication System for Decreasing High-Brightness LED Costs

Emerging Technology

Process Technology Reduces the Cost of MOCVD Epitaxy

Light-emitting diodes (LEDs) used in most solid-state lighting (SSL) applications are manufactured using epitaxy deposition layer growth on gallium nitride (GaN) substrates, similar to semiconductor device manufacturing. Wafer epitaxy processing and fabrication of LEDs have evolved such that defects resulting from lattice mismatches in the crystal structures are reduced and the thermal expansion properties of the substrate and the deposited epitaxial layers are more comparable. Addressing these two concerns has improved LED electrical and thermal performance, leading to superior quality and performing devices for SSL applications.

Veeco Instruments Inc., with funding from the U.S. Department of Energy's Building Technologies Program (as part of the American Recovery and Reinvestment Act), is developing a wafer fabrication process that will significantly reduce the cost associated with the epitaxial growth of GaN-based LEDs. Veeco is using metal-organic chemical vapor deposition (MOCVD) equipment and processes. The first phase of development, in collaboration with Sandia National Laboratory, addressed reducing manufacturing cost by controlling the process temperature to within ±0.5°C, maintaining a film thickness uniformity with 1% or lower variation, and controlling indium composition within the indium gallium nitride film to 0.2 atomic percent or less. Accurate chemical and thermal flow models for the prototype reactor design were developed to improve efficiency and material quality.

Current development work involves a number of tasks aimed at improving the cost of ownership of the new system by improving MOCVD tool uniformity, repeatability, and throughput, while lowering the capital cost of the tool (per wafer). Throughput will be increased by reducing the deposition time, increasing the capacity, and improving the uptime of the current system. A new cluster system based on the current reactor has been developed, which is available in either a two- or four-reactor version of the system. Efficiency will be increased by high-temperature gas injector to reduce parasitic gas phase reactions. Improving the process temperature control and wafer carrier design will achieve run to run repeatability and increase yield. System cost will be reduced (per wafer) for both the two- and four-reactor cluster MOCVD systems.



Veeco's Advanced MOCVD Wafer Processing System

Technology History

- Developed by Veeco Instruments Inc., partnered with Sandia National Laboratory.
- Continuing work to improve system uniformity, throughput, and capital cost.

Applications

Can be used to fabricate LEDs used in SSL applications.

Capabilities

- Achieves a temperature-reporting accuracy of ± 0.5°C.
- Achieves film thickness uniformity within 1%.
- Controls indium composition within 0.2 atomic percent.

Benefits

Cost Savings

Reduces of the cost of ownership of the MOCVD system by a factor of four by improving throughput, material efficiency, yield, and capital cost.

Manufacturability

Reduces scrap by 50% and increases throughput of the MOCVD process, reducing overall manufacturing cost of the LEDs.

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D.6 OLEDs

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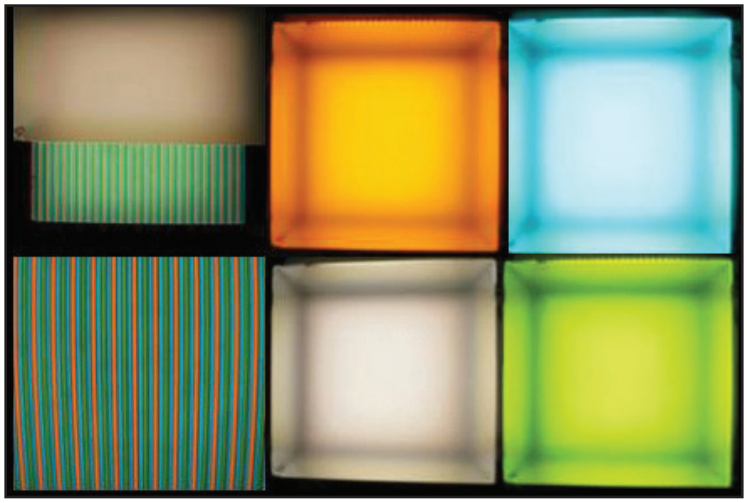
CCT-Tunable Phosphorescent OLED Luminaires for Energy Savings

Emerging Technology

Low-Cost OLED Lighting Manufacturing Enables Market Adoption

In 2010, lighting in commercial and residential buildings consumed 5.4 quads of primary energy.[1] New high-efficiency light sources are needed to reduce this energy demand. Until recently, few advances have been made in artificial lighting sources. Certain incandescent lighting technologies are being replaced by energy-saving compact fluorescent light bulbs. While energy-saving and longer-lifetime light-emitting diodes (LEDs) are becoming more widely accepted, they are costly to assemble because they require heat sinking to stop overheating and optics to reduce glare. On the other hand, organic LEDs (OLEDs) can be scaled to large areas at low cost because they do not require heat sinking and produce uniform diffuse light, eliminating glare. Also, OLEDs are potentially inexpensive and highly efficient diffuse light sources that may compete directly with and offer a green alternative to incandescent and fluorescent light sources. To realize this goal, highly efficient large-area OLED lighting panels must be developed and demonstrated.

Universal Display Corporation (UDC), in collaboration with Acuity Brands, Inc., and with funding from a U.S. Department of Energy Small Business Innovation Research grant, is developing commercial-performance OLED-based luminaires. As part of the effort to make OLED lighting a commercial reality, UDC is fabricating correlated color temperature (CCT)-tunable phosphorescent OLED luminaires that will demonstrate the high efficiency of large-area OLED lighting panels. The phosphorescence materials have ~100% conversion efficiency, converting electrical energy to light. The materials may be coated on glass, flexible plastic, or metal foil substrates using thermal evaporation. The process is easily scalable to large-area manufacturing. UDC is currently partnering with Moser Baer Technologies (MBT), Inc., to transfer its technology to a U.S.-based OLED lighting panel manufacturing facility being built by MBT.



UDC's OLED Technology Illustrating Various Color Mixing Capabilities

[1] *2010 Buildings Energy Data Book (Table 1.1.5)*, U.S. DOE, March 2011.

Technology History

- Developed by UDC.
- Continuing development work to produce 70 lm/W OLED CCT-tunable luminaires and technology transfer to manufacturing.

Applications

Can be used to replace traditional light sources for general illumination applications.

Capabilities

- Has the potential to provide an energy efficient light source capable of >150 lm/W efficacy with high quality, no glare, and CCT-tunable output.
- Operates at lower temperature compared with other light sources, eliminating the need for expensive heat sinking.
- Can be manufactured using relatively simple coating processes on flexible metal or plastic substrates.

Benefits

Cost Savings

Provides lower-cost, energy-saving, CCT-tunable high illumination quality technology that is environmentally friendly.

Durability

Achieves a 70% lumen maintenance lifetime of 30,000 hours with 3,000 lm/m^2 output.

Productivity

Allows OLED lighting to be manufactured with high efficiency, reduced thickness, flexibility, and transparency that will enable market adoption and commercialization.

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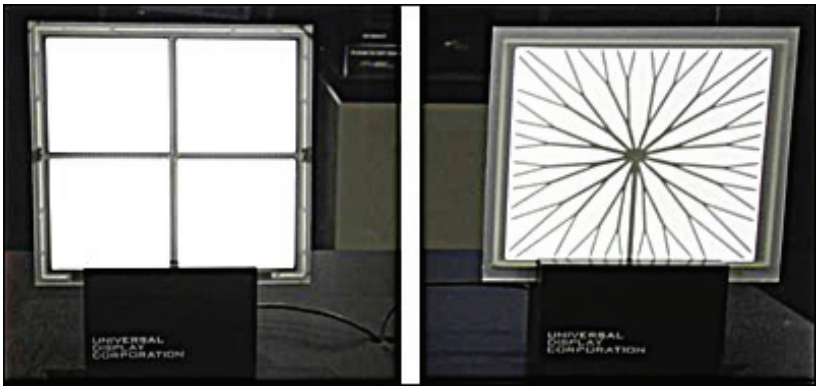
Efficient Large-Area WOLED Lighting

New Technology Provides Energy-Efficient, Uniform White Lighting Over Large Areas

The U.S. Energy Information Administration estimates that approximately 1600 TWh of electricity were used for lighting by the U.S. commercial and residential sectors in 2010.[1] This figure represents about 13% of total U.S. electricity consumption. Incandescent and fluorescent lighting, the dominant lighting technologies in use today, suffer from low energy efficiency. Energy-saving, long-lifetime light-emitting diodes (LEDs) have experienced some success entering the market for use in traffic lights and large advertisement panels. However, these large panels are costly to assemble because they are made up of many small LED light bulbs. A need exists for an LED technology that can be cost-effectively scaled to provide lighting over large areas.

With funding from a U.S. Department of Energy Small Business Innovation Research grant, Universal Display Corporation (UDC) is developing a new type of phosphorescent white organic LED (WOLED) technology for use in large-area illumination applications. UDC's WOLEDs require less energy to produce light than incandescent and most fluorescent lighting technologies and reduce the amount of energy lost to the surrounding environment as heat. UDC deposits the WOLED materials on glass substrates via thermal evaporation, a process that is easily scalable to large-area panels. The panels offer a diffuse source of illumination, eliminating the need for external diffusers such as lamp shades. UDC's WOLED technology also enables transparent window panels, such as skylights, to double as light sources. The panels can be transparent in the "off" state, allowing daylight to pass through. At night, the panels are turned to the "on" state to provide overhead lighting.

UDC is currently making 6" x 6" panels with efficacies exceeding 50 lm/W. The panels can be stacked side-by-side to cover large areas or cut into more intricate patterns for architectural designs. To bring the technology to the marketplace, UDC is partnering with Moser Baer Technologies and Armstrong World Industries, Inc. Moser Baer will manufacture the WOLED panels at a U.S.-based facility, while Armstrong will incorporate the panels into their TechZone™ ceiling systems.



UDC's Phosphorescent WOLED Lighting Panels

[1] *2010 Buildings Energy Data Book (Table 1.1.5)*, U.S. DOE, March 2011.

Technology History

- Developed by UDC, in partnership with the University of Michigan and the University of Southern California.
- Currently partnering with Moser Baer Technologies and Armstrong World Industries, Inc.

Applications

Can be used as a high-efficiency replacement for traditional lighting sources (i.e., incandescent, fluorescent, and halogen) used in general illumination applications.

Capabilities

- Produces a uniform white light output over a large area.
- Achieves a luminous efficacy exceeding 50 lm/W.
- Achieves an LT70 lifetime of 10,000 hours at a luminance of 1,000 cd/m^2.

Benefits

Cost Savings

Reduces operating costs relative to conventional lighting sources via energy-efficient operation.

Safety

Uses non-toxic materials in manufacturing without the mercury present in compact fluorescent bulbs.

Versatility

Can be fabricated on a variety of flexible substrate materials, including glass, plastics, and thin stainless steel.

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Low-Cost Integrated Substrate for OLED Lighting

Emerging Technology

Large-Area, Float-Glass-Based, Integrated Substrate Reduces Manufacturing Costs

White organic light-emitting diodes (OLEDs) are considered a potential high-efficiency, low-cost, solid-state replacement for general lighting. OLED lighting panels have been available since 2009, but commercial offerings have been limited to expensive luminaries for decorative applications and prototype panel kits. Widespread adoption of OLED-based solid-state lighting sources is constrained by the high cost of current OLED devices. Over 40% of the material cost of the OLED devices is attributed to the dressed (surface treating and polishing) substrate component, which includes the substrate, electrodes, and the extraction layers.

PPG Industries, Inc., with funding from the U.S. Department of Energy's Building Technologies Program (as part of the American Recovery and Reinvestment Act), intends to reduce the integrated substrate cost by replacing borosilicate substrate with float glass. PPG is also developing low-cost alternatives to indium tin oxide (ITO) anodes and scalable light extraction layers for integration with their float glass manufacturing process. The integrated substrate product will consist of a clear float glass substrate combined with a transparent conductive anode layer and light out-coupling (internal and/or external) layers that meet the manufacturer performance specifications (sheet resistance <10 Ohms per square (Ω /□), 85% average visible transmittance, and 1.5 - 2.0 times light extraction). The product is being developed using scalable technologies and has the potential to meet or exceed anticipated future competitive performance levels and cost targets.

PPG has already demonstrated that inexpensive float glass substrates could be used as an alternative to borosilicate or double-side polished glass substrates for OLED lighting. Several alternatives to the ITO anodes were also developed, and OLED devices with comparable performance were fabricated. PPG is currently exploring various internal and external light extraction layer technologies with encouraging preliminary results. PPG plans to launch a low-cost integrated substrate product for OLED lighting by late 2014 and has already targeted reducing current costs of $100/m^2 to $36/m^2 by 2012. Viable manufacturing techniques are being developed that would achieve a cost target of $26/m^2 by 2015 and enable product commercialization.



PPG's Substrate Used in a Green Phosphorescent OLED "Vertical Blind" Made by UDC

Technology History

- Developed by PPG Industries, Inc., with collaboration from Universal Display Corporation (UDC).
- Continuing work to develop processes for high-volume manufacturing of OLED substrates.

Applications

Can be used for manufacturing OLED lighting technology that would be cost competitive with conventional lighting sources.

Capabilities

- Meets substrate requirements and specifications for OLED manufacturing and replaces expensive borosilicate or double-side polished float glass.
- Achieves similar performance to expensive ITO anode coated substrates.
- Achieves up to two times the light extraction compared with conventional light extraction techniques.

Benefits

Cost Savings

Reduces substrate costs by using alternative anode materials, low-cost, large-area coated float glass and inexpensive light extraction technology.

Manufacturability

Uses large-area coated float glass substrate for high-throughput OLED manufacturing.

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OLEDs for General Lighting

Novel Technology Saves Energy and Enables New Product Configurations for Lighting

Lighting represents a large fraction of energy use in residential and commercial buildings. Any technological improvement that increases lighting efficiency and is adopted by large numbers of consumers will substantially reduce buildings' energy consumption. Conventional light sources, such as those based on incandescent and fluorescent technologies, are mature and therefore unlikely to experience dramatic increases in efficiency. Semiconductor-based light-emitting diodes (LEDs) have enabled significant energy-efficiency gains in lighting applications but are still primarily limited to use in rigid fixtures and surfaces. LEDs are also concentrated sources of light and therefore require a diffuser for use in most indoor lighting applications. A need exists for an energy-efficient lighting source that provides diffuse lighting in a variety of product configurations.

With funding from the U.S. Department of Energy's Building Technologies Program, GE Global Research is developing organic light-emitting diode (OLED) technology that will provide energy-efficient, diffuse light that can be tailored to a number of different product configurations. The organic semiconductors in OLEDs are amorphous, so they can be deposited on flexible substrates via low-cost techniques such as printing. Many lighting applications can take advantage of this flexibility, such as roll-up portable displays or large-area displays requiring curved surfaces. In addition, OLEDs are now being seriously considered for space lighting applications. GE's OLED technology is now four times more energy efficient than incandescent bulbs. OLEDs can also be installed directly into ceilings or walls without the need for external diffusers like lampshades. To accelerate the penetration of OLED technology into both the display and space lighting markets, GE continues to work on improving device performance and developing a high-volume, roll-to-roll manufacturing process.



GE's Flexible OLEDs

Technology History

- Developed by GE Global Research, beginning in 2000.
- Currently improving OLED performance and developing a roll-to-roll approach for OLED fabrication to enable low-cost production of flexible lighting products.

Applications

Can be used in general lighting applications, especially wherever diffuse illumination and/or flexible lighting devices are required.

Capabilities

- Produces high-quality diffuse light.
- Achieves a luminous efficacy four times greater than incandescent lighting.

Benefits

Cost Savings

Reduces costs by using high-volume, roll-to-roll manufacturing.

Design Flexibility

Enables lighting integration with curved or bendable surfaces in ways that are not possible for traditional lighting sources.

Versatility

Can be deposited on a variety of flexible substrates such as plastic, glass, and thin metal foil.

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Stable Materials for High-Efficiency Blue OLEDs

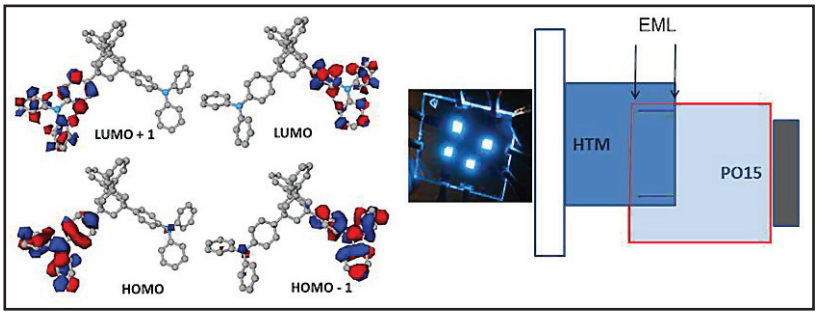
Emerging Technology

Novel Materials Increase Device Efficiency for Energy-Saving SSL Products

Considerable progress has been made in advancing organic light-emitting diode (OLED) based solid-state lighting (SSL) technology, which has the potential to offer higher efficacies than current traditional lighting technologies and to reduce energy consumption. OLEDs also provide new options for unique lighting applications for lighting designers. One of the main barriers to widespread adoption of large-area OLED lighting is the lack of stability in high-efficiency devices; development of stable materials for improved device stability has been identified as one of the critical OLED R&D tasks in the U.S. Department of Energy's (DOE's) multi-year program plan.[1]

With funding from DOE's Building Technologies Program (as part of the American Recovery and Reinvestment Act), Pacific Northwest National Laboratory (PNNL) is developing new hole transport materials (HTMs) and host materials (HMs) that are compatible with blue phosphorescent devices. These new materials have triplet energies higher than that of the phosphor dopant, which is known to reduce luminescence quenching (nonradiative transition), maximize efficiency, and provide charge transport properties analogous to state-of-the art HTMs. Previously developed computational tools and knowledge of degradation pathways of these materials within high-efficiency blue OLEDs were used to design inherently stable materials. These materials were used in device structures that were optimized to prevent holes or electrons from accumulating at charge transport layer interfaces. By using these new stable materials and improved OLED device architectures, PNNL has achieved improved device stability and efficiency of blue OLEDs at currents useful for SSL products.

Currently, PNNL is investigating potential collaboration with industrial stakeholders (i.e., component manufacturers, panel manufactures, and chemical companies) in the field and continues to work with strategic industrial partners to apply its technology to large-scale manufacturing and meeting DOE's performance goals on OLED lighting.



PNNL's Materials for Stable, High-Efficiency OLEDs

[1] *Solid State Lighting R&D: Multi Year Program Plan,* U.S. DOE, March 2011.

Technology History

- Developed by PNNL.
- Preparing for commercialization and high-volume synthesis with industrial partners.

Applications

Can be used in high-efficiency devices such as large area lighting and displays.

Capabilities

- Offers wider selection of materials to achieve balanced charge carriers in an OLED device.
- Enables OLED technology suitable for SSL products with higher power efficiencies.
- Enables durable OLED devices through rational design of stable hole transporting materials.

Benefits

Durability

Improves device lifetime and stability compared with devices using existing HTMs and HMs for OLEDs.

Efficiency

Optimizes OLED device properties by improving charge balance and exciton confinement in the emissive layer of the OLED.

Energy Savings

Reduces energy consumed for OLED lighting applications by increasing efficiency.

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Transparent Conducting Oxides and Undercoat Technologies for Economical OLED Lighting

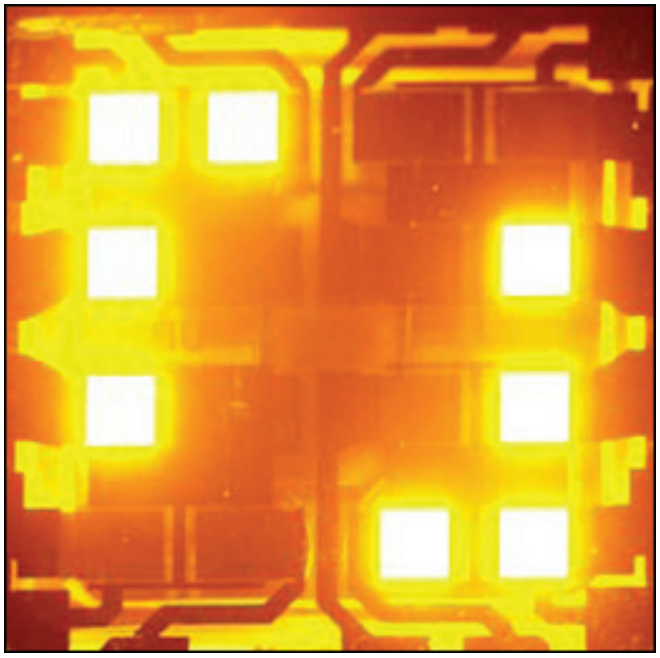
Emerging Technology

Alternative Material Reduces Cost of OLED Production

Organic light-emitting diode (OLED) devices require at least one transparent conducting layer as an electrode to carry electrical charge(s) while allowing light to pass through. Current commercial OLED devices use indium tin oxide (ITO) for the transparent conducting oxide (TCO) layer. Indium metal is relatively rare and expensive and is used predominately for optoelectronic applications such as flat panel displays. However, indium's high price and limited supply tend to make indium-based OLEDs expensive and will limit the market penetration of this energy-efficient technology. Recently, TCOs based on zinc oxide have shown promise as an economical alternative to ITO. Compared with indium, zinc is more abundant in nature and is used in a variety of applications, resulting in a stable supply and lower production costs.

Arkema Inc. and Philips Lighting, with funding from the U.S. Department of Energy's Building Technologies Program, are developing a process whereby a zinc-based TCO layer is deposited onto flat glass using atmospheric-pressure chemical vapor deposition (APCVD). APCVD technology is similar to what has been used for the last 20+ years to make low-emissivity windows with fluorine-doped tin oxide (FTO). The glass moves through the process very quickly, allowing only a few seconds for the deposition of precursors to form the TCO. The APCVD process also allows for excellent homogeneity across a glass ribbon (typically 3 meters) while achieving desired TCO electrical requirements and optical properties. Meeting these expectations by APCVD enables the potential production of millions of square meters of coated glass per float line at a reasonable cost.

The current project focuses on using APCVD to deposit doped ZnO TCO. The process advantages are similar to FTO, but the optoelectronic properties are superior to FTO and similar to the standard set by ITO in this market.



OLED Devices Containing Doped ZnO on a 6"x 6" Glass Substrate

Technology History

- Developed by Arkema Inc. and Philips Lighting.
- Continuing technology development and establishing industry partnerships.

Applications

Can be used as a TCO alternative to ITO for OLEDs or other devices that utilize ITO.

Capabilities

- Achieves >90% transmission in the visible spectrum.
- Offers electrical and thickness specifications equivalent to commercially available ITO.
- Offers comparable optical performance to commercially available ITO.

Benefits

Cost Savings

Provides an alternative, cost-effective raw material for OLED TCO layers.

Manufacturability

Processes easily and is highly adaptable to large-volume production.

Product Quality

Improves substrate adhesion compared with commercially available ITO.

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Transparent Conductive Oxides for OLEDs

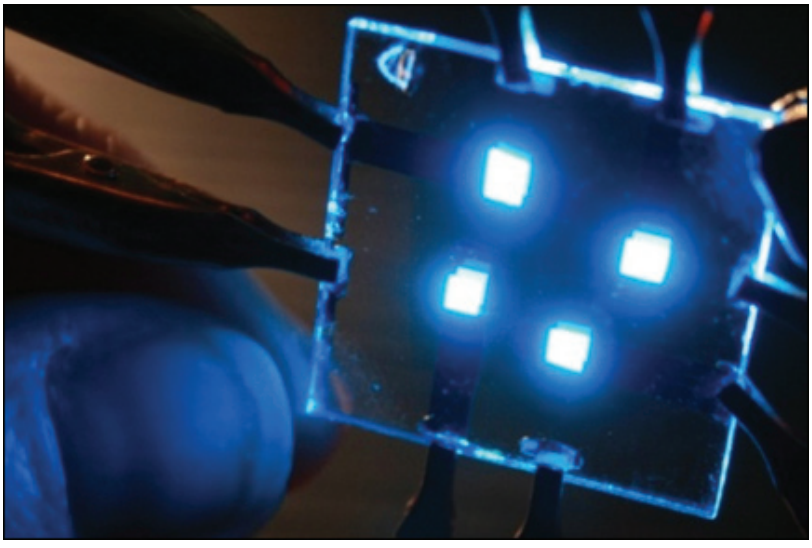
Emerging Technology

Indium-Free Flexible Substrate Reduces OLED Manufacturing Costs

Organic light-emitting diodes (OLEDs) have the potential to reduce lighting energy consumption and provide designers with options for unique lighting applications. The transparent conductive oxide (TCO) layer, an electrode that enables current flow through the device while allowing visible light to pass through, is a key component of all OLEDs. The majority of TCOs currently contain indium, which is very expensive due to its scarcity and the high demand for its use in liquid crystal displays and touchscreen devices. An alternative TCO material is needed that will reduce the costs associated with OLED manufacturing and enable the widespread adoption of OLED lighting.

With funding from the U.S. Department of Energy's Building Technologies Program, Pacific Northwest National Laboratory (PNNL) and the National Renewable Energy Laboratory (NREL) are developing a flexible OLED substrate technology that eliminates the cost and availability barriers associated with indium and can be manufactured on a large scale. The technology uses a sputtering technique capable of depositing an indium-free TCO (gallium-doped zinc oxide) uniformly over a large area. The process is performed at lower temperatures and allows for the use of flexible plastic substrates. Blue phosphorescent OLED devices fabricated using this method demonstrate excellent operating voltage (<4V) and efficacy (>35 lm/W) at a luminance of 800 Cd/m^2. General lighting applications typically would require approximately 5,000 Cd/m^2 at 4.9 V and 26 lm/W.

The new technology could serve as an inexpensive, flexible substrate for manufacturing large-scale OLED devices. Producing OLEDs on flexible substrates for mass production through high-volume processes such as roll-to-roll manufacturing could enable applications in general lighting, decorative lighting, displays, and solar panels.



PNNL's High-Efficiency Blue OLED

Technology History

- Developed by PNNL's lighting team and NREL's TCO team.
- Preparing to scale up for commercialization; seeking partner(s) for high-volume manufacturing.

Applications

Can be used for large-area displays, general lighting, decorative lighting, and photovoltaics on flexible substrates.

Capabilities

- Produces flexible electrode substrates.
- Provides an alternative to rigid, indium-tin-oxide based electrodes.
- Enables high-efficiency OLED technology that achieves 39 lm/W at 1 mA/cm^2.

Benefits

Cost Savings

Reduces costs by replacing indium with more abundant materials.

Energy Savings

Reduces energy consumed for lighting applications by increasing OLED efficiency.

Manufacturability

Enables high-volume manufacturing on flexible substrates.

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Ultra-High-Efficiency 80-lm/W Phosphorescent White OLED (WOLED) Lighting Panel

Emerging Technology

Light Panels Offer Highest Efficiency Recorded to Date for WOLEDs

Organic light-emitting diodes (OLEDs) are potentially inexpensive and highly efficient diffuse light sources that may compete directly with and offer a green alternative to incandescent and fluorescent light sources. OLEDs also offer unique design possibilities that could potentially revolutionize the industry through novel, nonhazardous, thin form factor lighting products. To realize this goal, highly efficient, large area OLED lighting panels must be developed and demonstrated.

With funding from a U.S. Department of Energy Small Business Innovation Research grant, Universal Display Corporation (UDC) is scaling up phosphorescent OLED (PHOLED®) technology to demonstrate its high-efficiency technology in large area lighting panels. Phase I goals were exceeded, and a white PHOLED pixel was demonstrated with efficacy = 125 lm/W, color rendering index (CRI) = 81, CIE (the RGB color space) 1931 (x, y) = (0.430, 0.428), and lifetime to 70% of initial luminance (LT70) = 11,000 hr at 1,000 cd/m^2. A second pixel with slightly lower efficacy was also demonstrated, but with chromaticity more closely matched to the Planckian curves: efficacy = 113 lm/W, CRI = 80, CIE 1931 (x, y) = (0.441, 0.414), and lifetime to LT70 =10,000 hr at 1,000 cd/m^2. This efficacy is the highest recorded to date for a white OLED pixel with emission color that meets stringent ENERGY STAR chromaticity requirements for solid state lighting.

Phase II plans include fabricating panels targeting a panel efficacy of >80 lm/W, which is 1.6 times higher than UDC's previous world record 15 cm x 15 cm OLED panel efficacy and 3-4 times more efficient that smaller area OLED panels that are commercially available today. The panel will have lifetime to 70% of initial luminance >20,000 hrs (at 1,000 cd/m^2) and CIE meeting ENERGY STAR criteria for solid state lighting. The panel will also have minimal thickness. UDC is currently partnering with Moser Baer Technologies to transfer its technology to a U.S.-based OLED lighting panel manufacturing facility.



UDC's OLED Light Panel

Technology History

- Developed by UDC.
- Developing 80 lm/W energy-efficient OLED light panels; demonstrated 15 cm x 15 cm OLED light panels with >60 lm/W efficacy with ENERGY STAR specifications.

Applications

Can be used to replace traditional light sources for general illumination applications.

Capabilities

- Offers energy-efficient light sources with the potential for >150 lm/W power efficacy.
- Allows manufacturing on flexible substrates with thickness <1 mm.

Benefits

Cost Savings

Can potentially be manufactured at low cost on flexible metal and plastic substrates. OLEDs run cooler than other light sources, avoiding the need for expensive heat sinking.

Product Quality

Provides lifetime of 30,000 hours at 3,000 lm/m^2.

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D.7 Other Lighting

- Advanced Coatings to Improve the Efficiency, Color Rendering, and Life of High-Intensity-Discharge Lamps D-80
- Arc Tube Coating System for Color Consistency D-81

Advanced Coatings to Improve the Efficiency, Color Rendering, and Life of High-Intensity-Discharge Lamps

Emerging Technology

Advanced Coating Significantly Increases Efficiency of HID Lamps

High-intensity-discharge (HID) lamps are used extensively for large area lighting such as parking lots, streets, and warehouses and are increasingly used for general lighting in stores and homes. HID lamps account for 16% of the lighting energy used in the United States, or about 128 GWh.[1] Based on this HID use, a 20% increase in the efficacy of HID lamps would result in a significant U.S. energy savings of 25 GWh per year.

With funding from a U.S. Department of Energy Small Business Innovation Research grant, Acree Technologies Inc. is developing an inexpensive, robust, single-layer coating that is applied to the outside of an HID lamp. The coating reflects infrared (IR) and ultraviolet (UV) photons back into the lamp, heating the plasma and increasing the lumen output for a given electrical energy input. Measurements demonstrate up to a 22% increase in the efficacy (lumens/watt) between coated and uncoated HID lamps, along with improved color rendering.

This optically selective transmissive coating is unique in that it is a single-layer coating that reflects IR and UV and is less expensive than previous multilayer coatings. The coating developed in this project can be applied for pennies per bulb, and the deposition process is compatible with large-scale production. The thickness of the coating is not critical, making the coating easy to produce. In addition, the coating is robust and lasts throughout the lifetime of the bulb.



HID Lamp with Acree's Optically Selective Transmissive Coating

[1] *2010 Buildings Energy Data Book (Table 5.6.4)*, U.S. DOE, March 2011.

Technology History

- Developed by Acree Technologies Inc.
- Partnering with Venture Lighting, a major HID lamp manufacturer.
- Currently testing coatings and anticipating that end user testing will continue.

Applications

Can be used on any HID lamp to significantly improve the lamp's efficiency and color rendering.

Capabilities

- Increases lamp efficacy over 20% compared with uncoated lamps.
- Offers a simple, inexpensive and adaptable process for retrofitting most HID lamps.
- Provides compatibility with existing manufacturing processes.

Benefits

Cost Savings

Improves lamp efficacy, significantly reducing lighting cost and energy consumption.

Durability

Provides a robust coating that lasts throughout the lifetime of the HID lamp.

Product Quality

Improves light output and the color rendering index of the lamp.

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Arc Tube Coating System for Color Consistency

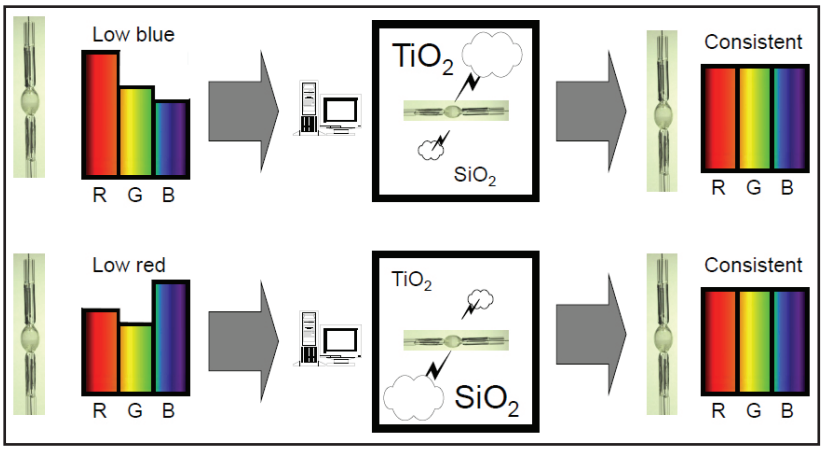
Emerging Technology

Automated Color Enhancement Coating Process Improves Light Output Quality

The accent and commercial spot lighting markets are dominated by inefficient tungsten-halogen lamps. Energy-efficient replacement technologies for incandescent spot lighting exist but have not gained widespread adoption because of their variability in lamp color and cost. High-wattage metal halide lamps are competing with solid-state lighting fixtures, which offer better color consistency despite being less efficient and more expensive. Metal halide lamp color consistency will need to be improved for this higher-efficiency lighting technology to maintain market share.

Energy Focus, Inc., with funding from a U.S. Department of Energy Small Business Innovation Research grant, is developing an automated, production-oriented, lamp color modification system for metal halide lamps. The system will reduce lamp color variation to that of current market-accepted tungsten-halogen lamps. The spectral output of a typical metal halide lamp has three large spikes, at wavelengths of 437, 547, and 577 nm, which result in a high correlated color temperature (CCT) and low color rendering index (CRI).

Energy Focus modified the spectral output by applying a thin film organometallic coating to the lamp. They have also developed a color correction algorithm that measures the lamp's spectral output and then calculates the exact coating composition to be applied to achieve the desired lamp color. This algorithm analyzes each lamp's spectral deficiencies (e.g., low blue and/or red output) and calculates the amount of color enhancement coating material to be applied, TiO_2 and SiO_2 for blue and red enhancement, respectively. This technique produces warm white CCT metal halide lamps and color variation within a four-step MacAdam ellipse, i.e., minimal perceived color difference between lamps. The technique will enable market acceptance of metal halide systems with a lower cost of light than incandescent, ceramic metal halide, and light-emitting diode systems. Currently, Energy Focus is developing and integrating their color correction algorithm into the manufacturing process to optimize and control the coating process. Fully automated lamp handling is in development. The color enhancement technique is being investigated for other cross-cutting applications such as different classes of metal halide lamps, light-emitting diodes, and photovoltaics.



Energy Focus' Color Correction Coating Process for Metal Halide Lamps

Technology History

- Developed by Energy Focus, Inc.
- Continuing development of an automated manufacturing process and investigating other applications of the technology.

Applications

Can be used for improving the quality of light output of metal halide lamps and other lighting technologies.

Capabilities

- Improves lamp quality of light output, CCT, and CRI.
- Provides lamp-lamp color consistency by individually tailoring each lamp's color enhancement coating.
- Provides a low-cost, convenient manufacturing process for improving metal halide lamp performance.

Benefits

Cost Savings

Provides a low-cost light technology with a quality of light equivalent to more expensive lighting technologies.

Durability

Provides improved lamp lifetime of >15,000 hours.

Product Quality

Produces lamps with minimal perceived color variation, i.e. within a four-step-MacAdam ellipse.

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D.8 Water Heating

- Accurate Feed-Forward Temperature Control for Tankless Water Heaters D-84
- CO_2 Heat Pump Water Heater D-85
- Gas-Fired Residential Heat Pump Water Heater D-86
- High-Efficiency CO_2 Heat Pump Water Heater for Commercial Applications D-87
- High-Performance Absorption Water Heater D-88
- ZigBee Open Standard Wireless Controller for Water Heaters D-89

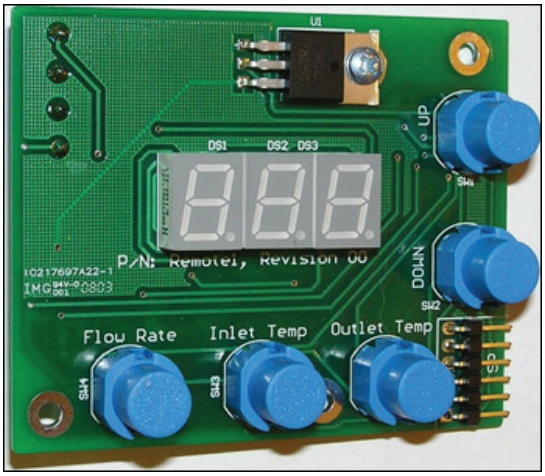
Accurate Feed-Forward Temperature Control for Tankless Water Heaters

Emerging Technology

New Algorithm Improves Temperature Control in Tankless Water Heaters

Water heating accounts for 13% of primary energy use in the residential sector of the U.S. economy, or about 3 quads of energy per year.[1] The current water heater market is dominated by traditional tank-style heaters, which accounted for 96% of all units sold in 2009.[2] All tank-style heaters suffer from standby losses, which is the continual loss of heat through the walls of the tank to the surrounding environment. Tankless water heaters (TWHs) eliminate the energy penalty of standby losses by heating water only as it is being used instead of storing heated water in a tank. Despite this benefit, TWHs have a very small market share (about 4%) due to a number of drawbacks. One important issue is the inability of many TWHs to maintain a desired outlet temperature across the rapidly changing flowrates common in residential water heating systems.

With funding from the U.S. Department of Energy's Building Technologies Program, Building Solutions, Inc. (BSI), developed an improved method of temperature control for electric TWHs. Conventional systems rely only on feedback control, whereby the water outlet temperature is compared to the setpoint and the controller adjusts power to the heating element to eliminate any difference between the two values. BSI used a control algorithm that incorporates both feedback and feed-forward control. By comparing the setpoint to the temperature of water entering the heater (feed-forward control), power to the heating element can be pre-adjusted to provide outlet water at the appropriate temperature. BSI's control algorithm results in faster convergence to the setpoint and an improved ability to maintain the water outlet temperature at the setpoint. A prototype TWH using BSI's control algorithm was developed that offers many improvements over currently available heaters, including a modular design for easy scalability. BSI is currently seeking a partnership with a water heater manufacturer to commercialize the control technology.



BSI's User Interface Controller for TWHs

[1] *2010 Buildings Energy Data Book (Table 2.1.6)*, U.S. DOE, March 2011.
[2] *ENERGY STAR Water Heater Market Profile (pg. 2)*, U.S. DOE, September 2010.

Technology History

- Developed by BSI.
- Currently seeking a partnership with a water heater manufacturing company to commercialize the technology.

Applications

Can be used to provide improved temperature control for TWHs in various applications (e.g., whole-house water heating, restaurant kitchens, industrial applications, and point-of-use showers or faucets).

Capabilities

- Improves the ability of TWHs to maintain a specified outlet temperature and quickly respond to changing flowrates.
- Spreads electric load evenly over time to avoid the flickering of lights in a home caused by rapid voltage fluctuations in conventional TWHs.

Benefits

Adaptability

Uses a modular design for easy construction of different capacity heaters, enabling use of the TWH as a booster heater for solar and heat pump water heaters.

Energy Savings

Offers a small size that enables point-of-use water heating, significantly reducing the distribution losses associated with conventional water heaters.

Safety

Can be programmed with fault detection and diagnosis routines to increase safety and enable easier maintenance.

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CO_2 Heat Pump Water Heater

Emerging Technology

High-Efficiency Heat Pump Provides Water Heating and Thermal Energy Storage

Water heating accounts for 9% of primary energy consumption in the U.S. buildings sector.[1] Improving energy efficiency in water heating applications is therefore an important part of the nation's energy strategies. Heat pump water heating (HPWH) technology is a significant breakthrough in water heating energy efficiency. However, the technology has several technical barriers that need to be addressed. Current commercialized systems use hydrofluorocarbon (HFC) refrigerants, which have high global warming potential (GWP) values. (On a scale where CO_2 has a GWP of 1, the common HFC refrigerant R-134a has a GWP of 1300.) Furthermore, current system designs operate with dual heating modes: heat pump with backup resistive heating. The backup resistive heating is activated at low ambient conditions, typically when ambient temperature is below freezing or when hot water demand increases. Finally, current HPWH technology cannot provide hot water temperature above 135°F.

Oak Ridge National Laboratory (ORNL), with funding from the U.S. Department of Energy's Building Technologies Program, is developing a CO_2-based heat pump water heater (CO2HPWH) that is an environmentally friendly alternative to units that use HFC refrigerants. The technology also provides a higher heating capacity and sustained performance at low ambient temperatures. This technology can supply hot water at temperatures sufficient for thermal energy storage (tank set point >135°F). The higher water temperatures are achieved by using a transcritical cycle, in which the gas cooling stage is above the critical pressure and the evaporation stage is below the critical pressure. Finally, the CO2HPWH can provide higher recovery efficiency and improved life-cycle climate performance compared with conventional HPWHs using HFC refrigerants. ORNL has developed and tested two fully functional prototypes. The current investigations have revealed that system performance is limited by the compressor efficiency. ORNL will continue to work on designing and testing field ready prototypes and will further investigate the techno-economic feasibility of this product.



ORNL's CO2HPWH Technology

[1] *2010 Buildings Energy Data Book (Table 1.1.5)*, U.S. DOE, March 2011.

Technology History

- Developed by ORNL.
- Currently focusing on identifying performance limits and design configurations that are economically suitable for retrofit and new construction in the U.S. market.

Applications

Can be used in residential and commercial water heating applications.

Capabilities

- Achieves higher first-hour rating, higher energy factor, and lower GWP compared with current HPWH technology.
- Provides improved hot-water-based thermal energy storage performance compared with current electric storage water heating technology.
- Uses an environmentally friendly alternative refrigerant to HFCs.

Benefits

Efficiency

Improves system efficiency at lower ambient temperatures with faster water heater recovery and higher first-hour ratings.

Emissions

Reduces global warming potential emissions by reducing the direct emissions associated with the refrigerant.

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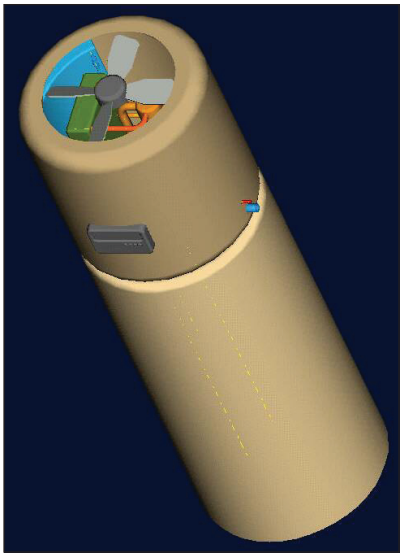
Gas-Fired Residential Heat Pump Water Heater

Emerging Technology

New Water Heater Design Increases Primary Fuel Efficiency and Reduces Costs

The U.S. residential water heater market has averaged about nine million water heater shipments per year over the past decade, with the sales almost evenly split between electric and gas units.[1] Electric heat pump water heaters, which give consumers an energy-efficient alternative to standard electric storage models, are now offered by most major water heater manufacturers and are rapidly gaining market share. Absorption-based heat pump water heaters, which use a heat source such as natural gas to drive the refrigerant cycle instead of an electric-motor-driven compressor, are currently not an available option for homeowners wishing to upgrade from standard gas storage units. New products are needed that will bring the inherent efficiency of a heat pump (i.e., moving heat from one place to another instead of generating it directly) into the gas water heater market.

With funding from the U.S. Department of Energy's Building Technologies Program (as part of the American Recovery and Reinvestment Act), Stone Mountain Technologies, Inc., is developing a gas-fired heat pump water heater for residential applications. The unit will use an ammonia-water absorption cycle and will have high-efficiency heat exchangers to minimize the refrigerant charge (amount of refrigerant) required for efficient operation. Several heat exchanger design options will be tested in single-effect and GAX (generator-absorber heat exchange) absorption cycles. Stone Mountain will conduct a cost-benefit analysis comparing efficiency with estimated cost to determine the cycle and heat exchanger technology that they will use for their packaged prototype unit. The successful commercialization of Stone Mountain's gas-fired heat pump technology will reduce the primary fuel consumption and carbon dioxide emissions associated with domestic hot water production. Stone Mountain plans to begin field testing their prototype water heater in 2013, with commercialization anticipated by the end of 2014.



Stone Mountain Technologies' Gas-Fired Residential Heat Pump Water Heater

[1] *ENERGY STAR Water Heater Market Profile (pg. 2)*, U.S. DOE, September 2010.

Technology History

- Developed by Stone Mountain Technologies, Inc., with assistance from the Gas Technology Institute, A.O. Smith Corporation, and the Georgia Institute of Technology.
- Currently conducting proof-of-concept testing and working to complete an alpha packaged prototype unit.

Applications

Can be used as an energy-efficient alternative to standard residential gas storage water heaters.

Capabilities

- Provides domestic hot water with an energy factor of 1.5.
- Reduces natural gas consumption by ≥50% compared with conventional gas storage and tankless gas water heaters.
- Offers a heating capacity of about 3 kW (10,000 Btu/hr) and a 60–80 gallon storage tank.

Benefits

Cost Savings

Reduces water heating gas bills by $125–$250 annually compared with gas storage water heaters (depending on hot water use and local gas rates).

Energy Efficiency

Achieves a primary fuel efficiency 2.4 times greater than conventional gas storage water heaters and 2.1 times greater than electric heat pump water heaters.

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Stone Mountain Technologies, Inc.
720 Watauga Avenue
Erwin, TN 37650

High-Efficiency CO_2 Heat Pump Water Heater for Commercial Applications

Emerging Technology

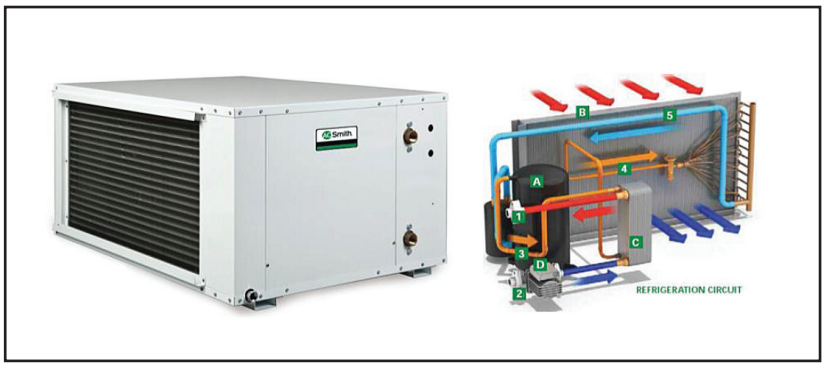
New Technology Provides Energy-Efficient Water Heating and Space Cooling

Heat pump water heaters (HPWHs) are beginning to gain market share in the U.S. residential sector, but their adoption has been slow in the commercial sector due to high capital/operating costs and performance/reliability issues. One way to make HPWHs more appealing in the commercial sector is to improve their performance for a relatively small increase in initial cost by using CO_2 (known as R-744 in refrigerant nomenclature) as the refrigerant.

R-744 is an excellent refrigerant for HPWHs because it enables the unit to operate within a wide range of ambient temperatures (satisfactory performance can be achieved at temperatures down to -20°F/-29°C). The ability of R-744 to match water to refrigerant temperatures on the high side results in very high exit water temperatures (up to 180°F/82°C) that are much more difficult to reach with other refrigerants. This feature of R-744 is helpful in applications where water is used for sanitation. HPWHs operating with conventional R-134a refrigerant require an additional electric resistance heater to reach sanitation water temperatures; this extra component is not needed when operating with R-744.

With funding from the U.S. Department of Energy's Building Technologies Program (as part of the American Recovery and Reinvestment Act), Creative Thermal Solutions, Inc. (CTS), is developing a high-efficiency R-744 HPWH for commercial sector applications that have a simultaneous need for hot water and space cooling. CTS initially tested an R-134a HPWH to obtain a performance baseline of current technology/refrigerants. A baseline R-744 HPWH was also fabricated by retrofitting the R-134a unit with R-744 components. The R-744 system matched the R-134a performance in many test conditions and was able to exceed R-134a performance in certain boundary conditions.

Using the test results from the baseline R-744 unit, CTS identified design modifications that are being implemented in an optimized, next-generation version with an anticipated 20% increase in cycle efficiency. The targeted efficiency improvement will be achieved by using two-phase ejectors, high-performance gas coolers, and high-efficiency interior permanent magnet motors in the refrigerant compressor.



CTS' R-744 Heat Pump Water Heater

Technology History

- Developed by Creative Thermal Solutions, Inc., with assistance from A.O. Smith Corporation.
- Currently optimizing a baseline R-744 HPWH and testing an improved internal heat exchanger.

Applications

Can be used in commercial buildings that have a simultaneous need for hot water and space cooling (e.g., restaurants, hotels, and hospitals).

Capabilities

- Provides a water heating capacity of 120,000 Btu/h (35 kW) and water outlet temperatures of up to 180°F/82°C.
- Produces a simultaneous space cooling effect of 85,000 Btu/h (25 kW).
- Achieves a combined (heating and cooling) COP of up to 8.

Benefits

Environment

Reduces global warming potential (GWP) compared with conventional refrigerants. (On a scale where CO_2 has a GWP of 1, R-134a has a GWP of 1300.)

System Size

Reduces system footprint compared with R-134a HPWHs because of the high volumetric heating/cooling capacity of CO_2.

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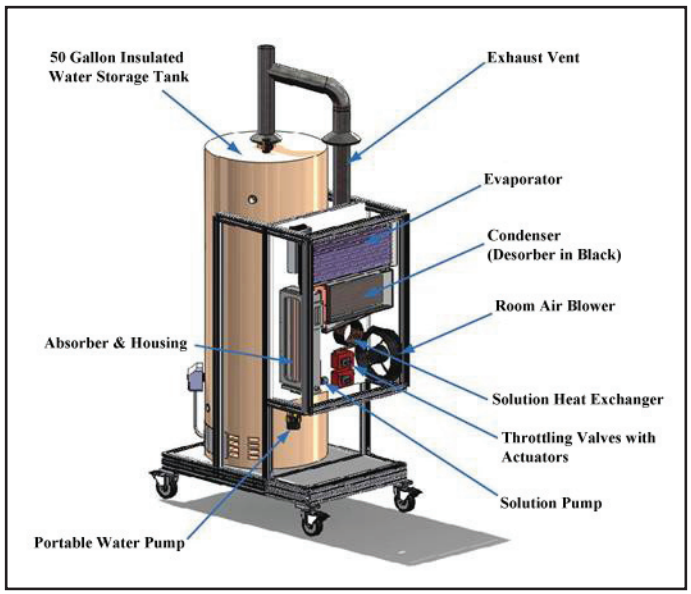
High-Performance Absorption Water Heater

Emerging Technology

Water Heater Uses Fuel-Fired Heat Pump Technology to Improve Energy Efficiency

Residential water heating is the second highest energy consuming end use in U.S. homes and accounts for 13% of U.S. residential primary energy consumption.[1] Current natural gas water heating technology has an energy factor (EF) of <0.7 and suffers from poor performance because of exhaust stack losses. Tankless and condensing tankless water heating technologies provide relatively higher energy efficiency (EF >0.8) and equipment capacity. However, the tankless technology requires significant infrastructure modifications: forced draft ventilation and higher-capacity natural gas supply lines. These modifications increase installation cost and reduce the attractiveness of the tankless natural gas water heating technology.

Oak Ridge National Laboratory (ORNL), with funding from the U.S. Department of Energy's Building Technologies Program, is developing an absorption water heater (AWH) technology for retrofit applications with no infrastructure modifications. The heart of ORNL's AWH is essentially an air source heat pump driven by natural gas instead of electricity. This technology is a breakthrough in natural-gas-fired water heating because it provides an EF >1.0 for the first time using fossil fuels. The design will be used as a drop-in replacement for conventional gas storage water heating equipment: no natural gas supply line upgrade and no ventilation modification are needed. The absorption heat pump augments the primary energy with energy extracted from the surrounding ambient temperature, resulting in a higher EF than previously attained for natural-gas-fired water heating applications. The AWH technology uses an advanced absorption heat pump cycle and aqueous lithium bromide (LiBr) additives to prevent LiBr crystallization at low ambient conditions. In 2011, ORNL designed, fabricated, and initiated testing of a prototype AWH. Future work involve comprehensive experimental testing, design modifications, and development of an advanced prototype AWH.



ORNL's AWH Technology

[1] *2010 Buildings Energy Data Book (Table 2.1.6)*, U.S. DOE, March 2011.

Technology History

- Developed by ORNL.
- Continuing work on testing and developing prototypes and fabricating a second-generation prototype AWH.

Applications

Can be used for residential and commercial water heating applications.

Capabilities

- Provides natural-gas-fired water heaters with EF >1.0 and first-hour rating >70 gallons.
- Scales up to meet the demand of commercial water heating.
- Operates at typical water heating temperatures without refrigerant solution crystallization problems.

Benefits

Cost Savings

Reduces natural gas consumption, also reducing annual water heating bills.

Efficiency

Improves natural gas water heating efficiency, with EF >1.0 for the first time.

Emissions

Reduces global warming emissions by reducing energy consumption.

Safety

Increases safety by replacing toxic ammonia with alternative environmentally benign safe refrigerants.

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ZigBee Open Standard Wireless Controller for Water Heaters

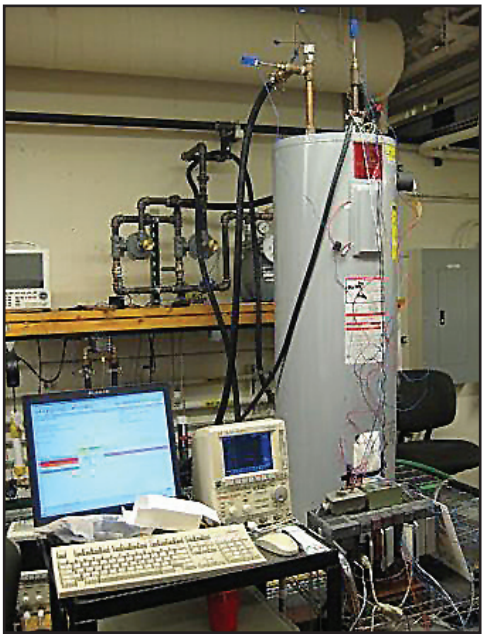
Emerging Technology

Wireless Controller Reduces Peak Electricity Demand from Appliances

Water heating is the third largest energy use in residential homes, accounting for ~14% of all residential building energy consumption.[1] Newer high-efficiency electric water heaters offer energy savings and the potential to lower peak electricity demand. Lowering peak demand is valuable to most power utilities because this reduces the required peak demand capacity (demand savings). Another method to reduce peak demand and energy costs is the use of a smart-grid-compatible water heater. Smart-grid-ready appliances have the capability to respond to external data and control signal input, e.g., power utility pricing information, and turn off during all or part of the peak demand period with no inconvenience or impact on the home occupants.

Emerson Electric Company, with funding from the U.S. Department of Energy's Building Technologies Program (as part of the American Recovery and Reinvestment Act), is developing a ZigBee open-standard-based wireless controller for water heater control and integration into a residential smart energy home area network. The network uses ZigBee wireless controllers to enable communication between utility companies, the smart grid, and household appliances to improve energy efficiency and to help consumers mange household energy consumption in near real-time.

Emerson's water heater ZigBee controller will reduce peak load demand and save energy by combining communications and load switching technologies. The controller provides "smart" operation in two ways: it is compatible with smart energy home area networks and uses a smart algorithm to manage energy usage by the water heater to reduce, prevent, and offset peak load events. This product will also include an interactive user display that supplies consumers with a tool to manage the costs and energy used by the water heater.



Emersons' Electric Water Heating Applications Laboratory

[1] *2010 Buildings Energy Data Book (Table 2.1.6)*, U.S. DOE, March 2011.

Technology History

- Developed by Emerson Electric Company.
- Continuing work on engineering development and market planning.

Applications

Can be used in residential and light commercial electric water heating applications.

Capabilities

- Uses ZigBee standard wireless communication.
- Provides connectivity to the smart energy home area network.
- Uses thermal energy stored in the water heater tank to defer energy usage to off peak times.
- Provides standard electric water heater control and enables "grid smart" capability.

Benefits

Compatibility

Provides "smart grid" compatible solution to control energy usage and reduce peak demand.

Cost Savings

Offers significant cost savings by automatically removing demand from the grid during on peak hours to off peak times.

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D.9 Windows Technologies

- Adaptive Liquid Crystal Windows D-92
- High-Rate Coating Technology for Low-Cost Electrochromic Dynamic Windows D-93
- Low-Cost, High-Energy-Savings, Solid-State Dynamic Glass D-94
- Vacuum Glazing Development D-95

Adaptive Liquid Crystal Windows

Emerging Technology

New Window Glazing Technology Reduces HVAC Energy Consumption

Almost 30% of the energy used to heat and cool U.S. homes (2.7 quads annually) is lost through windows.[1] Currently, energy conservation is a top national priority given the desire to reduce oil consumption and greenhouse gas emissions. A major contribution to energy conservation could be made by eliminating HVAC energy consumption from solar loading, especially during the warm summer months. Various reflective window technologies have been developed to reduce summer cooling loads, but these technologies do not provide any benefit during the winter.

With funding from the U.S. Department of Energy's Building Technologies program, AlphaMicron, Inc., is developing an active window glazing technology that adapts to seasonal climate change and reduces year round energy consumption. The adaptive windows reduce the amount of solar loading by controlling the amount of sunlight transmitted through the window, less in the summer and more in the winter. An additional benefit of this technology is that the light transmission is controlled without creating an unpleasant interior environment, e.g., excessive glare or darkness. Interior décor is also protected from ultraviolet and solar heating damage.

AlphaMicron's adaptive, smart window film technology consists of liquid crystal deposited on a flexible substrate instead of glass. The company is developing a unique manufacturing system that uses a roll-to-roll manufacturing process to produce a 14-inch-wide liquid crystal film. Successful commercialization of the technology will require wider films to accommodate most window sizes. AlphaMicron will therefore scale up their manufacturing capabilities to produce 48-inch-wide smart window films.



AlphaMicron's Adaptive Liquid Crystal Window Technology

[1] *2010 Buildings Energy Data Book (Table 2.1.15)*, U.S. DOE, March 2011.

Technology History

- Developed by AlphaMicron, Inc.
- Continuing development of a roll-to-roll manufacturing process to produce window films that are 36 inches wide.

Applications

Can be used as an energy-efficient replacement for conventional windows in residential and commercial buildings.

Capabilities

- Offers variable transmission: 70% in winter mode and 30% in summer mode.
- Reduces HVAC energy consumption by manipulating solar loading.

Benefits

Comfort

Controls light transmission to ensure a comfortable living/working space without excessive glare or darkness.

Emissions Reductions

Reduces greenhouse gas emissions by lowering building energy consumption.

Energy Savings

Reduces energy loss through windows and enables energy-efficient buildings.

Versatility

Adapts to residential and commercial applications.

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High-Rate Coating Technology for Low-Cost Electrochromic Dynamic Windows

Sunlight-Sensitive Window Tint Reduces Solar Heat Gain and Saves Energy

A promising approach for reducing HVAC energy consumption in buildings is to control solar heat gain so that it is maximized during the winter and minimized during the summer. A reflective coated glass window is only useful during the summer season and vice-versa for certain low-e, double-glazed windows in winter. To better control solar heat gain coefficient during the summer, dynamic electrochromic (EC) technologies have been developed. Unfortunately, the available EC window products suffer from high cost and inadequate EC performance. The poor value proposition (performance vs. cost) is mainly a result of the lack of a low-cost process technology to coat the chromogenic layers on large-area architectural glass substrates.

Applied Materials, Inc., with funding from the U.S. Department of Energy's Building Technologies Program (as part of the American Recovery and Reinvestment Act), is developing a market-viable, low-cost EC glass coating technology for dynamic window manufacturing. The process will reduce product cost and encourage widespread adoption of EC glass products in commercial and residential buildings, significantly saving energy on a national scale.

Applied Materials is focusing on developing high-rate coating sources, equipment, and techniques for depositing the key layers required for a working EC window film stack. An optoelectronic modeling software package was developed to optimize the EC device design to be compatible with the new manufacturing process. Applied Materials is investigating high deposition rates to maximize process throughput without jeopardizing product quality and consistency. Currently, lithium phosphorous oxynitride (LiPON) and Li deposition results appear to be the most promising. A multi-chamber, multi-process, integrated R&D vacuum coating system, Applied Materials' Aristo™ deposition platform, is being used to demonstrate the fundamental approaches. Prototype EC device fabrication and characterization are under way.



Applied Materials' ARISTO™ Deposition Platform for EC Device Processing

Technology History

- Developed by Applied Materials, Inc., in collaboration with Lawrence Berkeley National Laboratory.
- Continuing development of multi-process high-volume manufacturing platform to enable low-cost manufacturing of EC dynamic glass.

Applications

Can be used in residential and commercial building applications.

Capabilities

- Provides optimized high deposition rates for LiPON and Li, the two key EC materials.
- Provides a sequential coating system and process flow for producing a complete EC stack.
- Achieves high product manufacturing throughput of EC devices.

Benefits

Manufacturability

Reduces manufacturing costs using large substrate area and high-throughput manufacturing coating process.

Market Adoption

Enables consumer adoption of EC dynamic windows by lowering the cost of ownership and by providing potential energy savings.

Product Quality

Improves film quality and increases product yield by using the multi-chamber, multi-process integrated coating process.

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Santa Clara, CA 95054
Website: http://www.appliedmaterials.com

Low-Cost, High-Energy-Savings, Solid-State Dynamic Glass

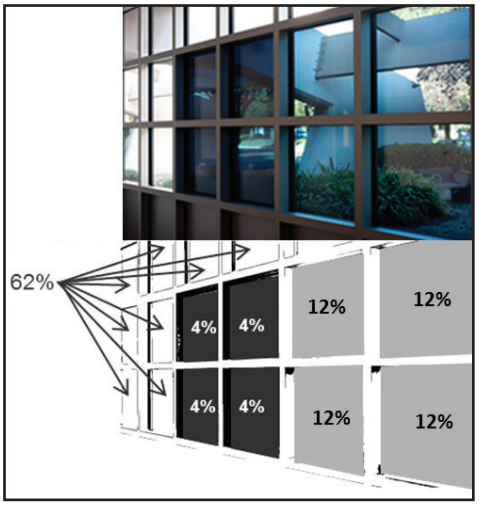
Emerging Technology

Electrochromic Glass Controls Solar Heat Loading to Reduce Energy Consumption

HVAC cooling during the summer months is a direct result of solar loading, which ranges from 3 to 14 kWh/m^2/day, depending on geographic location. A major contribution to energy conservation could be made by eliminating HVAC energy consumption from solar loading. Historically, window technology research has investigated various window technologies to reduce summer cooling loads. Most current state-of-the-art windows use spectrally selective low-emissivity (low-e) glass, which blocks some ultraviolet (UV) and near infrared (NIR) light and allows visible light to pass through. High-performing low-e insulated glass units (IGU) typically have a solar heat gain coefficient (SHGC) of 0.3 to 0.4 (i.e., blocking 60%-70% of the solar radiated heat), while transmitting 50%-60% of the visible light.

Soladigm, Inc., with funding from the U.S. Department of Energy's Building Technologies Program (as part of the American Recovery and Reinvestment Act), is developing dynamic glass based on electrochromic technology, which is formed as a multi-layer coating stack applied to the inner surface of the outer pane of glass in a double-pane insulated glass unit (IGU). The glass can be tinted by applying a DC voltage of <3 volts; reversing the applied voltage causes the glass to become clear. Soladigm's dynamic, electrochromic glass technology provides an SHGC that can be tuned in real-time from 0.09 to 0.48, with visible light transmission from 4%-62%. In the tinted state, Soladigm's dynamic glass blocks three times more solar heat than state-of-the-art low-e glass and eliminates glare. In cold weather, dynamic glass can adapt to raise the SHGC, allowing passive solar heating and reducing heating bills; low-e glass cannot provide such energy savings in winter.

Soladigm's dynamic glass has the potential to reduce the energy consumption in commercial buildings by up to 25% and peak load by up to 30% compared with current low-e glass. In residential buildings, the potential savings are 18% and 41% for energy and peak-load reduction, respectively. Soladigm's manufacturing process has the potential of costing four times less than current electrochromic windows on the market.



Soladigm's Dynamic Glass Demonstration of 4%, 12%, and 62% Transmission

Technology History

- Developed by Soladigm, Inc.
- Future work focusing on multiple demonstration field studies and ramping up to full manufacturing production in 2012.

Applications

Can be used for controlling the amount of light and heat entering building windows, reducing lighting and HVAC energy consumption.

Capabilities

- Controls radiant heat by blocking direct sunlight in summer and transmitting it in winter.
- Reduces direct sunlight glare through windows.
- Eliminates the need for blinds, shades, and related maintenance costs and provides unobstructed views and natural daylight to improve occupant comfort.

Benefits

Cost Savings

Provides an immediate break-even initial cost based on HVAC downsizing, eliminating blinds or shades.

Energy Savings

Provides 25% HVAC energy savings and 30% HVAC cooling peak load reduction.

Product Durability

Complies with industry standard performance and reliability testing per ASTM E2141-06.

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Vacuum Glazing Development

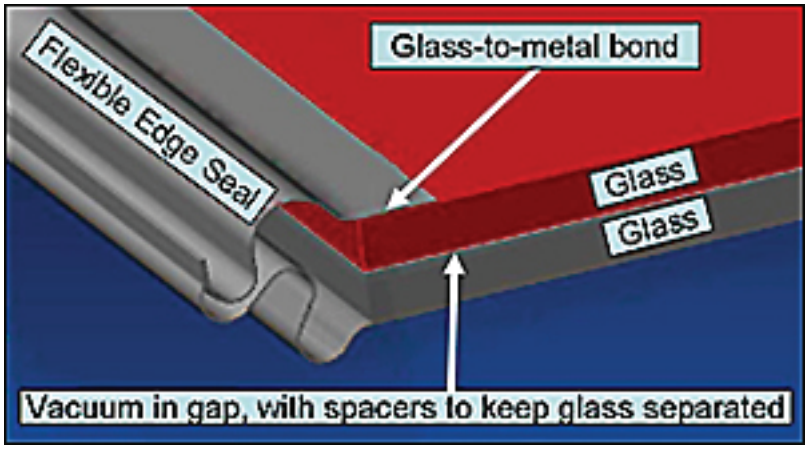
Emerging Technology

Novel Design Improves Durability and Insulating Performance of Windows

Conventional insulating glass units (IGUs) in windows have a typical lifetime of 10 to 20 years, after which seal failure and/or contamination of the internal airspace occurs. Once the seal has failed, a window's insulating performance is drastically reduced. The insulating capability of air-or-gas-filled IGUs is also limited, with double-pane IGUs achieving an insulating value of about R-3.5 and triple-pane IGUs reaching about R-5.5. Currently available vacuum insulating glass units (VIGUs) save more energy but do not last long enough to achieve a full payback of their higher initial cost. A need exists for a VIGU that will offer energy-saving insulative properties over a long lifetime.

With funding from the U.S. Department of Energy's (DOE's) Building Technologies Program and an American Recovery and Reinvestment Act grant, EverSealed Windows, Inc. (ESW), is developing a new sealing technology that will allow window manufacturers to produce long-lasting VIGUs with exceptional insulating values. The design employs a flexible metal edge seal that is gas-tight and allows the individual panes of a VIGU to expand/contract independently in response to differing inside and outside temperatures. The seal itself, which expands and contracts like an accordion, reduces stress on the window and extends window lifetime. ESW's proprietary glass-to-metal bond has demonstrated the sealing performance necessary for maintaining high-vacuum pressures between the glass panes. The durability of the seal will be verified by performing accelerated thermal cycling tests equivalent to 40 years of use in the field. The panes of glass themselves are kept apart by a system of nearly invisible standoffs.

ESW's VIGU is being designed to withstand the stresses of extreme-temperature environments for at least 25 years, while achieving an insulating value of R-14 or greater. This improved performance will enable a whole-window insulating value of R-10, a long-term DOE goal for helping to achieve cost-effective energy-efficient buildings. The insulating advantage of the VIGU also allows for building designs that incorporate more windows without increasing energy consumption. An increased number of windows allow a greater portion of a building to be lit with natural daylight, resulting in a more comfortable living/working space for the building's occupants.



ESW's Durable, Energy-Saving VIGU

Technology History

- Developed by ESW, with contributions from multiple national laboratories and leading North American window manufacturers.
- Currently testing and demonstrating various durability characteristics of the glass-to-metal bond under extremely hot and cold conditions.

Applications

Can be used wherever highly insulative glass windows and doors are needed, including extreme-temperature climates, sun-facing walls, refrigerated supermarket display units, and vending machine doors.

Capabilities

- Achieves an insulating value of R-14 or greater, enabling a whole-window R-value of R-10.
- Increases windows' high-performance insulating lifetime to 25 years or more.

Benefits

Durability

Increases window lifetime by using a hermetically bonded flexible seal.

Energy Savings

Reduces energy loss through windows, thereby lowering energy consumption for heating and cooling buildings.

Safety

Uses tempered (heat-strengthened) glass in standard units and laminated safety glass when hurricane-resistant windows are required by city or county building codes.

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Appendix E:
Directory of Technology Developers

Commercially Available Envelope Technologies

Billy Ellis Roofing, LLC
ThermaDeck: An Insulated and Ventilated Roof System C-5

Oak Ridge National Laboratory
Next-Generation Envelope Materials C-4

Commercially Available HVAC&R Technologies

Bard Manufacturing Company, Inc.
Quiet Climate 2: Efficient Heat Pump for Classrooms C-10

EchoFirst, Inc.
Echo™: A Hybrid Solar Electric/Thermal System C-8

IntelliChoice Energy
NextAire™ Packaged Gas Heat Pump C-9

Commercially Available LED Devices Technologies

Cree, Inc.
High-Efficiency LED Lamp for Solid-State Lighting C-13

Philips Color Kinetics
Integrated, Solid-State LED Luminaire for General Lighting C-14

Philips Lighting
Efficient LED System-in-Module for General Lighting C-12

Philips Lumileds Lighting Company
LUXEON® A and LUXEON® S: Warm White Illumination-Grade LEDs C-15

Commercially Available Other Lighting Technologies

ELB Electronics, Inc.
Adapting Wireless Technology for Lighting Control C-18

Energy Focus, Inc.
Ballast/Driver Technology for Metal Halide or Solid-State Lighting Systems C-19

Luminit, LLC
Optical Performance-Enhancing Material for Lighting Applications C-21

Redwood Systems, Inc.
Lighting Power and Control Network for SSL Systems C-19

Commercially Available Water Heating Technologies

A.O. Smith Corporation
Vertex™ Residential Gas Condensing Water Heater C-25

General Electric Company
GeoSpring™ Hybrid Water Heater C-24

Commercially Available Windows Technologies

GED Integrated Solutions, Inc.
ATLAS™: An Energy-Efficient Triple IG Window Manufacturing System C-28

Pleotint, LLC
Suntuitive™: Sunlight-Responsive Thermochromic Window Systems C-32

SAGE Electrochromics, Inc.
SageGlass® Electrochromic Windows C-31

Solutia Inc.
EnerLogic®: Low-Emissivity, Energy-Control Retrofit Window Film C-29

Traco, a division of Kawneer Company, Inc.
OptiQ™: An Advanced Commercial Window Technology C-30

Emerging Building Controls Technologies

Clean Urban Energy, Inc.
Predictive Optimal Control of Active and Passive Building Thermal Storage Inventory D-7

Eaton Corporation
Advanced Load Identification and Management for Buildings D-4

Johnson Controls, Inc.
Integrated Predictive Demand Response Control for Commercial Buildings D-5

United Technologies Corporation
Plug-and-Play Distributed Power Systems for Smart-Grid-Connected Buildings D-6

Emerging Envelope Technologies

Davis Energy Group, Inc.
Insulating Form System for Concrete Foundation Edges D-13

Dow Corning Corporation
Energy-Efficient EIFS Wall Systems D-11

EIFS Industry Members Association
Exterior Insulation and Finish System (EIFS) D-12

Industrial Science & Technology Network, Inc.
Advanced Building Insulation by Carbon Dioxide Foaming Process D-10

Nanotrons Corporation
Nano-Enabled TiO_2 UV Protective Layer for Cool-Color Roofing Application D-15

Oak Ridge National Laboratory
Reflective Elastomeric Roof Coating D-16

Syntroleum Corporation
Low-Cost Phase Change Materials For Building Envelopes D-14

Technova Corporation
Shape-Stable and Highly Conductive Nano-Phase Change Materials D-17

University of Nebraska-Lincoln
Three-Dimensional Building Energy Performance Measurement and Modeling System D-18

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Caitin, Inc.
Water-Based, Critical Flow, Non-Vapor-Compression Cooling System D-37

Chemtura Corporation
Next-Generation Refrigerant Lubricants D-34

Davis Energy Group, Inc.
HyPak: A High-Efficiency Rooftop Packaged HVAC System D-29

DeLima Associates
Comboflair®: An Integrated HVAC and Water Heating System D-26

Hi-Z Technology, Inc.
Thermoelectric Materials for Waste Heat Recovery D-36

Machflow Energy, Inc.
Bernoulli Principle Air Conditioning and Cooling System D-24

Mainstream Engineering Corporation
Wireless Remote Monitoring System for Residential Air Conditioners and Heat Pumps D-38

Oak Ridge National Laboratory
Air-Source Integrated Heat Pump D-22
Cold Climate Multi-Stage Heat Pump D-25
Ground-Source Integrated Heat Pump D-28
Improving Efficiency of Fuel-Fired Furnaces for Space and Water Heating Systems D-30
Multi-Zone HVAC Options for Residential Applications D-32
Nanographitic Additive for Enhanced Heat Transfer and Lubricity of Refrigerant Systems D-33
Residential Fuel-Fired, Multifunction Heat Pump D-35

Rensselaer Polytechnic Institute - CASE
Energy-Efficient Façades for Green Buildings D-27

Rocky Research
Ammonia Absorption Technologies for HVAC Systems D-23

Sandia National Laboratories
Air Bearing Heat Exchanger D-21

SMMA - The Motor & Motion Association
Improving Electric Motor Efficiency D-31

Whirlpool Corporation
Advanced Sequential Dual Evaporator Cycle for Refrigerators D-20

Emerging LED Devices Technologies

Applied Materials, Inc.
Epitaxy Tools for Manufacturing Light-Emitting Diode Devices D-42

Ecer Technologies, LLC
LECD Technology for Lighting and Signage D-44

GE Global Research
Affordable, High-Efficiency Solid-State Downlight Luminaires with Novel Cooling D-41

Emerging LED Devices Technologies *(cont'd)*

GE Lighting Solutions, LLC
Advanced Manufacturing Methods for Warm-White LEDs for General Lighting D-40

Light Prescriptions Innovators, LLC
Scaling Up: Kilo-Lumen SSL Exceeding 100 Lumens per Watt D-45

Osram Sylvania Inc.
High Flux Commercial Illumination Solution with Intelligent Controls D-43

Emerging LED Materials Technologies

Cermet Inc.
Phosphor-Free Solid-State Lighting Sources D-65

Fairfield Crystal Technology, LLC
Growth Technique for Large-Diameter AlN Single Crystal D-51

GE Global Research
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Inlustra Technologies, Inc.
High-Efficiency, Non-Polar, GaN-Based LEDs D-55

KLA-Tencor Corporation
Automated Defect Detection, Inspection, Analysis and Yield Management for LED Manufacturing D-48

Lawrence Berkeley National Laboratory
High-Performance Structured OLEDs and LEDs D-57

Lehigh University - Packard Laboratory
Enhancing Quantum Efficiency of InGaN-Based LEDs D-50

Lightscape Materials, Inc.
Nitride- and Oxynitride-Based Phosphors for Solid-State Lighting D-63

Nanosys, Inc.
High-Efficiency, Nanocomposite White Light Phosphors D-53

Philips Lumileds Lighting Company
Low-Cost Illumination-Grade LEDs D-60

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High-Performance Green LEDs D-56

Research Triangle Institute International
Photoluminescent Nanofibers for High-Efficiency Solid-State Lighting Phosphors D-66

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