Lighting Efficiency

Quick Facts

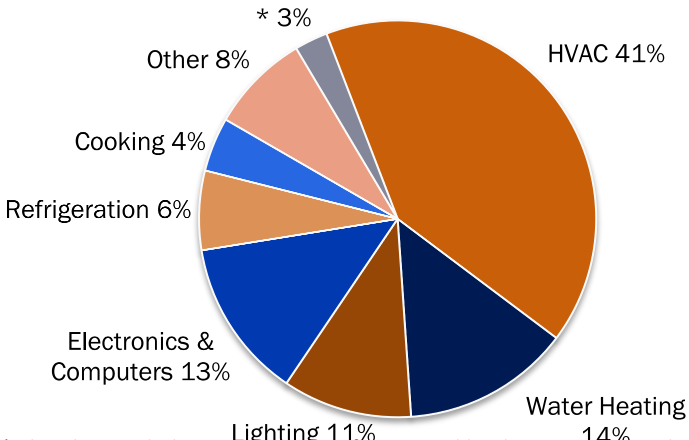
- Lighting accounts for about 11 percent of energy use in residential buildings and 18 percent in commercial buildings.
- Both conserving lighting use and adopting more efficient technologies can yield substantial energy savings. Some of these technologies and practices have no up-front cost at all, and others pay for themselves over time in the form of lower utility bills. In addition to helping reduce energy use, and therefore greenhouse gas emissions, other benefits may include better reading and working conditions and reduced light pollution.
- New lighting technologies are many times more efficient than traditional technologies such as incandescent bulbs, and switching to newer technologies can result in substantial net energy use reduction, and associated reductions in greenhouse gas emissions. A 2008 study for the U.S. Department of Energy (DOE) revealed that using light emitting diodes (LEDs) for niche purposes in which it is currently feasible would save enough electricity to equal the output of 27 coal power plants.

Background

Nearly all of the greenhouse gas (GHG) emissions from the residential and commercial sectors can be attributed to energy use in buildings (see *CLIMATE TECHBOOK: Residential and Commercial Sectors Overview*). Embodied energy – which goes into the materials, transportation, and labor used to construct the building – makes up the next largest portion. Even so, existing technology and practices can be used to make both new and existing buildings significantly more efficient in their energy use, and can even be used in the design of net zero energy buildings—buildings that use design and efficiency measures to reduce energy needs dramatically and rely on renewable energy sources to meet remaining demand. The Energy Independence and Security Act of 2007 (EISA 2007) calls for all new commercial buildings to be net zero energy by 2030.[1] An integrated approach provides the best opportunity to achieve significant GHG reductions because no single building component can do so by itself and different components often interact with one another to influence overall energy consumption (see *CLIMATE TECHBOOK: Buildings Overview*). However, certain key building elements can play a significant role in determining a building's energy use and associated GHG emissions.

Lighting accounts for about 11 percent of energy use in residential buildings and 18 percent in commercial buildings, which means it uses the second largest amount of energy in buildings after heating, ventilation, and air conditioning (HVAC) systems (see Figure 1).[2]

Figure 1: Residential Buildings Total Energy End-Use (2008)



* This chart includes an adjustment factor used by the EIA to reconcile two datasets.

Source: U.S. Department of Energy, *2010 Buildings Energy Data Book*, Section 2.1.5, 2010. http://buildingsdatabook.eren.doe.gov

Adjustments to lighting systems can be straightforward and achieve substantial cost savings. Consequently, addressing lighting can be a simple way to reduce a building's energy use, and related GHGs, in a cost-effective manner. Reducing energy use from artificial lighting can be achieved in two ways:

- **Conservation**
  Conservation efforts minimize the amount of time that lights are in use and can include behavioral change, building design, and automation, such as timers and sensors.

- **Efficiency**
  Efficiency improvements reduce the amount of energy used to light a given space, generally using a more efficient lighting technology.

Description

This section briefly describes some of the most common ways to reduce the amount of energy consumed by lighting systems. The following options illustrate a range of conservation options—from small adjustments in daily habits to larger building design elements—that can reduce the use of artificial lighting:

- **Behavioral Change**

  Turning off lights when they are not being used reduces energy use, GHG emissions from electricity, and utility bills. This practice may include turning off lights in unoccupied rooms or where there is adequate natural light. Adjusting artificial light output can also provide energy savings; for example, using task lighting (e.g., a desk lamp) rather than room lighting can reduce the number of fixtures in use, and dimmers allow lights to be used at maximum capacity when necessary and at low capacity when less light is needed, such as for safety lighting, mood lighting, or when some daylight is available.[3]

- **Technologies that reduce lighting use**
  Timers and sensors can reduce light usage to the necessary level; these options use technology to mimic the behavior described above. Sensors come in a variety of models that serve different purposes, and certain types of sensors and light fixtures are more appropriate together than others. For example, lamps that take a long time to start are not suitable for sensors that turn off and on frequently.
  - *Occupancy sensors* help ensure that lights are only on when they are being actively used. Infrared sensors can detect heat and motion, and ultrasonic sensors can detect sound. Both must be installed correctly to ensure that they are sensitive to human activity rather than other activity in the vicinity (such as ambient noise). Some estimates suggest that occupancy sensors can reduce energy use by 45 percent, while other estimates are as high as 90 percent.[4,5]
  - *Photosensors* use ambient light to determine the level of light output for a fixture. For example, photosensors might be used to turn outdoor lights off during daylight hours.
- **Improving building design to maximize natural light**

  Building designs that incorporate a substantial amount of natural light also reduce the need for artificial lighting; in these cases, artificial light may become a supplement for use during the night or when otherwise needed. Architects and land planners can play a role by designing buildings to include skylights or windows and orienting these toward the south or west. Designers and building occupants can choose light paint colors that maximize reflectance, and they can orient furniture to take advantage of available light.

  When addressing GHG emissions through building design, it is important to take a holistic approach that considers not just how design affects natural light, but also the heating and cooling requirements for the building. Increasing the amount of sunlight a building receives may also lead to high levels of heat intake, which can have important implications for the building's HVAC system. For example, large windows that reduce artificial lighting might also result in heat gain that requires more air conditioning in warm climates, or the same heat gain in a colder climate might reduce the need for additional heating.[6] In some cases, special coatings on windows can help maximize or minimize solar heat gain, depending on the desired effect (see *CLIMATE TECHBOOK: Building Envelope*). Coordinating window selection, building design, and lighting effectively can result in maximum solar light intake with the desired level of heat intake.

When artificial lighting is necessary, choosing efficient technologies can effectively reduce electricity use and related GHG emissions. In choosing among the available technologies, it is important to consider several factors, including the quality of lighting needed, the frequency of use, and the environment in which the light is being used (e.g., indoor or outdoor). The following types of lighting and fixtures are most common in buildings:

- **Incandescent bulbs**

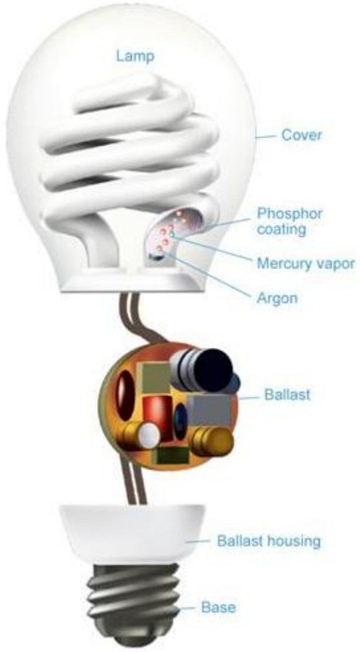
  These bulbs emit light when an electrical current causes a tungsten filament to glow; however, 90 percent of the energy used for the bulb is emitted as heat rather than light, making these bulbs the least efficient for most household purposes when evaluating them on a lumen (amount of light emitted) output to energy input basis. Halogen bulbs are a type of incandescent that are slightly more efficient than standard incandescent but less efficient than most other alternatives.

- **Compact fluorescent lamps (CFLs) and fluorescent tubes**

  These emit light when an electric current causes an internal gas-filled chamber to fill with ultraviolet (UV) light, which is then emitted as visible light through a special kind of coating on the tube.[7] All fluorescent bulbs require a ballast, a component that regulates the current going through the lamp. Ballasts can be integrated into the bulb, as is the case for most CFLs (allowing them to be used interchangeably with most incandescent bulbs) or non-integrated, which require the ballast to be part of the fixture, as is the case for many fluorescent tubes used in schools and offices. Ballasts come in two varieties: magnetic (which are older and less efficient) and electronic (which are newer and much more efficient). Efficiency upgrades for fluorescent tube lights require consideration of the ballasts because they contribute significantly to the overall energy draw of the fixture.

  Both CFLs and fluorescent tubes come in a variety of shapes, sizes, and efficiencies (see Figure 2 for a diagram of a typical CFL bulb).[8] They generally use 75 percent less energy than incandescent light bulbs.[9] A CFL produces between 50-70 lumens per watt, compared to the 10-19 lumens per watt for an incandescent bulb.[10] They are also long-lasting products, with a lifetime of 10,000 hours for CFLs and a lifetime of 7,000-24,000 hours for tubes.[11] Incandescent bulbs, by comparison, have a lifetime of 750-2500 hours.[12]

Figure 2: Diagram of a Compact Fluorescent Bulb



Source*:* U.S. EPA/ DOE Energy Star Program. "Learn About Compact Fluorescent Light Bulbs" http://www.energystar.gov/index.cfm?c=cfls.pr_cfls_about

- **High-intensity discharge (HID) lamps**

  HID lamps come in several varieties with widespread applications. They emit light when a current—also regulated through a ballast—is passed between two electrodes on either end of a gas-filled tube. Mercury, sodium, or metal halide gas can be used, each with different color outputs, lifetimes, and applications. These types of lights are not appropriate for all types of areas and use; for instance, HID lamps have a long start-up period—up to ten minutes—and are best used in areas where lighting must be sustained for several hours (e.g., on sports fields or for street lights). In general, HID bulbs are 75-90 percent more efficient than incandescent bulbs and have a long lifetime, with metal halide and high-pressure sodium bulbs being far more efficient than mercury vapor bulbs.[13]

- **Low-pressure sodium**

  Though these types of lamps are among the most efficient available for outdoor use, they are only useful for certain applications because of their long start-up time, cool-down time, and poor color rendition.[14] Low-pressure sodium lamps are typically used for street or highway lighting, parking garages, or other security lighting. Because of their niche application, they are not typically considered as a substitute for other types of less efficient bulbs.[15] See Table 1 for a comparison of HID and low-pressure sodium lighting.

Table 1: Characteristics of High-Intensity Discharge and Low-Pressure Sodium Lighting Types

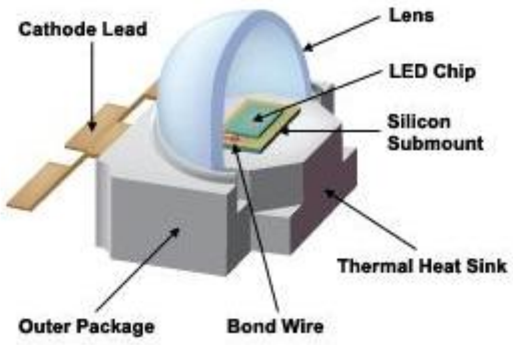
	Efficacy (lumens/watt)	Lifetime (hours)	Indoors/Outdoors
Mercury vapor (HID)	25-60	16,000-24,000	Outdoors
Metal halide (HID)	70-115	5,000-20,000	Indoors/Outdoors
High-pressure sodium (HID)	50-140	16,000-24,000	Outdoors
Low-Pressure sodium	60-150	12,000-18,000	Outdoors

Source: U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy "High-Intensity Discharge Lighting." http://www.energysavers.gov/your_home/lighting_daylighting/index.cfm/mytopic=12080; "Low-Pressure Sodium Lighting." http://www.eere.energy.gov/basics/buildings/low_pressure_sodium.html

- Light Emitting Diode (LED)

In light-emitting diodes, electrons and electron holes (atoms that lack an electron) combine, releasing energy in the form of light. This technology has been around for several decades, but many applications of LEDs for lighting have only recently become available commercially as improved color renditions have been developed and costs reduced. LED fixtures use 75-80 percent less electricity than incandescent bulbs, and can have a lifespan 25 times longer than incandescent light bulbs.[16] LEDs produce in the range of 27-150 lumens per watt, depending on the type of LED.[10] LEDs have small, very bright bulbs and because of their size, LED fixtures are often found in specialty applications such as decorative lamps as well as functional lamps in difficult-to-reach areas, such as for strip lighting, outside lighting, display lighting, stairway lighting, etc. (see the DOE website for more information about current LED applications). LEDs are more durable than most other lighting alternatives and are more controllable because the light can be focused in a particular direction and the LED can be dimmed.[17] Figure 3 shows the components of a typical LED.

Figure 3: Diagram of a Light Emitting Diode



Source: U.S. EPA/ DOE Energy Star Program. "Learn About LEDs" http://www.energystar.gov/index.cfm?c=lighting.pr_what_are#

The development of LEDs has generated a new field of lighting technology: solid-state lighting. Through the use of LEDs and similar products, researchers are developing an array of lighting options that use solid objects—rather than energy passed through a vacuum or gas—to produce light. The continued development of solid-state lighting will enable an even more widespread, general-use application for these types of products. At the moment, no other lighting technology offers the same level of potential to reduce energy use in the future.[18] The DOE estimates that energy savings in 2030 from solid-state lighting could reach 190 terawatt-hours, the annual electrical output of 24 large power plants (1,000MW). This would result in a 31.4 million metric ton reduction of carbon and $15 billion in energy savings in 2030 alone.[19]

- **Hybrid Solar Lighting**

  In this emerging technology, a roof-mounted solar collector sends the visible portion of solar energy into light-conducting optical cables, where it is piped to interior building spaces. Controllers monitor the availability of solar light and supplement it as necessary with fluorescent lights to provide the desired illumination levels at each location. Early experiments show that hybrid lighting is a viable option for lighting on the top two floors of most commercial buildings.[20]

  This technology has other promising benefits as well. The solar collector on the rooftop can separate visible light from infrared radiation; the visible light can then be used for lighting, and the infrared radiation can be used for other purposes, such as to produce electricity, for hot water heating, or for a space heating unit. Because the energy is split, less heat energy is wasted in lighting—it is instead used for other energy-consuming items within the building.

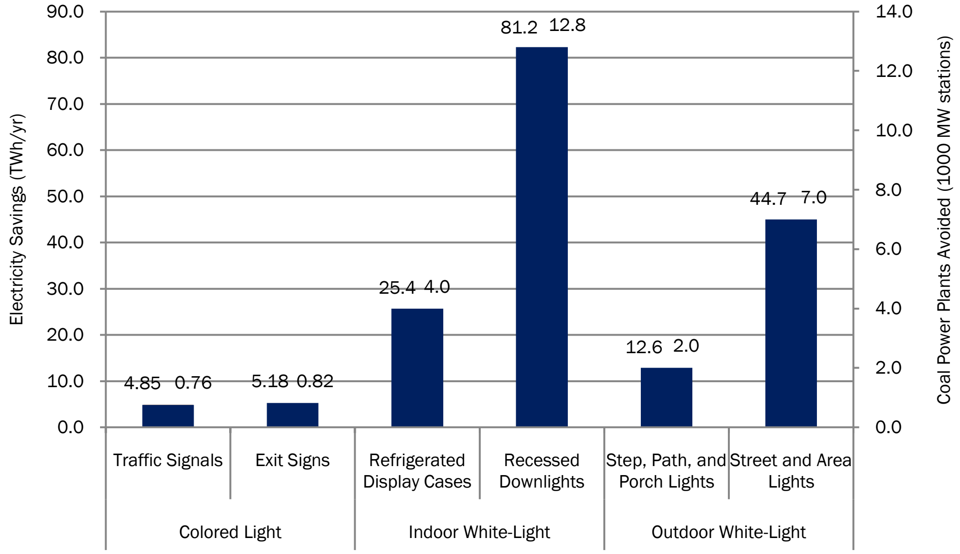
  While hybrid solar lighting systems have been developed and demonstrated in various facilities, they are currently not cost-competitive with most other lighting options. Research is underway with the goal of achieving commercial viability.

Environmental Benefit / Emission Reduction Potential

Through conservation and efficiency measures, GHG emissions associated with lighting can be reduced significantly. At the level of individual households and businesses, conservation and efficiency measures can provide lower utility bills, but widespread adoption at the societal level can result in broader GHG emission reductions and environmental benefits from the reduced demand for electricity. A range of options exists to address lighting efficiency, and using less artificial light altogether or using more efficient technologies can realize substantial environmental benefits. CFLs use 75 percent less energy and LEDs use 75 to 80 percent less energy than incandescent light bulbs; substituting these products for traditional lighting technologies, for example, can reduce net energy use.[9,16]

Widespread application of efficient lighting technologies will be essential for GHG emission reductions. A 2008 study for the U.S. DOE revealed that replacing LEDs for niche purposes in which LEDs are currently feasible would save enough electricity to equal the output of 27 coal power plants (see Figure 4). Though this represents only one percent of total energy consumption for lighting according to the most recent DOE estimates, savings from LED technology will increase as it is implemented on a more widespread basis.[21] McKinsey & Co's *Pathways to a Lower-Carbon Economy*, for example, projects significant energy savings from switching from incandescent and CFL bulbs to LED technology by 2030;[22] this would not only provide GHG emission reductions from lower energy consumption, but it is also cost-effective over the lifetime of the bulbs.

Figure 4: Electricity Saved and Potential Savings of Selected Niche Applications



Source: U.S. Department of Energy (DOE). Energy Savings Estimates of Light Emitting Diodes in Niche Lighting Applications, Figure ES.1, 2008.
http://www.management.energy.gov/documents/Energy_Savings_Light_Emitting_Diodes_Niche_Lighting_Apps.pdf

Greater GHG emission reductions can be achieved through integrated approaches that consider the entire building as a whole. Improving lighting may increase ambient heat (as in solar heat gain from daylighting) or decrease heat (such as reduced heat loss from inefficient bulbs), and depending on the region, season, and building design, this may relieve pressures on HVAC systems as well.

In addition to the climate benefits of efficiency and conservation in lighting, other benefits may include better reading and working conditions, reduced light pollution, and lower utility bills.

Cost

Some conservation efforts to reduce GHG emissions associated with energy use for lighting, such as turning off lights that are not in use, have no cost at all and provide immediate savings from lower utility bills. Newer technologies are more expensive up-front than incandescent light bulbs, but make up for the extra cost in savings within a months, depending on lighting use. For new buildings, incorporating design features that maximize natural light can also be an important, cost-effective element of constructing a net zero energy building.

Other conservation and efficiency measures require an upfront cost that is later recouped through lower utility bills, including:

- **Installing timers and sensors**

  The upfront price of timers and sensors varies depending on the type and scale of installation,[23] and overall savings depend on the net reduction in electricity consumption that results from the use of these technologies. Installation can result in net savings through lower utility bills.

- **Replacing incandescent bulbs with CFLs**

  CFLs are more expensive than incandescent bulbs, but they provide cost savings over the lifetime of the bulb through lower electricity bills. An ENERGY STAR® CFL, for example, saves about $40 over the lifetime of the bulb compared to an incandescent light, and the payback time can be just months, depending on light bulb use.[24,25]

- **Replacing incandescent or CFL bulbs with LED bulbs**

  LEDs range from $25 to $60 for small bulbs,[26] but their efficiency and lifetime provide longer term savings. LEDs are currently available for certain types of lighting, such as residential downlights, portable desk lights, and outdoor area lighting.[27] Compared to incandescent bulbs, payback periods for LEDs can range from 1.7-3.4 years, depending on the lighting use. Payback periods for LEDs compared to CFLs can range from 4.5-12.9 years.[28]

As new and emerging technologies, such as hybrid solar lighting, become commercially available, consumers will have more options for lighting indoor and outdoor spaces using less energy, resulting in lower GHG emissions. As these technologies improve and become more widely adopted, their costs are expected to decline.

Current Status

Behavioral changes to conserve energy from lighting are among the most important options for achieving emission reductions from lighting, and many of these opportunities can be realized without adopting new technology at all (for example, by turning off the lights when they are not in use). When artificial lighting is necessary, many efficient lighting products are currently available. Replacing incandescent bulbs with CFLs, for example, is both accessible and affordable. McKinsey & Company's *Pathways to a Low Carbon Economy* also projects significant savings over the lifetime of the bulb by switching from outdated florescent tube bulbs to more efficient models.[22]

In addition to those technologies that are now widely available, a variety of new and emerging highly efficient lighting systems are currently under development to improve the technology and reduce production costs. Some technologies that are promising but not yet commercially viable, include:

- **Hybrid Solar Lighting (HSL)**

  The technology has existed for decades, but cost considerations have thus far made widespread implementation infeasible. Currently, at least 25 facilities in the United States have installed HSL systems. Researchers are still trying to develop lower-cost systems that are marketable on a wider basis. Most research has been undertaken at the Oak Ridge National Laboratories in conjunction with DOE.[29]

- **Light Emitting Diodes (LEDs)/Solid-state Lighting.**

  DOE has developed a multi-year strategy to advance the research, development, and deployment of solid-state lighting technology for applications beyond the current niche opportunities for LEDs. DOE's program includes public- and a private-sector participants, and focus areas include basic and applied research, product development, manufacturing and commercial support, and standards development.[30]

Obstacles to Further Development or Deployment

The obstacles to increasing conservation and improving efficiency for lighting are similar to those faced by buildings broadly. These barriers include upfront cost concerns, market barriers, public policy and planning barriers, and customer barriers, such as behavioral change. Up-front costs pose a particularly notable barrier: while efficient lighting technologies and practices can pay for themselves over time, some of them – particularly cutting edge technologies – have significant up-front costs that consumers, businesses, or municipalities may be unable or unwilling to pay. Payback periods also vary in length, and building occupants may be reluctant to install efficient lighting technologies if they will be vacating the building before they can reap the full benefits of these technologies (while new occupants would realize benefits immediately).

Certain lighting technologies face unique challenges, including the following:

- **Sensors/Lighting Control**
  - Sensors are not always able to detect and match the needs of the occupant. This is because sensors react to different wavelengths, such as visible light, ultraviolent radiation, and infrared radiation, and because they are often located far from the area of occupancy. For example, photosensors are often located on the ceiling and cannot necessarily gauge lighting needs closer to the ground.[31]
  - Motion and occupancy sensors are not widely utilized because of logistical difficulties and consumer preference. Implementation in existing structures can be problematic because of the need for new fixtures, other wiring problems, and initial costs. Occupants may also object to automatic switch-off technology if it is poorly installed and is prone to premature switching; this can be remedied by more careful installation.[32]

- **Compact Fluorescent Lamps**
  - Skepticism about the quality of CFL bulbs has deterred many consumers. Consumers may install the common spiral or A-shape CFL in an enclosed, recessed fixture without recognizing that only certain CFLs were built with reflectors to withstand the resultant heat, leading to shorter CFL lifespan.[33,34] Moreover, manufacturers have been able to address other

technical problems with early CFL models, including the start-up time, buzzing sounds, and less-appealing color temperature (a measurement that refers to the hue of light). Newer models can start in less than a second, are nearly noiseless, and are available in a variety of color temperatures.

- Concerns about mercury may be a deterrent to some consumers. CFLs contain a very small amount of mercury in each bulb—less than 1/100 of the amount in an older thermometer.[35] However, as incandescent light bulbs require more energy and because mercury is emitted in the coal-burning process, the use of incandescent bulbs powered by coal-fired electricity generation results in mercury emissions that far exceed those of a CFL, particularly if the CFL is recycled.[36,37]

Policy Options to Help Promote Lighting Efficiency

Because lighting efficiency can be improved through many different technologies, a broad set of policies is needed to spur the development of new, highly-efficient technologies as well as to promote the adoption of existing efficient ones. Lighting standards are an important policy for driving innovation in lighting efficiency. The Energy Independence and Security Act (EISA) of 2007, for instance, contains mandates for energy efficiency standards for incandescent bulbs; these standards phase out light bulbs that do not meet a certain efficiency standard. Lighting manufacturers have since created more efficient versions of the incandescent bulb, recognizing their popularity and the policy-driven need for efficiency. While these more efficient incandescent bulbs have not approached the level of efficiency that is possible with CFLs, the phase-out of inefficient bulbs from these federal standards and the subsequent development of more efficient technology has illustrated the role federal standards can play in driving innovation.

Other policies can facilitate the adoption of efficient existing lighting technology. Loan programs and tax credits are two examples of policies that can enable people to opt for more efficient lighting as opposed to less efficient lighting options with a lower up-front cost.

Broader building policies can also inspire building owners, managers, and occupants to examine lighting systems and practices in order to reduce both costs and GHG emissions. Such policies include updated building codes, financial incentives, information and education campaigns, lead-by-example initiatives, and research and development assistance. (For more information about each of these options, see *CLIMATE TECHBOOK: Buildings Overview*.)

Related Business Environmental Leadership Council (BELC) Company Activities

ABB
Baxter
Exelon
GE
PG&E
United Technologies Corporation
Weyerhaeuser

Whirlpool Corporation

Related Pew Center Resources

CLIMATE TECHBOOK: Buildings Overview, 2009

CLIMATE TECHBOOK: Residential and Commercial Sectors Overview, 2009

MAP: *Commercial Building Energy Codes*

MAP: *Green Building Standards for State Buildings*

MAP: *Residential Building Energy Codes*

Pew Center on Global Climate Change's Corporate Efficiency Project

Further Reading / Additional Resources

DOE, Office of Energy Efficiency and Renewable Energy

- *20010 Buildings Energy Data Book*, 2010
- Energy Savers

Environmental Defense Fund, *Make the Switch: How to Pick a Better Bulb*

U.S. Environmental Protection Agency (EPA) and U.S. Department of Energy (DOE), ENERGY STAR®

National Institute of Building Sciences' Whole Building Design Guide

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[1] One Hundred Tenth Congress of U.S. Energy Independence and Security Act of 2007. Sec, 422. 2007

[2] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. Buildings Energy Data Book. 2010

[3] Fluorescent bulbs, which use devices called "ballasts" to regulate current through the bulb, require special ballasts that can work with dimmers.

[4] A Consumer's Guide to Energy Efficiency and Renewable Energy. U.S. Department of Energy. Toolbase Services. Tech Set 4: Energy-Efficient Lighting.

[5] California Department of General Services: Green California. Building Maintenance—Lighting and Occupancy Sensors.

[6] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. Energy Performance Ratings for Windows, Doors, and Skylights.

[7] The phosphor coating on fluorescent bulbs gives them their distinctive white color.

[8] For more information, please refer to the U.S. Department of Energy (DOE) Energy Savers and U.S Environmental Protection Agency (EPA) and DOE EnergySTAR® programs.

[9] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. New Light Bulbs: What's the Difference?

[10] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. Types of Lighting.

[11] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. Fluorescent Lighting.

[12] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. Incandescent Lighting.

[13] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. High-Intensity Discharge Lighting. The Energy Policy Act of 2005 outlawed mercury vapor; these lights are being phased out.

[14] Color rendition is a measure of the quality of color light indicating how colors will appear under different light sources, devised by the International Commission on Illumination (CIE). General Electric. GE Lighting.

[15] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. Low-Pressure Sodium Lighting.

[16] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. Lighting Choices to Save You Money.

[17] Toolbase Services. LED Lighting.

[18] U.S. Department of Energy. Office of Energy Efficiency and Renewable Energy. Solid-State Lighting.

[19] U.S. Department of Energy. Office of Energy Efficiency and Renewable Energy. Solid-State Lighting Portfolio.

[20] U.S. Department of Energy, Office of Renewable Energy and Energy Efficiency. Hybrid Solar Lighting Illuminates Energy Savings for Government Facilities. 2007

[21] Navigant Consulting, Inc. *Energy Savings Estimates of Light Emitting Diodes in Niche Lighting Applications*. Prepared for the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy. 2008.

[22] McKinsey & Co. 2009. *Pathways to a Low-Carbon Economy: Version 2 of the Global Greenhouse Gas Abatement Curve*.

[23] Lighting Controls. Toolbase.org.

[24] EPA and DOE. ENERGY STAR®: Compact Fluorescent Light Bulbs.

[25] The payback period is the amount of time it takes for the cost savings of the more energy efficient bulb to equal the difference in initial bulb costs. To calculate the cost of switching to CFL bulbs based on the current average price of electricity, please visit the EPA's CFL Calculator.

[26] Toolbase Services. LED Lighting.

[27] Recessed downlights are the most commonly installed type of lighting fixture in residential new construction. Please see the DOE's Solid-State Lighting webpage for more information about specific applications.

[28] Cleantech Approach. When Considering an LED retrofit or incentive policy, do your research.

[29] Maxey, Curt. Hybrid Solar Lighting. June 2008.

[30] Navigant Consulting, Inc. *Energy Savings Potential of Solid-State Lighting in General Illumination Applications 2010 to 2030*. 2010.

[31] Lighting Research Center at the Rensselaer Polytechnic Institute. Recommended Solutions—Photosensor Dimming: Barriers.

[32] Lighting Research Center at the Rensselaer Polytechnic Institute. Recommended Solutions—Automatic Shut-off Controls: Barriers.

[33] U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy. Compact Fluorescent Lighting.

[34] GE Lighting. Compact Fluorescent Light Bulbs (CFL) FAQs.

[35] The EPA also has detailed instructions for safely discarding broken bulbs.

[36] U.S. Department of Energy, Energy Star. Frequently Asked Questions: Information on Compact Fluorescent Light Bulbs (CFLs) and Mercury. November 2010.

[37] Many convenient collection sites are available across the country—see the EPA's Lamp/Bulb recycling site for more information.