Technology Focus
A New Technology Demonstration Publication
DOE/EE-0315

Federal Energy Management Program

Leading by example, saving energy and taxpayer dollars in federal facilities

Hybrid Solar Lighting Illuminates Energy Savings for Government Facilities

New technology provides high-quality lighting for facilities and reduces waste heat to lower energy loads

Fig. 1. Tracking solar collector

Hybrid Solar Lighting — Benefits

- Improved lighting quality
- Reduced energy usage
- Reduced building cooling load
- Reduced CO_2 emissions
- Non-energy benefits to building owner/ manager such as improved employee productivity and wellness and increased sales

Overview

Artificial lighting accounts for the largest component of electricity use in commercial U.S. buildings. Hybrid solar lighting provides an exciting new means of reducing energy consumption while also delivering significant benefits associated with natural lighting in commercial buildings. Hybrid solar lighting contributes to meeting the requirements set by the Energy Policy Act of 2005 for renewable energy consumption by the federal government to be not less than 3% in FY 2007–2009, 5% in FY 2010–2012, and 7.5% in 2013 and thereafter.

The hybrid lighting technology was originally developed for fluorescent lighting applications but recently has been enhanced to work with incandescent accent-lighting sources, such as the parabolic aluminized reflector (PAR) lamps commonly used in retail spaces. Commercial building owners—specifically retailers—use the low-efficiency PAR lamps because of their desirable optical properties and positive impact on sales. Yet the use of this inefficient lighting results in some retailers' spending 55–70% of their energy budgets on lighting and lighting-related energy costs.

Hybrid lighting has the potential to significantly reduce energy consumption while also maintaining or exceeding lighting quality requirements. Implementation of the hybrid solar lighting technology across the United States would represent significant energy savings to the country and would provide building managers with a near-term, energy-efficient, higher quality, economically viable alternative to incandescent lamps.

Artificial lighting accounts for almost a quarter of the energy consumed in commercial buildings and 10–20% of energy consumed by industry. Solar lighting can significantly reduce artificial lighting requirements and energy costs in many commercial and industrial buildings and in institutional facilities such as schools, libraries, and hospitals.

Future R&D is aimed at enhancing the performance and reliability of the technology as well as extending the application of the system to work with newly emerging solid-state lighting sources. The hybrid solar lighting technology delivers the benefits of natural lighting with the advantages of an electric lighting system—flexibility, convenience, reliability, and control—and overcomes the constraints that marginalized the use of daylighting in the 20th century.

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Internet: www.eere.energy.gov/femp/

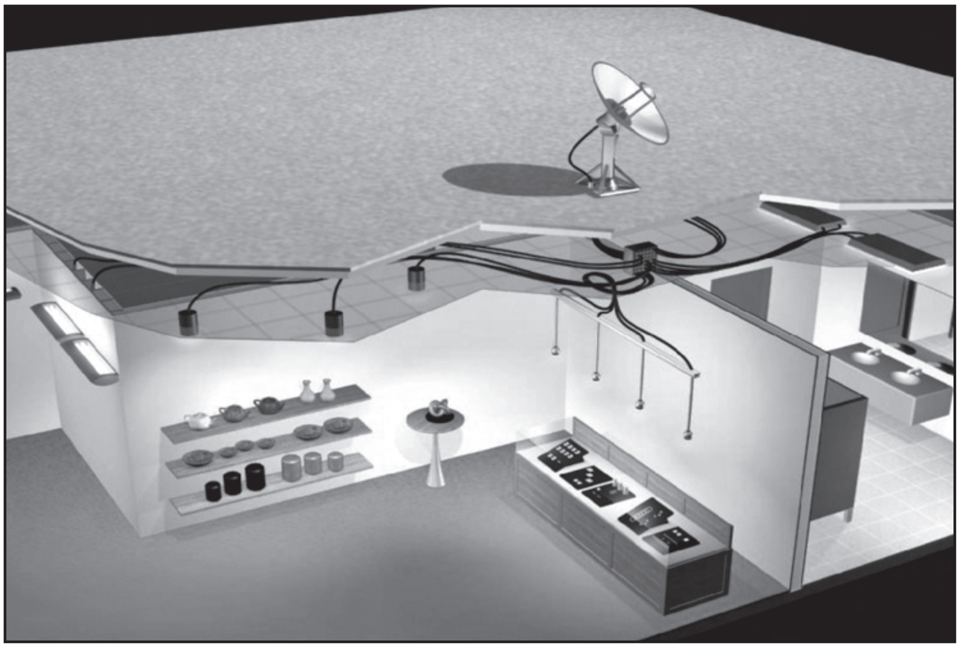

Fig. 2. Conceptual illustration of a hybrid solar lighting system.

Principles of Operation

The hybrid solar lighting system uses a roof-mounted solar collector (Fig. 1) to concentrate visible sunlight into a bundle of plastic optical fibers. The optical fibers penetrate the roof and distribute the sunlight to multiple "hybrid" luminaires within the building (Fig. 2). The hybrid luminaires blend the natural light with artificial light (of variable intensity) to maintain a constant level of room lighting. One collector powers about eight fluorescent hybrid light fixtures, which can illuminate about 1000 square feet.

When sunlight is plentiful, the fiber optics in the luminaires provides all or most of the light needed in an area. During times of little or no sunlight, a sensor controls the intensity of the artificial lamps to maintain a desired illumination level. Unlike conventional electric lamps, the natural light produces little to no waste heat, having an efficacy of 200 lumens/Watt (l/W), and is cool to the touch. This is because the system's solar collector removes the infrared (IR) light from the sunlight—the part of the spectrum that generates much of the heat in conventional bulbs. Because the optical fibers lose light as their length increases, it makes sense right now to use hybrid solar lighting in top-story or single-story spaces. The current optimal optical fiber length is 50 feet or less.

The hybrid solar lighting technology can separate and use different portions of sunlight for various applications. Thus, visible light can be used directly for lighting applications while IR light can be used to produce electricity or generate heat for hot water or space heating. The optimal use of these wavelengths is the focus of continued studies and development efforts.

ORNL Studies

Although clean and abundant, solar energy is diffuse and must be captured, concentrated, stored, and/or converted to be used in the highest-value energy form. Under DOE's Office of Energy Efficiency and Renewable Energy, Solar Technologies Program, Oak Ridge National Laboratory (ORNL) has demonstrated the technical feasibility of an entirely new, highly energy-efficient way of lighting and heating buildings using the power of concentrated sunlight. ORNL is currently developing techniques for transporting the sun's energy [visible light and radiant ultraviolet (UV) and IR energy] into buildings for use not only for interior lighting (as shown in Fig. 2), but for novel hybrid applications such as solar hot water heating and space heating. ORNL is also conducting materials and engineering R&D to improve the performance of the tracking mechanisms and fiber optic materials used in these systems.

The goal for future hybrid solar lighting systems is that they be:

- Multifunctional—compatible with various electric lamps, light fixtures, hot water heaters, photovoltaics, etc., and usable for various applications
- Reconfigurable—easily modified as space needs change
- Seamlessly integrated—connected to standard power sources to ensure that disruptions in service do not occur on cloudy days or at night
- Architecturally compatible—designed to eliminate architectural design hassles and maintenance problems limiting the use of solar power
- Affordable

The new hybrid solar lighting strategy is the logical pathway for achieving these goals because the technology uses small, flexible optical fibers to deliver the sunlight directly to where it is needed. Hybrid solar lighting is applicable to many building types and can be used for a variety of lighting and heating applications. As a result, the potential near-term energy savings of hybrid solar lighting could be significant.

Advantages of Hybrid Solar Lighting

Electric lighting is the greatest consumer of electricity in commercial buildings (Fig. 4), and the generation of this electricity by conventional power plants is the building sector's most significant cause of air pollution. Hybrid lighting can help conserve electricity in proportion to the amount of sunlight available. Hybrid solar lighting technology could benefit federal buildings, particularly in the Sunbelt where cooling is a significant source of energy use.

Full-spectrum solar energy systems provide a new and realistic opportunity for wide-ranging energy, environmental, and economic benefits. Because hybrid solar lighting has no infrared component, it can be considered a high-efficiency light source. Other advantages of hybrid solar lighting are:

- Roof penetrations are small and minimal, reducing the potential for leaks.
- IR and UV energy in sunlight is separated from the visible light, rather than being transmitted into buildings. Heating, ventilation, and air-conditioning (HVAC) loads are thus reduced by 5 to 10%, compared

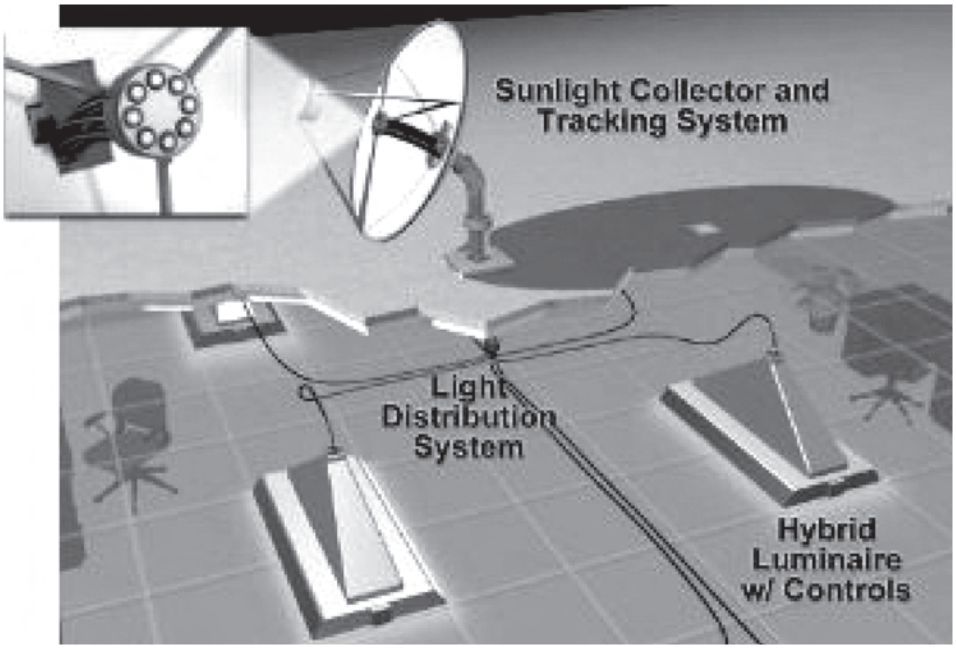

Fig. 3. In a solar lighting and power system, the roof-mounted concentrators collect sunlight and distribute it through the optical fibers (enlargement) to hybrid lighting fixtures in the building's interior.

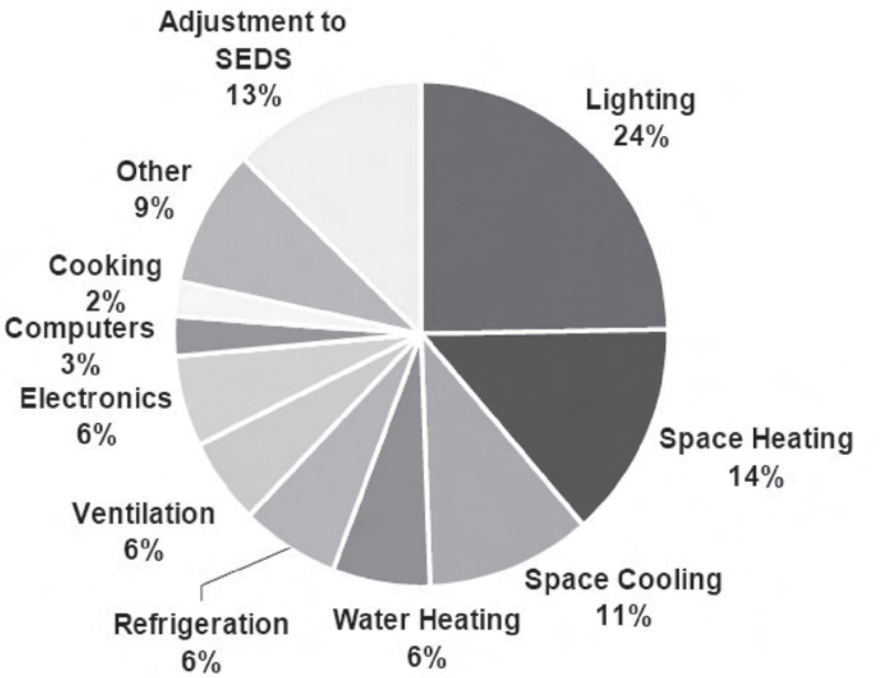

Figure 4. Commercial energy end uses, from the 2005 Buildings Energy Data Book, U.S. Department of Energy (http://buildingsdatabook.eren.doe.gov/?id=view_book&c=1). Lighting consumes almost a quarter of the electricity used in commercial buildings.

to buildings having conventional electric lighting systems.

- Hybrid solar lighting systems are readily adaptable to commercial buildings with multiple floors, relatively low ceiling heights, and interior walls, though currently fiber optic output is optimized on the top two floors. A single system can distribute enough sunlight to co-illuminate several rooms in a typical office building.

- Large portions of valuable plenum space—the area between the roof and drop ceiling—are not needed, so there is little competition with other building services, such as HVAC ducts, sprinkler systems, and electrical conduits.

- Hybrid solar lighting can be used both for direct ambient lighting (as in skylights) and for indirect lighting, task lighting, and accent lighting.

- In retrofit applications, hybrid solar lighting is easily incorporated into existing building designs, and the optical fibers can be rerouted to different locations as lighting needs change. By intentionally misaligning the solar collector from the sun, occupants can even dim or curtail distributed sunlight.

Cost Considerations

The concept of hybrid lighting has existed since the early 1970s, but it has been difficult to make the technology practical. Japanese researchers had earlier developed solar collectors with glass optical fibers — which are more heat-resistant, but also more expensive and harder to work with. The glass-based system costs about $40,000 to illuminate 1000 square feet. Through the use of plastic optical fibers and components, ORNL has been able to cut the system cost significantly, moving closer to a target of $3,000 for a system that illuminates 1000 square feet (see timeline for cost reductions in the following table). When that target price is reached, a building owner in Hawaii could pay for implementing the new technology in just 2–3 years with the savings on electricity bills alone. In other parts of the country, where sunlight is less abundant and utility costs are lower, this payback would obviously take longer.

The payback period for hybrid solar lighting lengthens in proportion to the efficiency of the electric lamps used in combination with distributed sunlight. Because linear fluorescent lamps are very efficient (65-90 lm/W), the models indicate that a hybrid configuration used with such lamps will require more than 10 years to pay for itself in most regions of the country during the early years of commercialization. As prices fall, hybrid solar lighting has the potential to become cost-competitive in most indoor lighting scenarios.

A hybrid configuration is likely to extend the typical life of incandescent and/or halogen lamps. When incandescent lamps are dimmed, filament temperatures decrease. As filament temperatures decrease, life expectancy increases. Although the lamps will last longer, a penalty in efficiency occurs because cooler filaments are generally less efficient at radiating visible light.

In contrast to roof penetrations for skylights, penetrations for hybrid solar lighting are few and small, reducing the potential for leaks.

As R&D improves system performance, increases system lifetime, and reduces system price, and as the secondary benefits of the technology are demonstrated (e.g., improved employee productivity), hybrid solar lighting will move into the larger market of existing buildings that use all fluorescent lighting.

Projected Hybrid Solar Lighting Savings

By the year 2012, hybrid solar lighting should be saving the nation more than 50 million kWh/year while also dramatically improving lighting quality in commercial buildings. Through commercialization efforts with industry partners, more than 5000 hybrid

Timeline for price reductions in hybrid solar lighting

Cost element	2006	2007 (product launch)	2012
System cost	$20,000	$16,000	$3,000
Installation cost	$4,000	$3,000	$1,000

solar lighting systems will be installed by 2012 in regions of the United States where solar availability and electricity rates make this technology cost-effective to consumers. A system tailored to commercial buildings with mixed fluorescent and incandescent lighting (commonly found in retail applications) is likely to be the first application of this technology that will succeed in the marketplace. For this application, a system price of $4000 (installed) has been identified as necessary to produce energy savings of 50 million kWh/year by 2012.

Availability

The components of the hybrid solar lighting system are commercially available. ORNL is partnering with industry suppliers of collectors, fiber optic distribution systems, and luminaries (light fixtures) to transfer the technology and make it cost-effective. ORNL maintains patents on the technology and anticipates that the bundled package will be commercially available in 2007.

Potential Candidates for Hybrid Solar Lighting

The first commercial use for hybrid solar lighting will probably be on the upper two floors of buildings having the following characteristics:

(1) Sunbelt location in areas where daytime electricity prices are highest;

(2) occupied every day, including weekends; and

(3) lighting quality (or color rendering) is important and less-efficient electric lamps are currently used.

Hybrid solar lighting technology could replace less efficient conventional electric lamps.

Type of Lighting	Typical energy efficiency (approx. lm/W)
Incandescent	15
Fluorescent	75
Hybrid Solar	200

Hybrid solar lighting is being targeted first for commercial buildings because in these buildings lighting can account for the largest part of the electricity bill. Residential uses may be farther down the road because the cost advantages there are not as great. However, federal sites would benefit from using hybrid solar lighting technology because decreased use of conventional electric lamps and the air-conditioning loads associated with them would result in energy savings.

Additional benefits would include improved lighting quality and positive environmental impacts from reducing the need to generate electricity. New construction projects create outstanding opportunities for holistic building designs that utilize highly efficient systems that can create satisfying working and living environments with minimized operating costs. Successfully balancing these factors against cost and scheduling issues is the key to creating a well designed and efficiently operating building.

New Developments in Hybrid Solar Lighting Technology

In FY 2005, a fabrication technique was identified for manufacturing an acrylic mirror that meets the tolerances and requirements of a hybrid solar lighting solar collector. A 48-in.-diameter parabolic acrylic mirror is being fabricated by Bennett Mirrors of New Zealand. Early efforts appear promising, with the surface quality of the mirror rivaling that of its glass counterpart. The estimated cost of the new mirror is less than $300 (as compared to $3500 for a glass mirror) and weighs only 9 pounds (as compared to 50 pounds for a glass mirror). Completion of a prototype mirror and manufacture of five mirrors was successful in FY 2006.

The HSL system houses a sun tracking control board that is used to calculate the sun's position based on latitude, longitude and time of day (Fig. 5). The control board uses a microprocessor to compute the astronomical equations, obtained by the U.S. Naval Observatory, which are good to 1/60° for the next 300 years. This precision allows the system to track at 0.1° accuracy. The calculations determine the positions in the Azimuth and Zenith Earth-Based coordinate system using latitude, longitude, and Coordinated Universal Time from a global positioning system receiver. The positions are then converted to units of encoder counts for the two encoders used to detect the location of

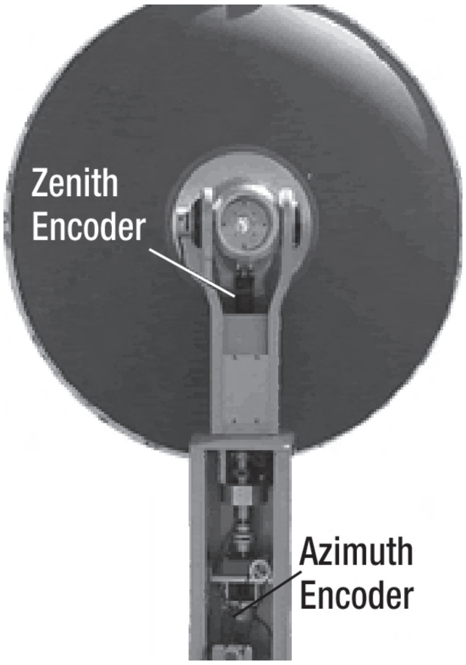

Fig. 5.
Controls enable the solar collector to track the sun to an accuracy of one-tenth degree.

the collector on each axis. The controller compares the actual direction it is pointing to the actual computed position of the sun and then determines if the collector needs to be moved to match its position with that of the sun. The motors then move at a speed proportional to the difference in the actual and computed positions. This process is performed continuously throughout the day in order to track the sun accurately. The control board operates on a 12V or 24V dc supply and uses less than 2 Watts. A photovoltaic solar cell can also be used to power the board.

The development of a redesigned and less expensive tracking mechanism for the solar collector was also begun in FY 2005. Among suggested design modifications from an initial "manufacturability" analysis was the use of a high-precision linear actuator in combination with a gear-train drive to reduce cost while still providing high tracking accuracy. The analysis indicated that the tracker cost could be reduced from $25,000 to less than $4000. In 2007, the tracker cost is projected to be reduced to $5250. Detailed modeling and final drawings have been completed, and fabrication of ten new HLS3000 solar tracking units was completed in FY 2006.

Aging of the polymers used in optical fibers to distribute concentrated sunlight is still a concern, as is the need for more efficient methods of coupling converging sunlight into fiber optic bundles. New luminaires that provide seamless spatial and chromatic uniformity during transitions between natural and electric illuminants must be developed for several lighting applications. Ultimately, the advent of hybrid solar and solid-state lighting systems that use light-emitting diodes (LEDs) capable of chromatically adapting to match the spectrum of sunlight throughout the day is expected. An early prototype hybrid LED/hybrid-solar lighting system is shown in Fig. 6.

Prototypes are already proving that the hybrid solar lighting concept is viable both technically and economically. The latest prototype provides lighting practitioners with unprecedented design flexibility and control over where and how sunlight is used inside buildings.

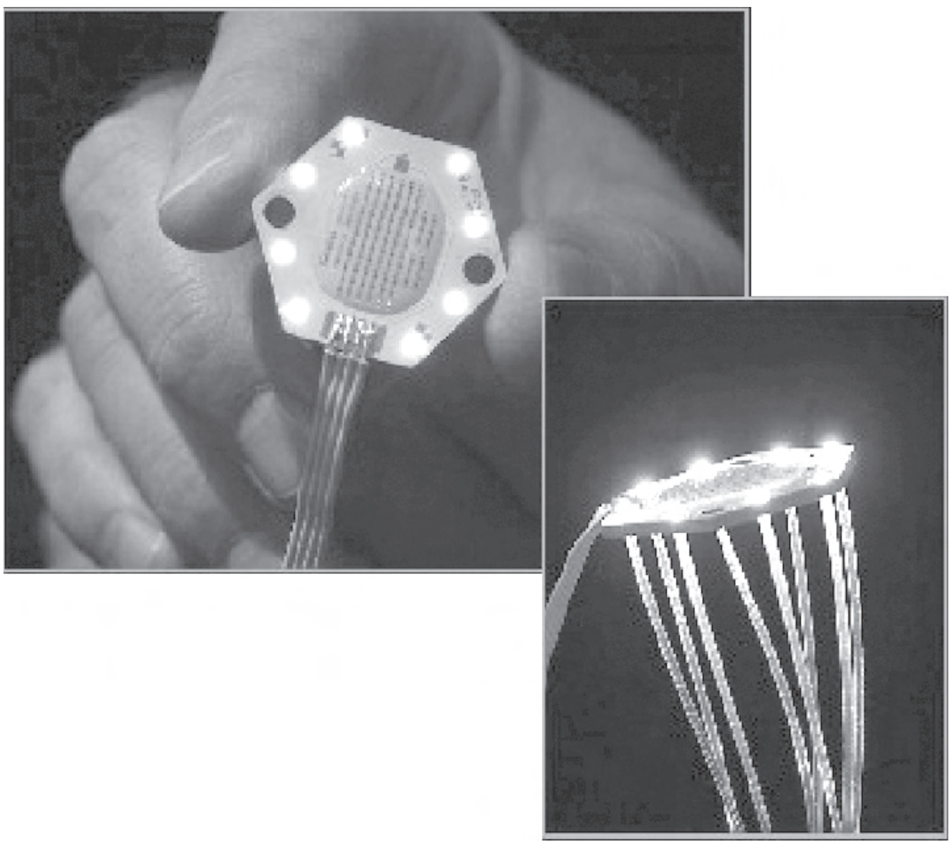

Fig. 6. LEDs now being developed will adapt to the spectrum of sunlight throughout the day.

This prototype uses a bundle of 127 small optical fibers, each of which can distribute 350 lumens to several different hybrid luminaires on a sunny day, making possible numerous daylighting applications. For example, some hybrid luminaires being developed allow hybrid solar lighting to be used with linear and compact florescent lamps and with incandescent/halogen lamps.

Field Trials: The Sunlight Inside Initiative

During a 2006-2007 field trial program at ORNL entitled the "Sunlight Inside Initiative," Sunlight Direct, Inc. (www.sunlight-direct.com), working in collaboration with ORNL, is purchasing and installing hybrid lighting system components for each participating host-site. The component suppliers are ready to mass-produce HSL components for Sunlight Direct. The goals of the field trial project are the following:

1. Demonstrate the technical feasibility and energy-savings potential of hybrid solar lighting in the commercial lighting market

2. Expose emerging hybrid solar lighting technology to users and stakeholders across the country

3. Acquire needed experience and field data on hybrid solar lighting equipment and associated installation, operation, and maintenance issues and requirements

4. Create an initial demand for hybrid solar lighting technology by installing 100 or more units in 2008

5. Provide an initial incentive for original equipment manufacturers of

The Hybrid Lighting Partnership

Industry, Utility, and State Partners	Academic & National Laboratory Partners
• 3M	• Los Alamos National Laboratory
• Advance Transformer Company	• National Renewable Energy Laboratory
• Advanced Lighting Systems, Inc.	• Oak Ridge National Laboratory
• Array Technologies	• Ohio University
• California Energy Commission	• Rensselaer Polytechnic Institute
• Enhancement Electronics, Inc.	• Sandia National Laboratories
• JX Crystals, Inc.	• University of Nevada - Reno
• LSI Industries, Inc.	• University of Wisconsin - Madison
• Protomet	• University of Arizona - Tucson
• ROC Glassworks	
• Science Applications Int'l Corp.	**Partnering Sponsors**
• Sacramento Municipal Utility District	• U.S. DOE (EERE and Fossil Energy)
• Sunlight Direct, Inc.	• California Energy Commission
• The Watt Stopper	• Tennessee Valley Authority
• Tennessee Valley Authority	
• Wal-Mart Stores, Inc.	

hybrid solar lighting to begin investing in automation of component-level manufacturing with the goals of reducing costs and improving market viability.

Sunlight Direct is installing systems at $24,000 per system for ORNL's field trial program, based on individual interest. Built into this cost is a one-year service agreement that covers any maintenance needed on the system. Following the field trial, host sites will be offered an extended service agreement. All installations should be complete by March 2007. ORNL will analyze all data collected from the field trial program and publish the results.

The host sites include the new research facilities on the ORNL campus, the American Museum of Science and Energy (AMSE) in Oak Ridge, the Sacramento Municipal Utility District in Sacramento, California, and a Wal-Mart store in McKinney, Texas. The experience gained from these sites and other field trials will be used to evaluate and improve the technology.

The field trials will establish the hybrid solar lighting technology as a means of saving energy by reducing electrical loads for lighting and by decreasing the amount of heat generated by lighting, thereby decreasing air conditioning costs. This is particularly important in regions where facilities face high peak demand charges on hot summer days. Also, the daylighting character of hybrid solar lighting can greatly improve lighting quality by providing full-spectrum, high-color, low-temperature lighting. Studies have shown that daylighting can increase productivity in both the workplace and the classroom.

Hybrid Lighting Partnership

A broad-based public–private alliance is working to commercialize hybrid solar lighting. The Hybrid Lighting Partnership includes the organizations listed in the following table. The partnership's mission is to develop and deploy hybrid solar lighting worldwide early in the 21st century. By 2020 in the United States, hybrid solar lighting is expected to provide:

- annual energy savings of more than 30 billion KWh (> 0.3 Quads),
- reductions in carbon emissions exceeding 5 megatonnes of carbon per year, and
- total economic benefits exceeding $5 billion.

The partnership will improve quality of life by providing more efficient and affordable solar energy, cleaner air, lower utility bills during peak demand periods, and a healthier, more productive work environment.

Future of Hybrid Solar Lighting

Electricity use for artificial lighting in commercial building space costs building owners nearly $17 billion a year (personal communication, Energy Information Administration). Despite the high energy consumption and cost of electric lighting, natural lighting from conventional options such as skylights and windows illuminates only a tiny fraction of existing commercial buildings. This limited use of natural lighting is a result of the architectural limitations of skylights and windows and the uncontrollable nature of the sunlight itself (i.e., it fluctuates in intensity, and it can be highly directional, producing glare and unwanted heating).

The future is bright for hybrid solar lighting. The nationwide field trial program will provide system performance data and user feedback essential for successful use of this solar energy technology. During the field trial program R&D will continue at ORNL in collaboration with industry and university partners to lower component costs, improve the longevity of optic fibers, and advance system control. New solid-state (LED) hybrid luminaires are also being researched for increased energy efficiency. Exciting new areas of R&D for ORNL and its industry and university partners include utilizing hybrid solar lighting technology for space heating, water heating, and hydrogen production.

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Hybrid Solar Lighting Information and Resources

ORNL Hybrid Solar Lighting R&D Program: www.ornl.gov/solar

Data from the Energy Information Administration: www.eia.doe.gov

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