• INNOVATING SAFETY STANDARDS FOR ENERGY-EFFICIENT LIGHTING
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NEW CHALLENGES

CALL FOR NEW SCIENCE

Progress is an unstoppable, transformative force. New technologies, product advances and globalization are arriving one on top of another at a dizzying pace. Innovation makes us more efficient, more productive and more connected. But there is a cost, and that cost is risk. To help mitigate the emerging risks, UL is developing New Science. Through fundamental discovery, testing methodologies and equipment, procedures, software and standards, UL is creating new and important ways to make the world a safer place.
SUSTAINABLE ENERGY
OVERVIEW

Rising costs, energy efficiency and environmental impact demand innovations in energy generation, distribution, management and usage. Our Sustainable Energy journal covers four subjects that demonstrate important ways UL’s team of dedicated scientists, engineers and researchers are developing New Science to make energy cleaner, more reliable, more efficient and more secure. We are Innovating Safety Standards and using Thermal Modeling to safeguard current and future LED lighting products and to develop more effective tests. We are advancing Grid Interconnection Standards to facilitate the safe and secure expansion of distributed generation technologies. And we are innovating fast-tracked safety requirements to help ensure the safety of Emerging EV Battery applications.

INNOVATING SAFETY STANDARDS FOR ENERGY-EFFICIENT LIGHTING, PG.4
UL is advancing the safety standards for LEDs, developing new requirements that effectively address thermal management to minimize the risks of fire posed by LED products today while anticipating future LED product designs and usage.

PROGRESSING GRID INTERCONNECTION STANDARDS, PG.9
Working closely with regulators, energy utilities and inverter manufacturers, UL is evolving the grid interconnection safety standards to keep pace with new power production applications, new product opportunities and new customers.

MITIGATING EMERGING EV BATTERY RISKS, PG.14
UL is innovating fast-tracked safety requirements for electric vehicle (EV) batteries that will be the basis for a new set of standards. The requirements provide safeguards today and help facilitate new applications of EV batteries.

THERMAL MODELING OF LED LIGHTS, PG.18
Using computational fluid dynamic software to model different product assessment configurations, including the details of an LED, UL is seeking to develop better ways to evaluate LED safety and performance and to update the safety standards.
INNOVATING SAFETY STANDARDS FOR ENERGY-EFFICIENT LIGHTING

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THERMAL MODELING OF LED LIGHTS
WHY INNOVATING SAFETY STANDARDS FOR ENERGY-EFFICIENT LIGHTING MATTERS

The light-emitting diodes (LEDs) market is expanding rapidly, largely due to the energy efficiency and long life span of this technology relative to incandescent lighting. While this expansion is in progress, lighting experts are considering the potential safety risks emerging as the industry moves from glass and brass to semiconductor technology. It is important to innovate safety standards for LEDs to facilitate the growth of this sustainable technology. There is a specific need for safety requirements that not only effectively address thermal management to minimize the risks of fire posed by LED products today, but are also effective for future LED product designs and usage.¹

CONTEXT

According to the U.S. Department of Energy, LED lighting uses 75% less energy, lasts up to 25 times longer than incandescent lighting, and by 2027 will be able to save energy that is equivalent to the annual electrical output of 44 large electric power plants (1,000 megawatts each) in the U.S. alone.² The sustainability benefits and growth of LED lighting have translated to different applications and technological advances to drive performance. As a result, a McKinsey study now projects 840% growth globally for LED lighting, from $10 billion in 2010 to $94 billion in 2020 when LEDs will account for 60% of the total lighting market.³ Additionally, the LED lighting market is expected to grow at a compound annual growth rate (CAGR) of 36% globally between 2012 and 2016.⁴

Lighting products that use LEDs or other solid-state light sources produce heat in a way that is different than that of lighting products that use incandescent or other legacy light sources. Incandescent light sources are known for substantial energy losses, especially due to radiated heat that produces no light. To accommodate this heat, incandescent lamps are made from high-heat-resistant parts such as brass and glass. Over the years, safety design practices were developed to segregate the heat from the other parts of the lighting product. With LED lighting products, the overall energy loss is substantially lower, but high temperatures are generated within small areas of the LED light sources and associated electronics. Thermal management techniques are needed for satisfactory performance of LED light sources, and also to address the risk of fire if heat is not safely conducted away from vulnerable parts and materials. These statistics and technical challenges make a strong case for a need to advance LED safety standards.⁵

WHAT DID UL DO?

UL saw that LED technology was advancing rapidly and published the first general illumination LED Safety Standard, UL 8750, in 2009. The Standard created a platform of safety requirements for LED lighting equipment as well as the entire supply chain of components used in lighting products employing LED technology.⁶
We determined that the most effective and flexible approach would be to develop a “horizontal” standard with requirements relevant to LED technology that could be common to and referenced from the various lighting end-product standards. This approach enables a high degree of consistency in the technical requirements. At the same time, it allows the UL Standards Technical Panel (STP) responsible for the content of each lighting end-product standard to determine what is relevant within the horizontal LED-technology standard for their particular types of lighting products.

Our approach involved an innovative and collaborative process with industry representatives (component through end-product producers), trade associations, government agencies (e.g., EPA, DOE, CEC) and users/specifiers to help ensure that product safety kept pace with the fast-moving advances in the LED lighting industry. UL convened an LED Lighting Summit as a forum for dialogue with nearly 100 lighting professionals and thought leaders, which led to the formation of one of our largest standards panels. Discussion topics included “horizontal” versus other standards structures, emerging products, integrating crossover industry products (e.g., power supplies), safety issues and industry plans for interchangeability, all of which resulted in a commitment to keep current.

Since the Summit, UL has published technical requirements that are routinely updated and has stayed abreast of new developments and their implications. STPs continue to regularly bring together key stakeholders to stay on the cutting edge of safety standards. Due to the rapid development of LED technology, revised and new requirements are frequently discussed, debated and developed. The following represent a sample of critical developments on which UL is focusing.

**LED FIRE BARRIER CONCERNS**

In fixed commercial lighting (such as streetlights and high bay fixtures), lenses serve dual purposes. They are relied on as a part of a fire barrier for the electrical product, and they affect the quality of the light exiting from the luminaire. Traditionally, these lenses are made out of glass or certain types of plastic that satisfy the fire barrier concerns but are not the best solution for light quality. With LED lighting, these are known as secondary lenses because there is already a primary lens over the LED package. We have been working with the industry to find alternate methods for evaluation of fire barrier concerns to achieve the desired safety outcome while offering greater flexibility in choosing polymeric lens materials that are known to maintain and enhance light quality.
COMPONENT INTERCHANGEABILITY

With traditional lighting technologies there is a high degree of interchangeability within the major components of a luminaire. This allows manufacturers to continue to innovate new designs using standard “mix and match” parts with known safety and performance characteristics. Although there are concerted attempts at driving interchangeability, this has not been substantially achieved with LED lighting today. Most parts are custom-made to match other specific or proprietary parts that make up the electrical components of a luminaire. We have been working with the industry to facilitate interchangeability with LED drivers (power supplies). One expert task group within STP 8750 is focused on simplifying LED driver selection during the initial luminaire design process and in cases where an alternate LED driver would be required during the life of the product.

Many of the LED driver parameters are already covered to a degree by current requirements contained in either UL 8750 or other UL standards. However, there were specific areas where requirements needed to be added to UL 8750, related to the expected ambient and driver operating temperatures. In collaboration with STP members, we conducted laboratory temperature tests on LED drivers to validate assumptions. Based on our findings, a set of new and revised safety requirements were developed.

CROSSOVER TECHNOLOGY INTEGRATION

We are innovating the standard to be flexible enough to integrate information technology equipment (ITE)-type power supplies into lighting systems, where appropriate. The global community of ITE power supply manufacturers observed that their products could be easily reengineered to work as LED drivers. To meet this need we compared the ITE and LED driver technologies, considered the similarities and differences in the use and life span of the products and created a comparison document to identify potential safety gaps. Eventually published as Appendix B of UL 8750, this document identifies the additional requirements for ITE power supplies that already meet the requirements in the Standard for Information Technology Equipment (UL 60950-1) to be used in the lighting application. This document has greatly simplified the process for ITE power supply manufacturers to ensure that their products are safe and compliant with the lighting standards.

UL’s efforts to innovate safety requirements and build consensus around them help us keep pace with LED advancements and mitigate the evolving risks.
IMPACT

UL is dedicated to keeping new LED lighting applications “just as safe” as what came before them through our collaborative and integrated approach. The basic safety risks for lighting products using LEDs are comparable to those of lighting products that use other types of light sources — risk of electric shock injury (where hazardous electric current can conduct through a person), fire (where heat can ignite the lighting product or surrounding surfaces) and personal injury. However, there is also a need to minimize hazards specific to LEDs and other solid-state light sources. Our efforts to innovate safety requirements and build consensus around them help us keep pace with LED advancements and mitigate the evolving risks.
INNOVATING SAFETY STANDARDS FOR ENERGY-EFFICIENT LIGHTING

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WHY PROGRESSING GRID INTERCONNECTION STANDARDS MATTERS

One of the most important potential ways to enhance the viability of renewable energy sources and the evolution to smarter, more efficient energy grids is to facilitate the connectivity of distributed generation to the grid system. Distributed generation — or on-site, decentralized energy production that powers localized applications and connects to an electric grid via inverter technology — is already a reality that is continuing to expand because of its numerous benefits. Distributed generation supports more environmentally friendly power sources and promises to help reduce energy costs, add supplemental power sources when and where needed, and empower energy consumers to make more sustainable choices. Progressing utility grid interconnection standards is critical to help ensure that inverters connect on-site generation to grid systems in ways that are safe and secure without risking the stability of the grids. If implemented properly, distributed generation with advanced functionality and communications capability may even increase the reliability and stability of the grid.

CONTEXT

Today, energy-related emissions are responsible for 60% of the world’s total greenhouse gases and 80% of carbon dioxide production.1 According to a 2013 study published by the Lawrence Livermore National Lab, the U.S. currently wastes 61% of its energy and 67% of its generated electricity.2 Given these statistics, it is clear that there is a need to improve the sustainability of energy across generation, transmission, distribution and usage, and that doing so promises environmental, efficiency and economic benefits.

Distributed generation enables businesses and communities to invest more directly in a transition to renewable energy energy. It does so by encouraging diversity in resources and scale, allowing for the installation of capacity based on business or community preference, and offering the potential to defray some of the costs of renewable energy by the sale of excess capacity to energy utilities.3 Distributed generation also reduces the amount of energy lost in transmitting electricity because power is generated near the point of consumption, often in the same building or facility.4
From the perspective of the energy utility industry, distributed generation has sometimes been viewed as a growing and potentially disruptive force that could weaken the traditional, centralized electric utility business model. However, a 2012 ZPryme/IEEE (Institute of Electrical and Electronics Engineers) survey of smart grid industry executives identified three key benefits of properly designed and implemented distributed generation to energy utilities: the ability to add supply where needed, reduced costs compared to larger-scale generation facilities and improved power reliability.

In the U.S. and around the world, distributed generation is growing rapidly due to its many benefits. There are potential risks, however, and the effective mitigation of those risks is essential to fostering additional growth. Traditional utility electric power systems were designed to support a one-way power flow from the point of generation through a transmission system to distribution load levels. The integration on the energy grid of distributed generation sources creates potential operational issues that can result in undesirable operating conditions that destabilize the grid or lead to system failure. These developments require advanced control and protection schemes. It should not be surprising, then, that the most important consideration in developing and deploying distributed generation — cited by 94% of smart grid industry executives — is standards.

UL had developed a standard for interconnection equipment, UL 1741, and contributed significantly to the IEEE 1547 interconnection system requirements. We then worked with the U.S. Department of Energy (DOE) and the National Renewable Energy Laboratory (NREL) to harmonize UL 1741 and IEEE 1547. This effort resulted in the revision of UL 1741 to require compliance with IEEE 1547 and IEEE 1547.1 (covering interconnection system testing). The combined safety and grid certification program addressed most electrical AHJ (authority having jurisdiction) and distributed generation interconnection needs and has delivered a solid safety and performance history in the U.S. and Canada.

Given the expansion of distributed generation technology innovations and providers in recent years, there is a growing need to update the existing IEEE 1547 grid interconnection standards, which define basic functionality with voltage and frequency ranges for operational and corresponding disconnect times. The continued growth of distributed generation also requires an evolution of these utility grid interconnection standards to help ensure that advanced renewable generation sources connect to the grid safely and securely. Advancing technology provides the mechanism for this evolution through so-called smart inverters.
WHAT DID UL DO?

UL is working closely with regulators, energy utilities and inverter manufacturers — each of which has its own perspectives and priorities — to evolve the Standard UL 1741 to include requirements for new and advanced inverter functions. Specifically, we are working with all the key stakeholders to expand and revise the existing single grid interconnection option to keep pace with new and emerging developments. To this end, we are developing new grid interconnection requirements and certification options.

Our first concrete step was to develop a set of requirements that provide a means to certify products for special-purpose applications such as solar (PV) and wind power generation farms. These applications may have utility interconnection requirements that are different from those defined in IEEE 1547 or IEEE 1547.1, which necessitate a provision for different grid interconnection protection features, functions and operating parameters. The new requirements enable UL to test, rate and certify products for the special-purpose applications. We are fast-tracking the development of new requirements to UL 1741, which will go through the American National Standards Institute (ANSI) consensus standards process to ensure that the updated standard provides the safeguards regulators and utilities need along with the flexibility manufacturers want.

UL has been participating in the revision and expansion of the standards IEEE 1547 and IEEE 1547.1. The updated IEEE 1547A incorporates clarifications for:

- Voltage regulation, allowing stabilizing functions to be performed to enhance and maintain grid voltage (when agreed upon by grid and distributed resource operators).

- Additional and alternative voltage and frequency trip limits and times at which an inverter ceases to energize its output when grid voltage or electric frequency extend beyond specified normal levels, including the ability to ride through longer periods of suboptimal voltage or frequency.

The IEEE 1547A standard is currently going through the consensus process, and we have begun work on IEEE 1547.1A, which incorporates test procedures for the new functionality defined in IEEE 1547A.
We are also working closely with the state of California — the state at the forefront in incorporating distributed generation into its energy system — to expand its grid interconnection requirements as part of California Rule 21. Under UL 1741, we have developed a path for special-purpose grid interconnection requirements for utility-scale generation, and we are developing requirements for advanced inverter functionality to provide greater flexibility in the ways that distributed generation sources interact with and support the power grid.  

**IMPACT**

UL’s work to advance utility grid interconnection standards is focused on increasing the safety of renewable energy while helping to ensure the stability and reliability of the electric grid. Our work has brought together energy utilities, manufacturers, government agencies, regulators and other interested parties to ensure that the installation codes, standards and certifications meet each group’s specific needs. The new requirements and forthcoming standards are designed to facilitate a streamlined process in which renewable energy equipment and systems can be designed, produced, evaluated, certified, sold, installed and operated in a way that is safe, efficient and beneficial to all stakeholders.

**RELATED ARTICLE**

Since you were interested in reading Progressing Grid Interconnection Standards, we thought you might find the following related article of interest.
INNOVATING SAFETY STANDARDS FOR ENERGY-EFFICIENT LIGHTING

PROGRESSING GRID INTERCONNECTION STANDARDS

MITIGATING EMERGING EV BATTERY RISKS

THERMAL MODELING OF LED LIGHTS
WHY MITIGATING EMERGING EV BATTERY RISKS MATTERS

Electric vehicle (EV) sales have grown dramatically over the past few years and are projected to grow more rapidly in the future. The growth is largely a function of the environmental benefits of EVs, which are substantial. However, one of the biggest barriers to the purchase of EVs is the up-front cost, largely due to the high cost of the batteries, which make EVs more expensive than conventional (nonelectric) automobiles. Innovative uses of EV batteries have the potential to reduce the cost of ownership and provide additional benefits that could further advance market penetration. However, these new uses also create safety risks and underscore a critical need for new safeguards.

CONTEXT

In the U.S. alone, more than 250 million vehicles travel nearly four trillion passenger miles each year. It is, therefore, not surprising that transportation accounts for one-third of U.S. carbon dioxide emissions. Worldwide, 13 billion tons of carbon dioxide are released annually from electricity generation, and an additional seven billion tons are released through transportation.

The greenhouse gas emissions and carbon footprint of EVs vary, based on where they are charged. Charging an EV in an area with a coal-burning power plant, for example, would yield an overall carbon footprint on par with that of a high-efficiency gas-burning car. However, a range of studies that do “well to wheels analysis” show that EVs lead to significantly less carbon dioxide emissions overall.

With lithium-ion battery capacity expected to double by 2025, the total cost of ownership of an EV will be competitive with that of internal combustion engine automobiles. However, a 2012 study shows that the impact of such a development is likely to be diminished because consumers generally do not value future savings over the higher initial cost of an EV.

Longer term, EV battery cost may not be the issue it is today. In 2012, the U.S. government funded a five-year project at Argonne National Laboratory to develop a battery that holds five times as much energy as a standard lithium-ion battery at one-fifth the cost. At the present time and into the immediate future, however, the development of new applications for EV batteries can provide important ways to add immediate value to an EV and help overcome the initial cost barrier to purchase. These new Vehicle to Grid (V2G), Vehicle to Home (V2H) and Vehicle to Load (V2L) — collectively referred to as V2X — applications use the EV battery as a distributed generation power source to export electric power to an external load, premise wiring system, electric grid or external.
application. V2X will enable EV owners, and particularly fleet owners, to earn credits from the electric utility by feeding excess load back into the grid during peak demand periods. Other applications include using the EV battery to feed electricity to the home to reduce its utility-generated energy use or to use the EV battery as a portable generator to provide electricity for appliances such as power tools for convenience or home use during an emergency.\(^5\)

With over 3,000 electric utilities in the U.S. (investor-owned, rural electric cooperatives and publicly owned), the U.S. electric power landscape and regulatory environment are complex and nonuniform — as are the technical requirements of V2X systems.\(^4\) Given the considerable interest in establishing the deployment of V2X technologies, there is a critical need for new safeguards that meet the needs of multiple stakeholders.\(^5\)

**WHAT DID UL DO?**

As a leader in the electrical safety community, UL is at the forefront, deeply involved with the development of safety requirements for new technologies. UL has experts on each Code Making Panel of the National Electric Code (NEC) and, with the UL Electrical Council, we have a long-standing source of practical advisors on code requirements. We also have relationships with many U.S. electric utilities and a deep understanding of the infrastructure safety and interoperability issues that V2X technologies face.\(^6\)

Our experience with and understanding of electric utility codes as well as product/electrical safety issues put us in an ideal position to create an Outline of Investigation — a collection of safety requirements based on our investigations of relevant products — which is the first step toward development of a Proposed Standard.\(^7\) As part of the Outline, we developed fast-tracked safety requirements to support the rapid market introduction of V2X technologies. V2X products typically involve charger, inverter and personnel protection equipment, all of which are existing technologies for which we have developed safety Standards. We had to examine how to apply what we know about the technologies to help ensure that the new uses would be safe. We worked with utilities and equipment manufacturers to identify gaps in the existing Standards created by the new uses. We then developed requirements to provide safeguards for these gaps. The requirements specifically identify the criteria necessary to certify V2X products.\(^8\)
IMPACT

With the Outline of Investigation, UL is providing safeguards today for V2X applications. The Outline has also allowed us to begin the consensus process to formalize a new robust safety Standard that bridges the desire of automobile and inverter manufacturers to deploy new V2X technologies with the needs of the electric utility industry to protect the integrity of the grid and to ensure the safety of those who connect to it. In so doing, we are helping to facilitate new applications of EV batteries and, ultimately, helping to accelerate the adoption of EVs.19

RELATED ARTICLE

Since you were interested in reading Mitigating Emerging EV Battery Risks, we thought you might find the following related article of interest.

WIRELESS CHARGING OF ELECTRIC VEHICLES
INNOVATING SAFETY STANDARDS FOR ENERGY-EFFICIENT LIGHTING

PROGRESSING GRID INTERCONNECTION STANDARDS

MITIGATING EMERGING EV BATTERY RISKS

THERMAL MODELING OF LED LIGHTS
WHY THERMAL MODELING OF LED LIGHTS MATTERS

LEDs (light-emitting diodes) are far more efficient than traditional incandescent lighting technology and thus have the potential to reduce energy use and greenhouse gas emissions. This, coupled with decreasing manufacturing costs, is driving explosive growth for the LED industry and attracting the aggressive development of new applications and products that are projected to help the industry expand, particularly in the automotive and general lighting sectors. UL is using thermal modeling to rapidly evaluate and refine tests as well as to validate products, all of which helps us safeguard LED innovations.

CONTEXT

Today, lighting accounts for 19% of the world’s energy use and produces carbon dioxide emissions equivalent to what 70% of the world’s passenger vehicles produce each year. LED lights use at least 75% less energy than incandescent bulbs and last 25 times longer, providing an opportunity to reduce light-related energy consumption by 50% and global carbon dioxide emissions by 10% by 2025. To realize these sustainability benefits, the LED lighting industry must achieve its projected growth rate, which will increase LED market share globally from 10% in 2010 to 60% in 2020.

Some of the LED industry growth is being driven by governmental regulation around the world pushing for energy efficiency; lighting companies are responding by pursuing the development and enhancement of LED technologies that are poised to transform the industry. Heavy investment by these companies is cutting LED manufacturing costs by 30% each year.

Today, LED technology is creating entirely new lighting possibilities. These include dynamically changing light color temperature and flexible designs, as seen in cars, that challenge the standard interfaces that have been in place for decades. New growth opportunities are also emerging in the area of intelligent lighting systems, which result from the greater controllability of LED-generated light. The growth of LED lighting will lead to a fundamental disruption of the lighting industry along its entire value chain. The new LED products and applications that emerge will create a need for new and updated standards and, in turn, new ways to evaluate safety and performance. And the pace of change inherent in the projected 500% increase in LED market share from 2010 to 2020 means that standards and testing methodologies will need to be updated or developed quickly.
WHAT DID UL DO?

We used thermal modeling to enable us to simulate, explore and understand LED performance and safety characteristics, and to validate test methods. Today we use computational fluid dynamics (CFD) software specifically to help us create new tests and modify existing LED tests. Our CFD modeling tools help us determine which tests are most appropriate, given a specific set of criteria. The optimal test will simulate realistic worst-case conditions to properly assess safety performance.12

One example is our use of CFD software to model different LED testing configurations, including the details of an LED, to understand the impact of various parameters on actual airflow and temperature patterns within the LED created by a test box (i.e., a test chamber designed to determine the thermal performance of an LED light engine, or LLE). This is important because one of the key challenges in the design and performance of LEDs is thermal management. Unlike incandescent lighting, which dissipates heat via infrared radiation mostly through the front, LEDs dissipate two-thirds of generated heat via conduction to heat sinks attached to their backs. As such, thermal management is critical in maintaining low juncture temperatures within the LED that ensure long product life and safety.13

Specifically, we employed thermal modeling to determine whether the temperature test box proposed to update the Standard UL 1993 could realistically represent worst-case thermal luminaire designs. These would allow a typical LLE to operate within its rated limits. We developed a detailed thermal simulation of an LLE enclosed in a test box, and we also modeled the same test for a redesigned test box (having some space between the LLE and the box) to understand the effect of vertical clearance in temperature distribution. UL had to also build three-dimensional numerical models and carry out conjugate heat transfer analyses to predict the temperature and flow profile for each test box configuration.14

However, before carrying out the actual thermal analysis, we compared our CFD model with experimental test results. With confidence in the model predictions, we performed thermal analyses of the same LLE model placed inside different test boxes.15

The results of this work helped us establish that the initial test box design in the UL 1993 CRD (Certification Requirement Decision, a document that addresses a potential change in the application of safety requirements included in a Standard) could be improved. The results also highlighted the sensitivity of the LED performance to the vertical clearance between the LLE and test box in determining the temperature.
IMPACT

UL’s CFD models successfully predicted the temperature limits of an LED light engine enclosed inside a box. Given the assumptions used for the study and the actual results obtained, we are confident that our CFD tool can accurately predict temperature by modeling an LED luminaire and LLE system.\(^{16}\)

Ultimately, computational modeling is an important tool we use to gain insight into how a product functions, how it malfunctions and the risks involved. With the data our modeling generates, UL can help product design engineers develop better ways to evaluate LED safety and performance and provide technical justification to the Standards Technical Panel (STP) and other interested stakeholders to accelerate test development times internally and eventually adopt them into standards. Overall, reduced development times help UL customers who are looking for certification that is relevant to their product. Accelerating the process of safeguarding LEDs is critical to supporting the growth of the industry and the adoption of this highly sustainable lighting technology.\(^{17}\)

RELATED ARTICLES

Because you were interested in reading Thermal Modeling of LED Lights, we thought you might find the following related articles of interest.
INNOVATING SAFETY STANDARDS FOR ENERGY-EFFICIENT LIGHTING


11. Ibid.

12. Ibid.

13. Ibid.

14. Ibid.

15. Ibid.

16. Ibid.

17. Ibid.

PROGRESSING GRID INTERCONNECTION STANDARDS


SUSTAINABLE ENERGY JOURNAL/SOURCES

MITIGATING EMERGING EV BATTERY RISKS


3 Ibid.


6 Ibid.


11 Boyce, K., Personal Interview, 4 Nov. 2013.


13 Ibid.

14 Ibid.

15 Ibid.


18 Ibid.

19 Ibid.

20 Ibid.

21 Ibid.

22 Ibid.

23 Ibid.

THERMAL MODELING OF LED LIGHTS


7 Ibid.

8 Ibid.

9 Ibid.

10 Ibid.

11 Ibid.


14 Ibid.

15 Ibid.

16 Ibid.
