PNNL-28506

Pacific Northwest
NATIONAL LABORATORY

SSL R&D Data Mining

Screening for Potential Field Validation Candidates

February 2019

Beeson, Tracy A
Sandahl, Linda J
Davis, Robert G

U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

DISCLAIMER

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

Printed in the United States of America

Available to DOE and DOE contractors from the
Office of Scientific and Technical Information,
P.O. Box 62, Oak Ridge, TN 37831-0062;
ph: (865) 576-8401
fax: (865) 576-5728
email: reports@adonis.osti.gov

Available to the public from the National Technical Information Service
5301 Shawnee Rd., Alexandria, VA 22312
ph: (800) 553-NTIS (6847)
email: orders@ntis.gov <http://www.ntis.gov/about/form.aspx>
Online ordering: http://www.ntis.gov

SSL R&D Data Mining

Screening for Potential Field Validation Candidates

February 2019

Beeson, Tracy A
Sandahl, Linda J
Davis, Robert G

Prepared for
the U.S. Department of Energy
under Contract DE-AC05-76RL01830

Pacific Northwest National Laboratory
Richland, Washington 99352

Executive Summary

In 2019, Pacific Northwest National Laboratory (PNNL) conducted a review for the U.S. Department of Energy (DOE) of the projects that have been awarded research and development (R&D) funding for the advancement of solid-state lighting (SSL) technologies . The projects were reviewed with the intent of finding research that is now utilized in commercially available products and to identify potential field-validation project candidates. This report discusses the research approach as well as what PNNL learned regarding the commercial availability of the technologies that were advanced with DOE R&D funding. PNNL reviewed 82 projects from the DOE-supported SSL R&D portfolio and identified 11 projects to evaluate for potential laboratory and field validations in commercial buildings. For these 11 projects, reports were reviewed and interviews were scheduled with principal investigators to discuss commercialization status. Six projects were identified as holding promise as field validation candidates: four are being commercialized and two projects have products or systems using some of the advancements that were developed during the funding period. Of the remaining five projects: two appear slated for commercialization in the next few years and three we are uncertain of because we were not able to reach the manufacturers to obtain updated information.

The four projects that are the farthest along in their commercialization status are

1. Low-Cost, High-Efficiency Integration of SSL and Building Controls using a PET Power Distribution System

2. Luminaires for Advanced Lighting in Education

3. High-Efficacy High-Power LEDs for Directional Applications

4. Innovative Office Lighting System with Integrated Spectrally Adaptive Controls.

The other two commercially available products that showcase technologies developed during the R&D funding period are from the following projects:

5. Innovative Patient Room Lighting System with Integrated Spectrally Adaptive Control

6. Lowering Barriers to Intelligent SSL Adoption through a Combination of a Next Generation Installation/Configuration Software Platform and a Novel Luminaire.

Projects that appear to be slated for commercialization in the next couple of years are:

7. Highly Integrated Modular LED Luminaire

8. Daylighting Digital Dimmer.

Contents

Tables

1.0 Introduction

In 2019, Pacific Northwest National Laboratory (PNNL) conducted a review for the U.S. Department of Energy (DOE) of the projects that have been awarded research and development (R&D) funding for the advancement of solid-state lighting (SSL) technologies. The projects were reviewed with the intent of finding research that is now utilized in commercially available products and identifying potential field validation project candidates. This paper discusses the research approach as well as what was learned regarding the commercial availability of the technologies that were advanced with DOE R&D funding.

The U.S. Department of Energy has been focused on accelerating and facilitating a smooth transition to SSL as the technology has evolved to be more effective and accessible since 2000. As the years have progressed, the funding allocated for research and development of technologies that help accelerate SSL in the marketplace has also shifted to address various aspects of the challenges that are unique to SSL.

Some of the technologies that R&D funding has helped to develop and accelerate have now become integral to the products that are commercially available. It is of great interest to understand where and how these technologies are being used and how DOE can build upon the initial investments through ongoing research that can help define priorities for future generations of technology. Our objective in this report is to identify a number of R&D projects that have become integral to commercially available products so that we can undertake laboratory testing under various realistic conditions and field validation projects of actual installations to better inform the needs and challenges of future technology generations.

2.0 Process

Overall, we reviewed 82 projects from the DOE-supported SSL R&D portfolio, dividing them into 10 categories that we felt were most representative of the primary focus of the project (see Table 1). We were interested primarily in identifying projects that furthered the integration of advanced lighting technologies and controls, as these systems are of particular interest to DOE because they have the potential to facilitate significant energy savings in the installed environment. Next, we identified projects that showed significant promise and that might benefit from third-party laboratory testing and field validation.

Our review was initially limited to projects that were completed after 2015 in an attempt to identify projects that have not yet resulted in products and systems that have achieved full market adoption. The initial limited date range, along with the specific focus on advanced systems and controls integration, yielded only six projects on our short list, so we expanded the contract end date for systems-based research to include projects with contract end dates as far back as 2009. A complete listing of these projects is provided in Appendix A. We also decided to take a closer look at some of the projects that focused on product efficacy on the luminaire level, with the assumption that the late-stage research would more likely be commercially available. Two additional systems-based projects were identified in addition to three projects geared at increasing luminaire efficacy, yielding 11 projects on our short list.

We then reviewed the detailed results from these 11 projects to explore the status of commercial availability and the potential for field validations in buildings. Once the final reports were gathered and reviewed, we scheduled follow-up calls with the principal investigators of each project to discuss commercialization status. All but three of the contacts provided an update on the progress made on the technology since the end of the funding period.

Table 1. Project Category Summaries

	Category	# of R&D Projects:	Summary of Group
1	Controls	6	The projects in this category address a surprisingly large range of issues associated with the installation and commissioning of advanced lighting control systems. Projects have focused on distribution, architecture, integration, exploration of novel hardware and software, and simplification of achieving and maintaining appropriate light levels.
2	Cost	4	Of the few projects with a primary focus on reducing the cost of SSL systems; two focused on costs associated with driver optimization or substrate fabrication, while two more recent R&D efforts in this area focused on luminaire optimization (either through the heat sink and thermal optimization or the optical properties achieved with novel light-guiding substrates).
3	Efficiency (diodes)	17	This category covers a wide spectrum of early stage research focused on increasing the efficiency of light-emitting diodes, from reducing the quantum deficit to enhancing the performance of phosphors and achieving higher efficiency colored LEDs.
4	Efficiency (luminaire)	8	Many of the projects that are central to increasing efficiency on the luminaire level explore concepts like vertical integration of luminaire component development, standardization of components, streamlining the manufacturing process, and increasing light output and/or optical control.
5	Health	2	The importance of health topics in lighting is widely understood, but much of the R&D work is still underway. Both projects are set to end at the end of FY 19.
6	Testing	2	One project is aimed at accelerated life testing while the other addresses color concerns associated with white SSL technologies. Neither project leads to a commercially available product.
7	Manufacturing	7	Projects in this category span the diode gamut from enhanced phosphors to printed films. There is also a great emphasis on optimizing thermal conductivity and temperature control through novel architectures.
8	OLEDs	30	These projects are focused on various aspects of OLED research and development. As OLED performance is still being optimized, there is a wide range of ways in which R&D efforts are accelerating the uptake and market availability and feasibility of these products for general lighting applications. However, very few OLED luminaires are currently available. If any future commercially available OLED products seem to be good candidates for field validation projects, we can review the R&D portfolio to determine which possible R&D efforts fed directly into their development.
9	Quantum Dots	3	Quantum dots provide a promising and efficient potential for next generation SSL luminaires. Current efforts revolve around reducing the toxicity associated with the manufacturing, reducing manufacturing costs, and advancing the baseline for the rigorous performance metrics that will be required for the technology to be utilized in commercially available products.
10	System	3	The R&D efforts that have gone into systems research are focused around offices, educational settings, and healthcare applications. The systems solutions include commercially available technologies and would make prime candidates for field validation and third-party laboratory testing regarding the applicability of the research findings.

3.0 Results

Many of the technologies that were developed during the award period are not yet commercially available. However, for the short list of technologies we identified, some efforts are underway by technology developers to pilot and/or release products with these advanced technologies. After reviewing the 82 projects from the SSL R&D portfolio and sorting them into the 10 categories shown in Table 1, we identified 11 projects where further technology development might benefit from third-party laboratory testing and field validation (see Table 2). In the short term, there are six projects that hold promise as field and laboratory validation candidates, although only four of the technologies are being commercialized, while the remaining two have products or systems using some of the advancements that were developed during the funding period.

The four projects that are the farthest along in their commercialization status are:

1. Low-Cost, High-Efficiency Integration of SSL and Building Controls using a PET Power Distribution System, Phase II – demonstration project showing conversion of conventional driver to a high-efficiency, more reliable, safer packet energy transfer (PET) power supply.
2. Luminaires for Advanced Lighting in Education - a small-scale pilot installation of these luminaires in Folsom, CA was evaluated by PNNL with DOE SSL funding.
3. High-Efficacy High-Power LEDs for Directional Applications - although this project resulted in a luminaire component and it would be necessary to identify a commercially available luminaire utilizing the technology for a field validation.
4. Innovative Office Lighting System with Integrated Spectrally Adaptive Controls - presently being installed as a prototype and the release of a commercially available product is on the roadmap as the manufacturer is committed to commercialization.

The other two commercially available products that showcase technologies developed during the R&D funding period are from the following projects:

5. Innovative Patient Room Lighting System with Integrated Spectrally Adaptive Control - The entire system is not available, but certain components are being engineered to order. Some follow-up research on elements of this system is underway at Georgia Institute of Technology in collaboration with PNNL with DOE SSL funding.
6. Lowering Barriers to Intelligent SSL Adoption through a Combination of a Next Generation Installation/Configuration Software Platform and a Novel Luminaire - Sensor technology advancements developed with support from the DOE R&D funding were released in the most recent version of their sensors available.

The potential “second tier” of projects that appear to be slated for commercialization in the next couple of years are:

7. Highly Integrated Modular LED Luminaire - originally targeted for an exterior application and, while that turned out to not be feasible for the manufacturer, they have begun the development of an interior luminaire using the technology, which is slated to be released by early 2021.
8. Daylighting Digital Dimmers, Phase II – This project has encountered many roadblocks due to the fragmentation of the wireless systems market. These roadblocks have set the commercialization of the product back, but the product developer hopes to release a product by 2020, although it will not have all of the light level and spectral tuning capabilities they eventually hope to include in their sensors.

Not enough information was available to fully assess projects 9, 10, and 11 since the manufacturers could not be reached for comment.

Table 2. Summary of Projects with Field Validation and Laboratory Testing Potential

	#	Title	Technology Developer	Summary	Status
Commercially Available	1	Low-Cost, High-Efficiency Integration of SSL and Building Controls using a PET Power Distribution System (Phase II)	VoltServer, Inc.	This will demonstrate a novel approach to reducing cost of SSL ownership by 35% or more. Conventional low-efficiency driver circuitry is replaced with a high-efficiency, highly reliable, and intrinsically safe centralized Packet Energy Transfer (PET) power supply design that improves conversion efficiency while also providing individual luminaire control and network communications. [Category 4-Efficiency (Luminaire)]	The 12-kW transmitter is commercially available and is being used in multiple applications. There is a Marriott in Ft. Worth, TX that is utilizing the technology and might be a good field validation site.
	2	Luminaires for Advanced Lighting in Education	RTI International	The primary objectives of the proposed research are to develop and test novel SSL luminaire designs that comprise the next-generation integrated classroom lighting system (NICLS) for use in an educational setting. The core building block of each luminaire in the NICLS portfolio is an addressable light engine that provides color tuning (between 2700 K and 6500 K) and full dimming (0% to 100%). The NICLS technology includes advanced recessed and pendant designs to provide general illumination and a wall wash design to illuminate special areas of the classroom such as white boards. [Category 10-System]	Finelite is commercializing the technology. PNNL was involved with validation of a small-scale pilot installation in Folsom, CA.
	3	High-Efficacy High-Power LED for Directional Applications	Lumileds, LLC	The objective is to develop a high-efficacy, high-power LED emitter to enable the best possible luminaire performance in the high-brightness application space. The LED will be optimized for high drive current, high-temperature operation, and a radiation profile suitable for directional applications. [Category 4-Efficiency (Luminaire)]	Commercially Available; Luxeon product V2. Designed for outdoor use.
	4	Innovative Office Lighting System with Integrated Spectrally Adaptive Controls	Signify (was Philips Lighting North America Corporation)	The goal is to provide an aggressive energy-saving system that is capable of variable modulation of intensity, distribution, and spectrum of lighting, in order to support visual and non-visual needs contributing to personal and organizational goals for workplace wellbeing. [Category 10-System]	Prototypes being installed, not available commercially yet. PNNL exploring pilot installations with manufacturer.
Commercial Product utilizing components	5	Innovative Patient Room Lighting System with Integrated, Spectrally Adaptive Control	Signify (was Philips Lighting North America Corporation)	The goal of this project is to deliver an innovative LED patient suite (patient room and bathroom) lighting system solution that is energy efficient and meets all the visual and non-visual needs of patients, caregivers, and visitors through better design, optics, and controls. [Category 10-System]	Some components that were developed during the funding period are being commercialized. Studies were conducted at hospitals in Oregon. PNNL is involved with ongoing research.

	#	Title	Technology Developer	Summary	Status
Pending Commercialization	6	Lowering Barriers to Intelligent SSL Adoption through a Combination of a Next Generation Installation/Configuration Software Platform and a Novel Luminaire	InnoSys, Inc.	The objectives of this project are to design and demonstrate the ability of a novel hardware and software application platform to dramatically simplify the installation, configuration, control, and analytics of an intelligent lighting system, so that it can be self-commissioning and give users greater control of their lighting experience. This will enable a lighting system that is dramatically more energy-efficient than conventional lighting, with user-experience driven to accelerate adoption of SSL and reduce energy consumption. [Category 1-Controls]	Product is not being commercialized but some of the controls advancements are in newest generation sensors. Contact offered connections to possible validation sites.
	7	Highly Integrated Modular LED Luminaire	GE Global Research	The project proposed a highly integrated modular light engine and driver solution for either an outdoor or high bay luminaire with a luminaire efficacy of 200 lm/W and a first cost reduction of 30%. [Category 4-Efficiency (Luminaire)]	Commercialization for intended application is not feasible. Interior luminaire is now being developed for commercialization in late 2020/early 2021.
	8	Daylighting Digital Dimmers (Phase II)	Mojo Labs	This Phase II project will refine and expand on the novel SSL control architecture that was successfully demonstrated during Phase I to produce a commercial product that provides the following: light intensity control at the task location without sensing the light level at the same location, daylight sensing with an external photosensor, spectral control of resultant electric and daylight, simple installation commissioning, and operation that uses ubiquitous digital personal devices for advanced individual user controls and scheduling. [Category 1-Controls]	In Spring 2019, they plan to release an initial sensor (not with lighting functionality that was developed during the award period), as they have been navigating the fragmentation of the wireless system market and dealing with the set-backs it has caused. By 2020, they anticipate having a commercial product that incorporates the light-level and spectral control technologies that were developed during Phase II.
	9	High Flux Commercial Illumination Solution with Intelligent Controls	Osram Sylvania	The objective of this project is to develop an LED based luminaire with controls to replace existing 2' x 2' luminaires that use fluorescent lamps. The replacement solution consists of a metal housing enclosing a custom-developed light engine, intelligent control electronics, and a power supply. The intelligent controls sense occupancy and ambient lighting conditions then use switching and dimming to gain additional energy savings. [Category 1-Controls]	No response to requests for information.
	10	Auto-Commissioning and Auto-Discovery Control System for Solid-State Lighting (Phase I)	Redwood Systems	This project will address cost, energy usage, complexity, and comprehensive coverage by centralizing power conversion in an electronic appliance capable of powering or dimming up to 64 light fixtures over low-voltage wiring. In addition, the new network will enable easier installations and automate configuration of motion and ambient light sensors, thereby saving lighting energy by using comprehensive daylighting, occupancy sensing, scheduling, and user tasking features. [Category 1-Controls]	No response to requests for information.
	11	Scalable Light Module for Low-Cost, High-Efficiency LED Luminaires	Cree, Inc.	This project plans to develop a versatile, low-cost, low profile LED light module architecture that facilitates the assembly of a variety of high-efficacy, broad-area LED luminaires. The light module will be driven by a novel, compact LED package for a combination of high color rendering index and high-efficacy over a wide range of correlated color temperatures. [Category 4-Efficiency (Luminaire)]	No response to requests for information.

Appendix A

DOE SSL Program R&D Projects Completed after 2015

Table A.1. DOE SSL Program R&D Projects completed after 2015 (or meeting our additional criteria for earlier projects to consider), listed alphabetically by organization

Title	Organization	Contract End	Category #
OLED Luminaire with Panel-Integrated Drivers and Advanced Controls	Acuity Brands Lighting	10/30/16	8
Stable and Efficient White OLEDs Based on a Single Emissive Material	Arizona State University	6/30/18	8
High-Efficiency and Stable White OLED using a Single Emitter	Arizona State University	9/30/15	8
Novel Transparent Phosphor Conversion Matrix with High Thermal Conductivity for Next-Generation Phosphor-Converted LED-Based Solid-State Lighting	Carnegie Mellon University	10/31/16	7
Graded Alloy Quantum Dots for Energy-Efficient Solid-State Lighting	Columbia University	8/31/18	9
Scalable Light Module for Low-Cost, High-Efficiency LED Luminaires	Cree, Inc.	8/31/15	4
Scalable Economical Fabrication Processes for Ultra-Compact Warm-White LEDs	Cree, Inc.	1/31/16	4
Materials and Designs for High-Efficacy LED Light Engines	Cree, Inc.	6/30/17	4
High-Efficacy, Multi-Functional SSL Platform	Cree, Inc.	1/15/18	4
Print-Based Manufacturing of Integrated, Low-Cost, High-Performance SSL Luminaires	Eaton Corporation	6/30/16	2
Narrow Emitting Red Phosphors for Improving pc-LED Efficacy	EIE Materials, Inc. (dba Lumenari, Inc.)	8/31/18	3
Highly Integrated Modular LED Luminaire	GE Global Research	2/14/18	4
Stable White Organic Light-Emitting Diodes Enabled by New Materials with Reduced Excited-State Lifetimes	Georgia Institute of Technology	8/31/19	8
Lowering Barriers to Intelligent SSL Adoption through a Combination of a Next Generation Installation/Configuration Software Platform and a Novel Luminaire (Phase I)	InnoSys, Inc.	4/12/17	1
Integrating Energy Efficient SSL with Advanced Sensors, Controls, and Connectivity (Phase I)	Innotec, Corporation	3/8/15	7
Enhanced Light Extraction from Low-Cost White OLEDs Fabricated on Novel Patterned Substrate	Iowa State University	9/30/18	8
High-Throughput, High-Precision Hot Testing Tool for HBLED Testing	KLA-Tencor Corporation	12/31/15	6
Next-Generation “Giant” Quantum Dots: Performance-Engineered for Lighting	Los Alamos National Laboratory	11/30/17	9
Ultra-Thin Flexible LED Lighting Panels (Phase I)	Lucent Optics, Inc.	3/13/17	2
Ultra-Thin Flexible LED Lighting Panels (Phase II)	Lucent Optics, Inc.	7/30/19	4
High-Voltage LED Light Engine with Integrated Driver	Lumileds, LLC	2/29/16	2
Development and Industrialization of InGaN/GaN LEDs on Patterned Sapphire Substrates for Low-Cost Emitter Architecture	Lumileds, LLC	11/30/15	2
Improved InGaN LED System Efficacy and Cost via Droop Reduction	Lumileds, LLC	8/31/17	3
Improved Radiative Recombination in AlGaInP LEDs	Lumileds, LLC	9/30/19	4
High-Efficacy High-Power LED for Directional Applications	Lumileds, LLC	2/28/18	4
Light Extraction System for OLED (LESO) (Phase I)	Luminit, LLC	12/11/17	8
Tunable Nanocrystal-Based Phosphors with Reduced Spectral Widths (Phase II)	Luminsyn, LLC	4/9/19	3
Nanocrystal-Based Phosphors with Enhanced Lifetime Stability (Phase I)	Lumisyn, LLC	11/16/15	3
Nanocrystal-Based Phosphors with Enhanced Lifetime Stability (Phase II)	Lumisyn, LLC	4/10/18	3
High-Performance Colloidal Nanocrystals (Phase I)	Lumisyn, LLC	11/21/16	3

Title	Organization	Contract End	Category #
LED Downconverter Phosphor Chips Containing Nanocrystals (Phase I)	Lumisyn, LLC	3/12/17	3
High-Performance Nanocrystals in Silicones (Phase I)	Lumisyn, LLC	11/20/17	3
R2R Production of Low-Cost Integrated OLED Substrate with Improved Transparent Conductor & Enhanced Light Outcoupling (Phase II)	MicroContinuum, Inc.	4/5/17	8
Al x In 1-x P LEDs with II-VI Cladding Layers for Efficient Red and Amber Emission (Phase I)	MicroLink Devices, Inc.	11/20/17	3
Daylighting Digital Dimmer (Phase I)	MoJo Labs	11/7/14	1
Daylighting Digital Dimmer (Phase II)	MoJo Labs	1/27/18	1
Next-Generation LED Package Architectures Enabled by Thermally Conductive Transparent Encapsulants	Momentive Performance Materials Quartz, Inc.	9/30/16	7
Improving Product Yield of OLEDs	Moser Baer Technologies, Inc.	3/31/15	8
Low-Cost Corrugated Substrates for High-Efficiency OLEDs	North Carolina State University	8/31/18	8
OLED Lighting Panel with Directional Light Output and High-Efficiency (Phase I)	OLEDWorks, LLC	3/8/15	8
Shorting Reduction Layer Process Development for OLED Lighting Panels (Phase I)	OLEDWorks, LLC	11/16/15	8
High-Performance OLED Panel and Luminaire	OLEDWorks, LLC	9/30/16	8
Innovative High-Performance Deposition Technology for Low-Cost Manufacturing of OLED Lighting	OLEDWorks, LLC	3/31/17	8
RKS, LLC, Development of High-Efficiency White OLEDs using Thermally Activated Delayed Fluorescence Emitters (Phase I)	OLEDWorks, LLC	11/21/16	8
OLED Lighting Substrate and Encapsulation System for Breakthrough Cost Reductions (Phase I)	OLEDWorks, LLC	11/20/17	8
Ultra-Thin, Curved, High-Efficacy OLED Light Engine (Phase I)	OLEDWorks, LLC	3/11/18	8
Mask-Free OLED Fabrication Process for Non-Tunable and Tunable White OLED Panels	OLEDWorks, LLC	9/30/19	8
Pedestrian-Friendly Outdoor Light with Solar Power (Phase I)	OLEDWorks, LLC	3/7/16	8
High-Flux Commercial Illumination Solution with Intelligent Controls	Osram Sylvania	4/30/12	1
Understanding, Predicting, and Mitigating Catastrophic Shorts for Improved OLED Lighting Panel Reliability	Pennsylvania State University	8/31/18	8
Innovative Patient Room Lighting System with Integrated Spectrally Adaptive Control	Philips Lighting North America Corporation (now Signify)	2/28/17	10
Innovative Office Lighting System with Integrated Spectrally Adaptive Control	Philips Lighting North America Corporation (now Signify)	6/30/17	10
Plasmonic-Enhanced High Light Extraction Phosphor Sheets for Solid-State Lighting (Phase I)	PhosphorTech Corporation	11/26/15	3
Plasmonic-Enhanced High Light Extraction Phosphor Sheets for Solid-State Lighting (Phase II)	PhosphorTech Corporation	4/10/18	3
Hybrid Down-Converting Structures for Solid-State Lighting (Phase I)	PhosphorTech Corporation	11/21/16	7
Hybrid Down-Converting Structures for Solid-State Lighting (Phase II)	PhosphorTech Corporation	4/9/19	3
Advanced Light Extraction Structure for OLED Lighting	Pixelligent Technologies, LLC	4/30/17	8
Advanced Light Extraction Material for OLED Lighting (Phase II)	Pixelligent Technologies, LLC	4/5/17	8

Title	Organization	Contract End	Category #
Advanced Light Extraction Material for OLED Lighting (Phase IIA)	Pixelligent Technologies, LLC	11/20/17	8
Advanced Light Extraction Material for OLED Lighting (Phase IIB)	Pixelligent Technologies, LLC	6/30/19	8
Manufacturing Process for OLED Integrated Substrate	PPG Industries, Inc.	12/31/16	8
ITO-Free White OLEDs on Flexible Substrates with Enhanced Light Outcoupling	Princeton University	11/9/16	8
Auto-Commissioning and Auto-Discovery Control System for Solid-State Lighting (Phase I)	Redwood Systems	9/30/09	1
System Reliability Model for SSL Luminaires	RTI International	2/28/17	6
Luminaires for Advanced Lighting in Education	RTI International	3/31/17	10
Real Time Learning Temperature Control for Increased Throughput in LED Manufacturing (Phase I)	SC Solutions, Inc.	11/21/16	7
Radiation-Assisted MOCVD Heating for Improved Within-Wafer Temperature Uniformity in LED Manufacturing (Phase I)	SC Solutions, Inc.	11/20/17	7
Integrated Plastic Substrates for Organic Light-Emitting Devices (OLED) Lighting	Sinovia Technologies	12/1/17	8
Light-Emitting Diodes on Semipolar Bulk GaN Substrate with IQE > 80% at 150 A/cm^2 and 100° C	Soraa, Inc.	3/30/15	3
TRITON SYSTEMS, INC. Improved Light Extraction from GaN LEDs (Phase I)	Triton Systems, Inc.	11/16/15	3
Nonradiative Recombination Pathways in Noncarcinogenic Quantum Dot Composites (Phase I)	UbiQD, LLC	8/21/16	9
The Approach to Low-Cost High-Efficiency OLED Lighting	University of California, Los Angeles	11/30/16	8
Novel Lighting Strategies for Circadian and Sleep Health in Shift Work Applications	University of California, San Diego	9/30/19	5
Identification and Mitigation of Droop Mechanism in GaN-Based Light Emitting Diodes	University of California, Santa Barbara	6/30/18	3
High-Performance Green LEDs for Solid-State Lighting	University of California, Santa Barbara	8/31/19	3
Stable, High Efficiency White Electrophosphorescent Organic Light-Emitting Devices by Reduced Molecular Dissociation	University of Michigan	2/28/18	8
Eliminating Plasmon Losses in High Efficiency White Organic Light-Emitting Devices for Lighting Applications	University of Michigan	8/31/18	8
Combining Fluorescence and Phosphorescence to Achieve Very Long Lifetime and Efficient White OLEDs	University of Southern California	9/30/19	8
Alternative Interconnect Manufacturing (Phase I)	Vadient Optics, LLC	11/21/16	7
Low-Cost, High-Efficiency Integration of SSL and Building Controls using a PET Power Distribution System (Phase I)	VoltServer, Inc.	3/8/15	1
Low-Cost, High-Efficiency Integration of SSL and Building Controls using a PET Power Distribution System (Phase II)	Voltserver Inc.	1/27/18	7
Investigating the Health Impacts of Outdoor Lighting	Virginia Polytechnic Institute and State University	8/31/19	5

Pacific Northwest
NATIONAL LABORATORY

www.pnnl.gov

902 Battelle Boulevard
P.O. Box 999
Richland, WA 99352
1-888-375-PNNL (7665)

U.S. DEPARTMENT OF
ENERGY