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

2016 Solid-State Lighting R&D Workshop

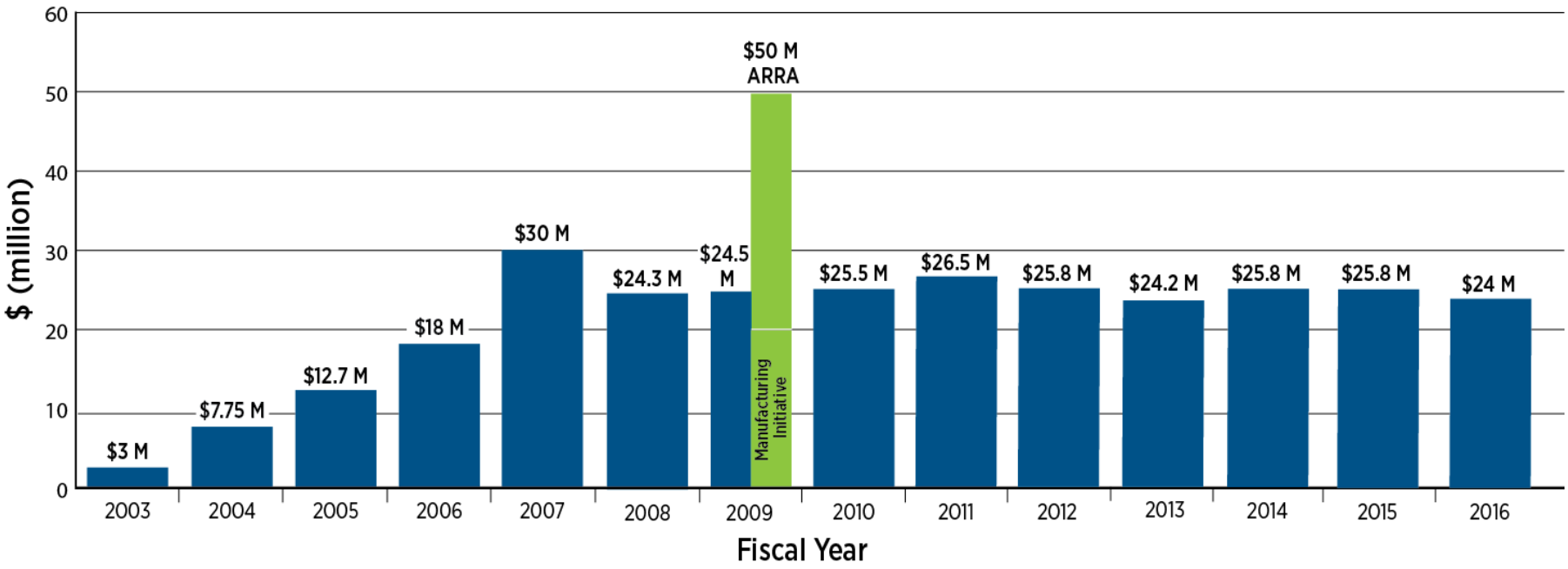
R&D Program Update

February 3, 2016

James R. Brodrick, Ph.D.

U.S. Department of Energy

Congressional Appropriations



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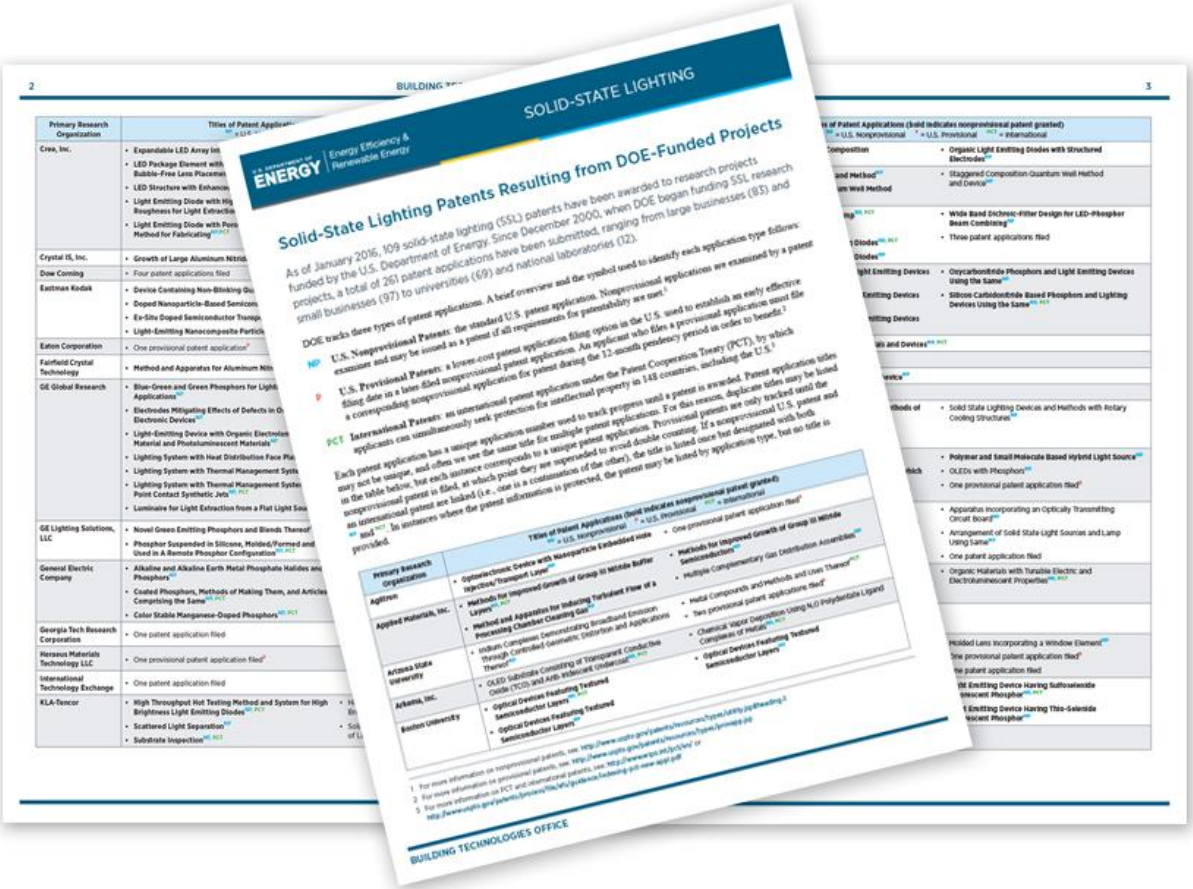
Results-Oriented R&D

Nearly **250** cost-shared projects funded to date have yielded more than **260** patents and a huge industry footprint



SOLID-STATE LIGHTING

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Solid-State Lighting Patents Resulting from DOE-Funded Projects

As of January 2016, 109 solid-state lighting (SSL) patents have been awarded to research projects funded by the U.S. Department of Energy. Since December 2000, when DOE began funding SSL research projects, a total of 261 patent applications have been submitted, ranging from large businesses (83) and small businesses (97) to universities (69) and national laboratories (12).

DOE tracks three types of patent applications. A brief overview and the symbol used to identify each application type follows:

NP **U.S. Nonprovisional Patents**: the standard U.S. patent application. Nonprovisional applications are examined by a patent examiner and may be issued as a patent if all requirements for patentability are met.[1]

P **U.S. Provisional Patents**: a lower-cost patent application filing option in the U.S. used to establish an early effective filing date in a later-filed nonprovisional patent application. An applicant who files a provisional application must file a corresponding nonprovisional application for patent during the 12-month pendency period in order to benefit.[2]

PCT **International Patents**: an international patent application under the Patent Cooperation Treaty (PCT), by which applicants can simultaneously seek protection for intellectual property in 148 countries, including the U.S.[3]

Each patent application has a unique application number used to track progress until a patent is awarded. Patent application titles may not be unique, and often we see the same title for multiple patent applications. For this reason, duplicate titles may be listed in the table below, but each instance corresponds to a unique patent application. Provisional patents are only tracked until the nonprovisional patent is filed, at which point they are superseded (or, one is a continuation of the other); the title is listed once but designated with both an international patent are linked (i.e., one is a continuation of the other); the title is listed once but designated with both NP and PCT. In instances where the patent information is protected, the patent may be listed by application type, but no title is provided.

Primary Research Organization	Titles of Patent Applications (Bold indicates nonprovisional patent granted) NP = U.S. Nonprovisional P = U.S. Provisional PCT = International
Agiltron	• Optoelectronic Device with Nanoparticle Embedded Inks • One provisional patent application filed[P]
Applied Materials, Inc.	• Methods for Improved Growth of Group III Nitride Buffer Layers[NP, PCT] • Methods for Improved Growth of Group III Nitride Semiconductors[NP] • Multiple Complementary Gas Distribution Assemblies[NP] • Method and Apparatus for Inducing Turbulent Flow of a Processing Chamber Cleaning Gas[NP]
Arizona State University	• Indium Compounds Demonstrating Broadband Emission Through Controlled Geometric Distortion and Applications[NP] • Metal Compounds and Methods and Uses Thereof[PCT] • Two provisional patent applications filed[P]
Arkema, Inc.	• OLED Substrate Consisting of Transparent Conductive Oxide (TCO) and Anti-Iridescent Underlayer[NP, PCT] • Chemical Vapor Deposition Using ALD Polydentate Ligand Complexes of Metals[NP, PCT]
Boston University	• Optical Devices Featuring Textured Semiconductor Layers[NP] • Optical Devices Featuring Textured Semiconductor Layers[NP] • Optical Devices Featuring Textured Semiconductor Layers[NP]

1 For more information on nonprovisional patents, see http://www.uspto.gov/patents/resources/types/utility.jsp#heading-1
2 For more information on provisional patents, see http://www.uspto.gov/patents/resources/types/provisap.jsp
3 For more information on PCT and international patents, see http://www.wipo.int/pct/en/ or http://www.uspto.gov/patents/process/file/efs/guidance/ledwing-pct-new-app.pdf

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 http://energy.gov/sites/prod/files/2016/01/f28/patents_factsheet_jan2016.pdf

Huge Industry Footprint

Nearly **200** products can be directly traced to DOE-funded SSL R&D

Millions of LED products have DOE R&D inside

143 tBtu of energy saved in 2014

Cree AR troffer

GE Evolve™ LED roadway lighting

Cooper Lighting Lumark® LED roadway lighting

Finelite HP-4 Direct/Indirect

Philips Advance LED drivers for UL Class 1—Fixed

Leotek LEDGreen King Cobra™ streetlight

SOLID-STATE LIGHTING

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Solid-State Lighting Commercial Product Development Resulting from DOE-Funded Projects

The U.S. Department of Energy (DOE) Solid-State Lighting (SSL) Program began funding SSL R&D in 2000, and to date has supported 230 cost-shared SSL projects in the areas of applied research, product development, and manufacturing R&D. This support has directly advanced the understanding and performance of SSL through the publication of articles in technical journals, the creation of intellectual property (with more than 245 patents applied for or awarded), and the direct development of nearly 200 state-of-the-art products. Those products—which include lamps, luminaires, LED components, power supplies, materials, and manufacturing tools—have contributed to more than $2.8 billion in U.S. energy savings to far.

It is challenging to track the full range of impact resulting from DOE-funded R&D projects, particularly related to commercial-level and high-risk. Some don't pan out, while others prove to be too expensive, inconsistent, short-lived, or of limited benefits. Even when they aren't, the results are still valuable in terms of educating the researchers and inspiring them for their next steps. This, coupled with the fact that the full development of some product concepts extends beyond the duration of the DOE funding, makes it difficult to estimate the full range of impact of DOE R&D funding.[1] Thus, the figures in this table below represent a conservative estimate; they are not comprehensive and are continually updated.

- They only include products directly developed or enabled by DOE SSL R&D funding.[2]
- They do not include derivative products, influenced products, or next-generation products based on those that received DOE support.

Product Type	# of Products	Manufacturers
Manufacturing Tools	5	Veeco, Ultratech, KLA-Tencor
Materials	17	Lightscape Materials, WhiteOptics
LED Components	158	Cree, Luminus
Power Supplies	3	Philips Lighting
Lighting Products	16	General Electric, Philips Lighting
Total	199	

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 http://energy.gov/sites/prod/files/2015/07/f24/comm-product-factsheet_jun2015.pdf

Broad Mix of R&D Partners

RTI INTERNATIONAL
whiteoptics™
CREE®
QD VISION
Veeco
Georgia Institute of Technology
PHILIPS LUMILEDS
COOPER Lighting
GE
ARKEMA
UF UNIVERSITY of FLORIDA
SORAA™
Sandia National Laboratories
Ultratech
UNIVERSAL DISPLAY CORPORATION™
ASU ARIZONA STATE UNIVERSITY
OLEDWorks Naturally Illuminating
INNOSYS inc.
PPG
LITECONTROL making light work™
KLA Tencor
Yale University
APPLIED MATERIALS®
Pacific Northwest NATIONAL LABORATORY
Crystal IS High Performance UVC LEDs
SYLVANIA
UCLA
PRINCETON UNIVERSITY
Rensselaer

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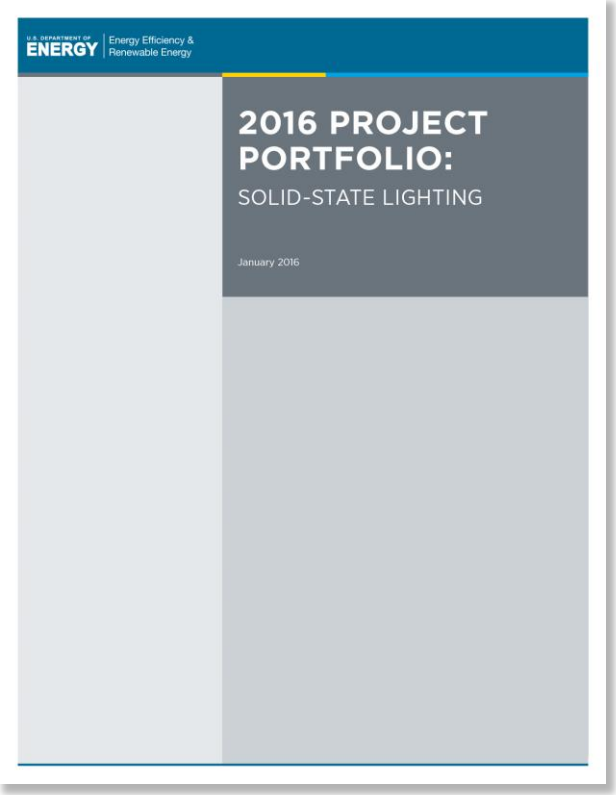
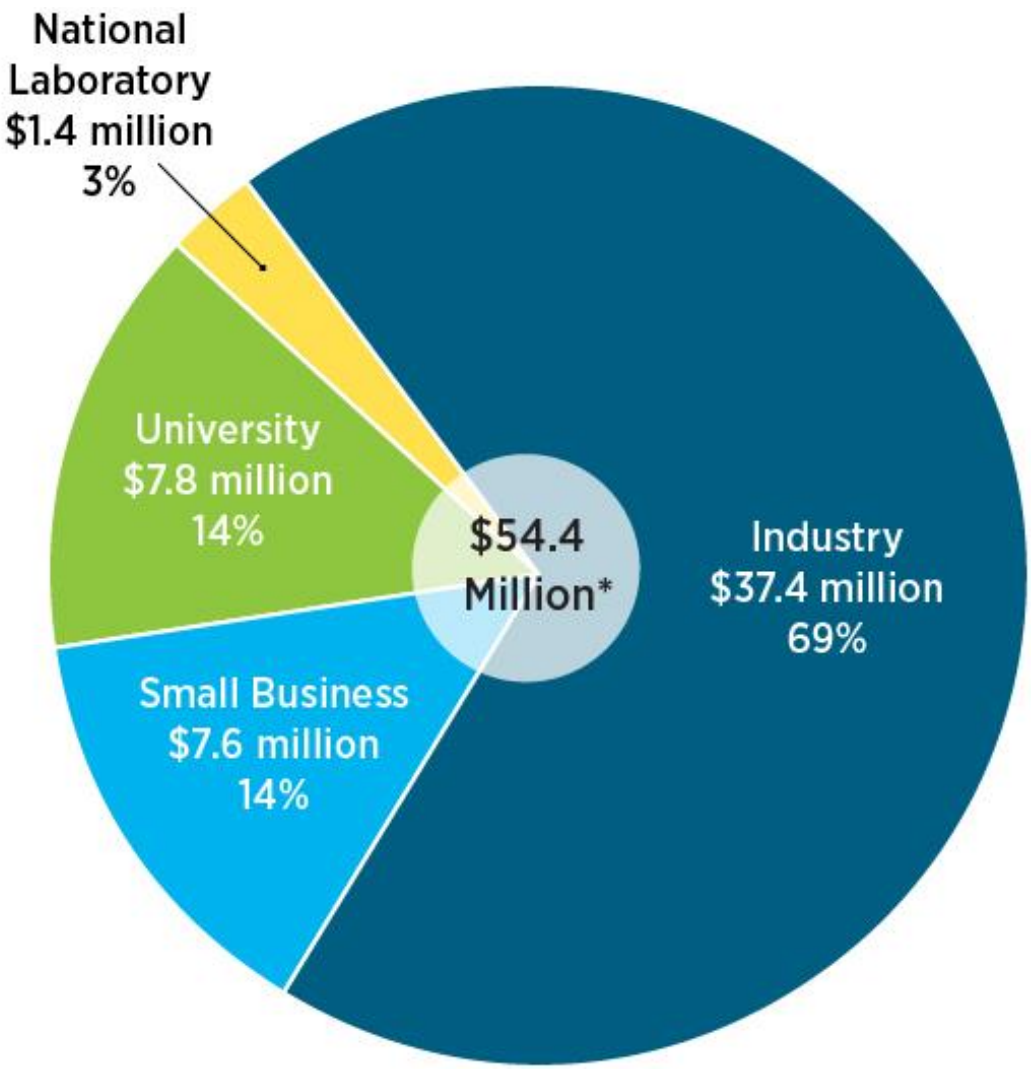
DOE SSL R&D Project Portfolio

- Results-oriented, competitively selected R&D projects
- Total current project value: $54.4M
  - OLED: $17.4M (10 projects)
  - LED: $37.0M (15 projects)
- Industry and university partners provide average of 36% cost share



energy.gov/eere/ssl/rd-program; http://energy.gov/sites/prod/files/2016/01/f28/2016_ssl-project-portfolio.pdf

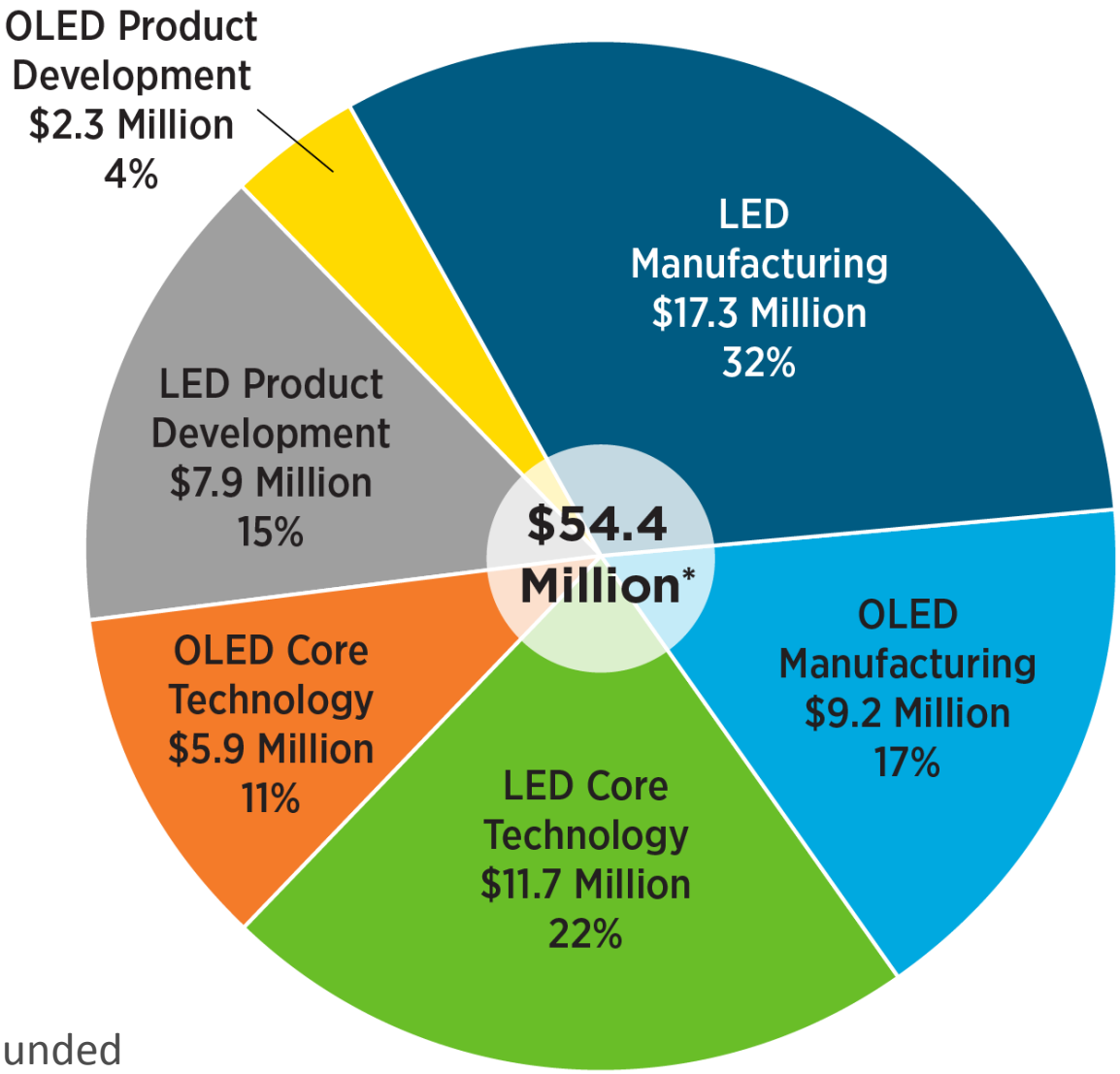
Recipients of SSL Program Investments



DOE funds SSL R&D in partnership with large and small companies, academia, and national labs

* Figures are rounded

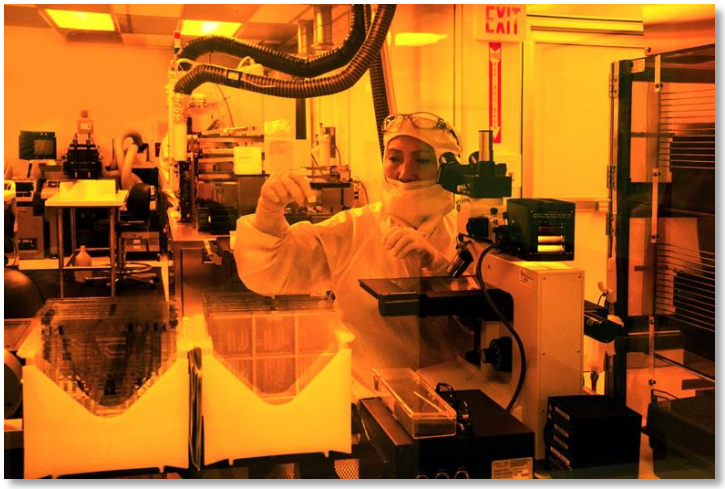
Breakdown of Funding by Focus Area



* Figures are rounded

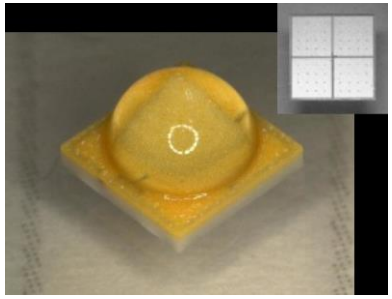
Success with SBIR

- $40M in SBIR SSL funding since 2000
- 126 awards in total
  - 87 Phase 1 awards
  - 39 Phase 2 awards
- Projects conducted by small companies; objectives align with DOE SSL R&D Plan
- Examples:
  - Universal Display Corporation
  - MicroContinuum
  - Pixelligent
  - VoltServer

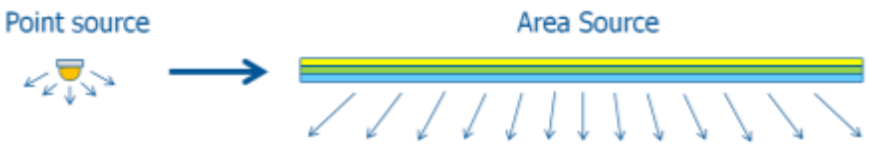


With SBIR funding support, Universal Display Corporation has been working for more than a decade to successfully advance the state of the art in OLED technology.

FY15 Highlights

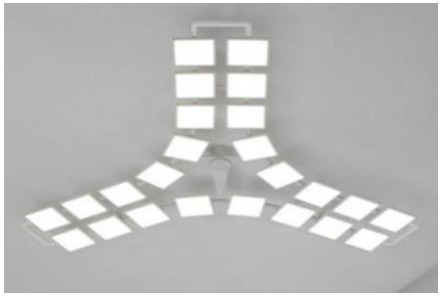


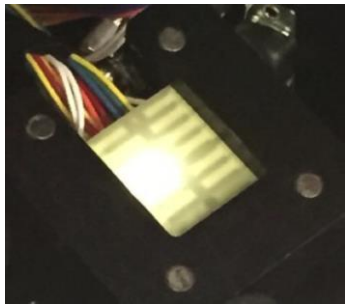
Lumileds develops high-voltage LED light engine with integrated driver



Cree demonstrates scalable module optical efficiency of >90%

OLEDWorks develops high-performance OLED panel and luminaire





Princeton University improves outcoupling efficiency of thin-film OLEDs

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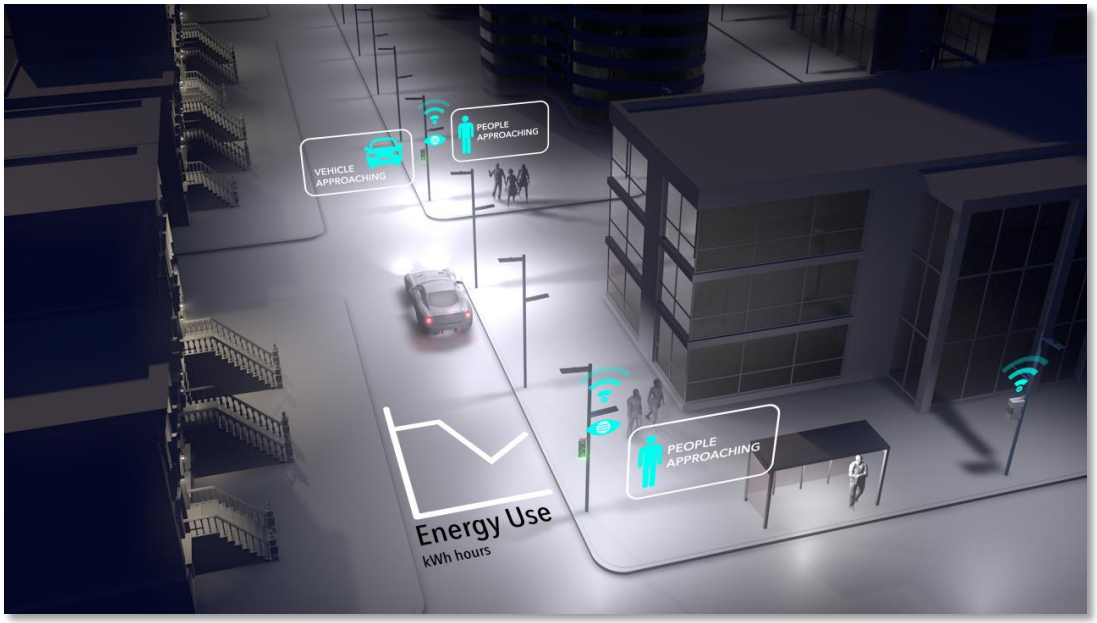
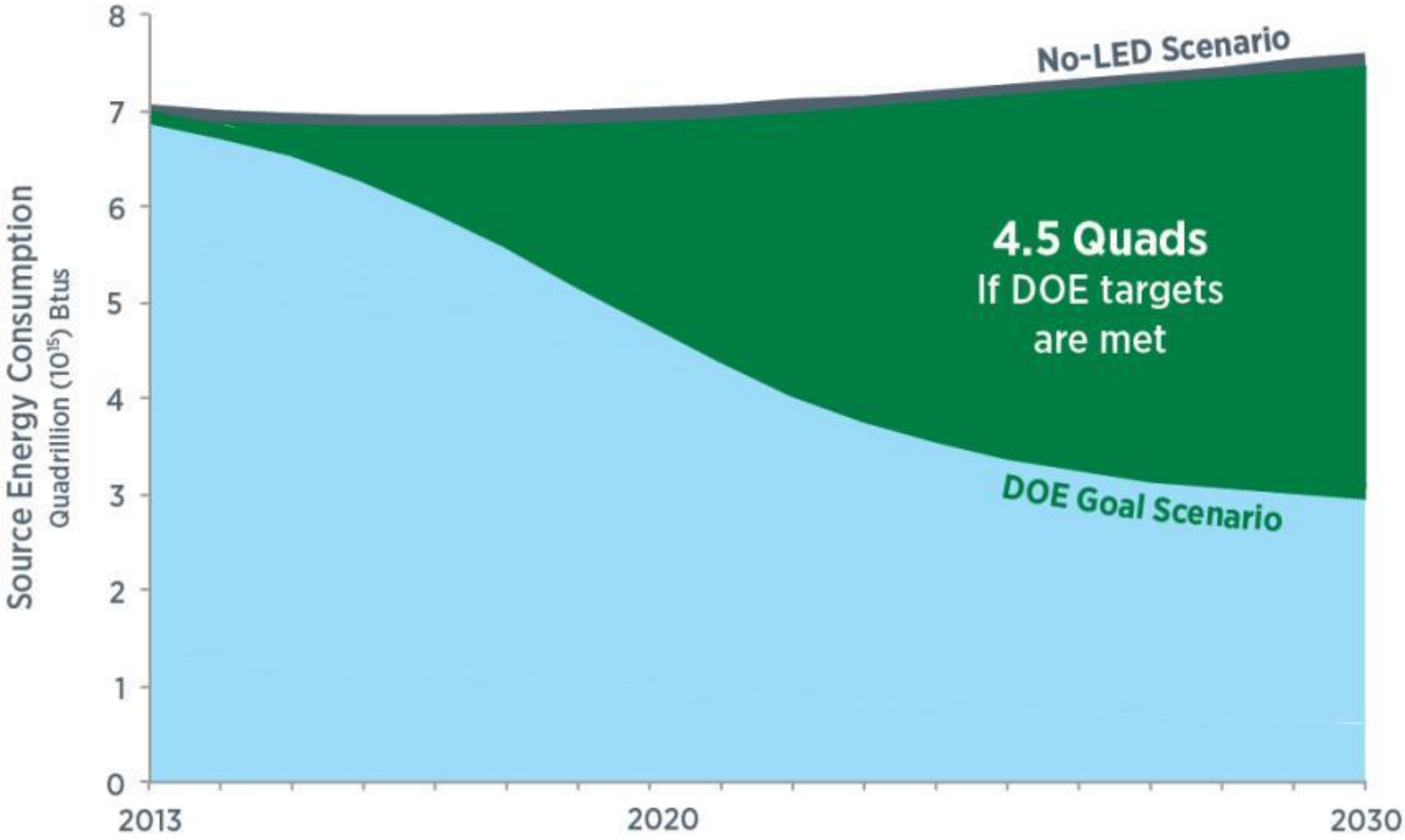
SSL Program Is Continuously Evolving

- Connected lighting
- Light quality
- Human factors
- Reliability
- OLED testing

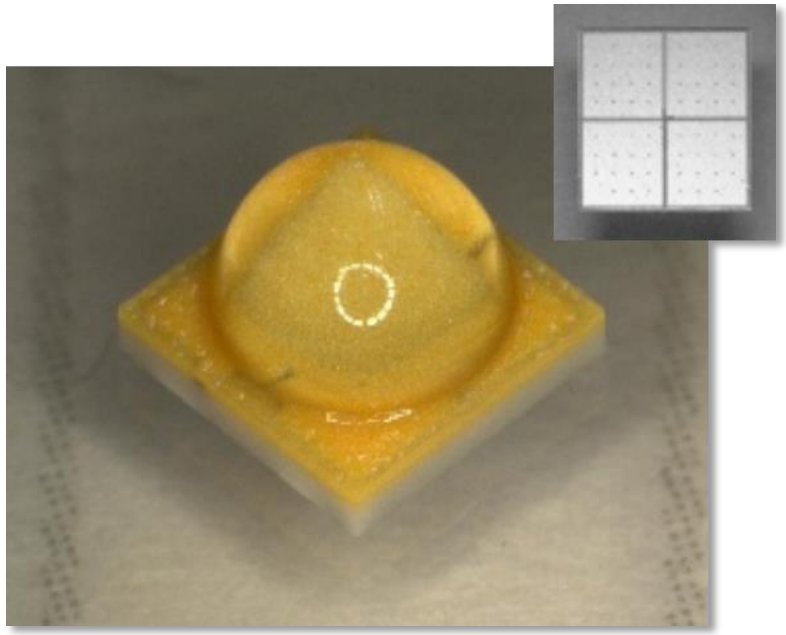


The Best Is Yet to Come



 energy.gov/sites/prod/files/2015/05/f22/energysavingsforecast14.pdf

Program Targets



LED Devices:
160 lm/W to 250 lm/W

LED Luminaires:
125-135 lm/W to 200 lm/W

LED Efficacy: What America Stands to Gain

1. Enormous energy savings
2. Far-reaching scientific and technological advances
3. Better LED products with improved lighting quality
4. Lower first-costs for LED products
5. Stronger positioning of domestic manufacturing

DR. ROLAND HAITZ

1935–2015

"Solid-state lighting is where the internet was in the 1980s. Just as we could not then have predicted what the internet is now, 30 years later, we cannot foresee all that light and lighting will become in the next decades. We know simply that it will be wondrous and beautiful."

Photo: QuarkStar

Roland Haitz: Career Highlights

PhD under
William Shockley
- A physicist's engineer
- Power electronics!

Joins
HP

Master Recruiter
Fairchild of LEDs!

Retires from
HP/Agilent

Joins
QuarkStar

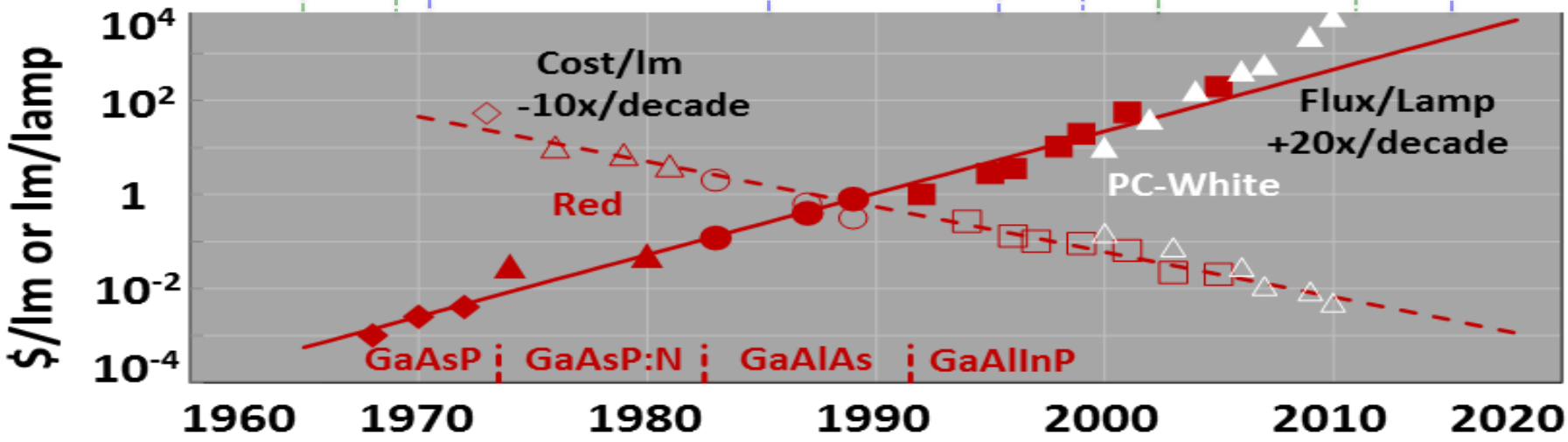
Optocouplers
7 Segment Displays

Power
LEDs

The Case for SSL
White Paper

Lumileds

Ann der
Physik
Expert
Opinion



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Roland Haitz: Sui Generis

1. Consummate Engineer
   - A historian's engineer
   - A physicist's engineer
   - A businessman's engineer
2. Mensch
   - Truth
   - Courage
   - Hard work

THE CASE FOR A NATIONAL RESEARCH PROGRAM ON SEMICONDUCTOR LIGHTING[1,2]

Roland Haitz and Fred Kish, Hewlett-Packard Company, Palo Alto, CA 94304
Jeff Tsao and Jeff Nelson, Sandia National Laboratories, Albuquerque, NM 87185-0601

EXECUTIVE SUMMARY

Dramatic changes are unfolding in lighting technology. Semiconductor light emitting diodes (LEDs), until recently used mainly as simple indicator lamps in electronics and toys, have become as bright and efficient as incandescent bulbs, at nearly all visible wavelengths. They have already begun to displace incandescent bulbs in many applications, particularly those requiring durability, compactness, cool operation and/or directionality (e.g., traffic, automotive, display, and architectural/directed-area lighting).

Further major improvements in this technology are believed achievable. Recently, external electrical-to-optical energy conversion efficiencies exceeding 50% have been achieved in infrared light emitting devices. If similar efficiencies are achieved in the visible, the result would be the holy grail of lighting: a 200*lm/W* white light source two times more efficient than fluorescent lamps, and ten times more efficient than incandescent lamps.

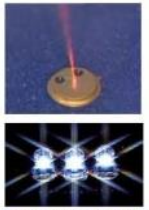
This new white light source would change the way we live, and the way we consume energy. The worldwide amount of electricity consumed by lighting would decrease by more than 50%, and total worldwide consumption of electricity would decrease by more than 10%. The global savings would be more than 1,000*TWh/yr* of electricity at a value of about US$100B/year, along with the approximately 200 million tons of carbon emissions created during the generation of that electricity. Moreover, more than 125*GW* of electricity generating capacity would be freed for other uses or would not need to be created, a savings of over US$50B of construction cost.

Bringing about such revolutionary improvements in performance will require a concerted national effort, of the order $0.5B over ten years, tackling a broad set of issues in semiconductor lighting technology. The effort would also require harnessing the most advanced high-technology companies, the best national laboratory resources, and the most creative university researchers in this area.

Fire

Candles and Lamps

Bulbs and Tubes


Semiconductors

[1] This white paper was first presented publicly at the 1999 Optoelectronics Industry Development Association (OIDA) forum in Washington DC on October 6, 1999.

[2] Revision B:03/30/1999

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Roland Haitz: Behind Every Great Person…

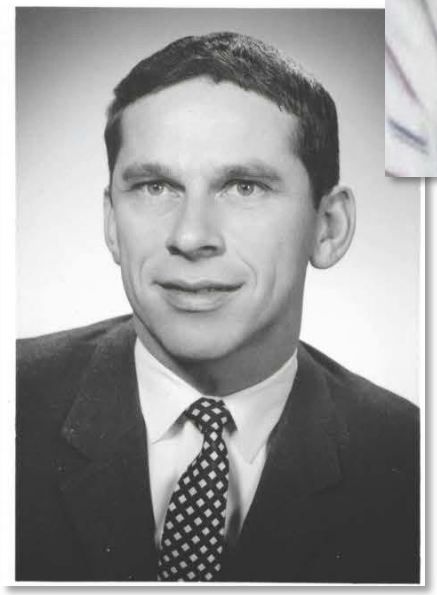

Photo: Paolo Vescia