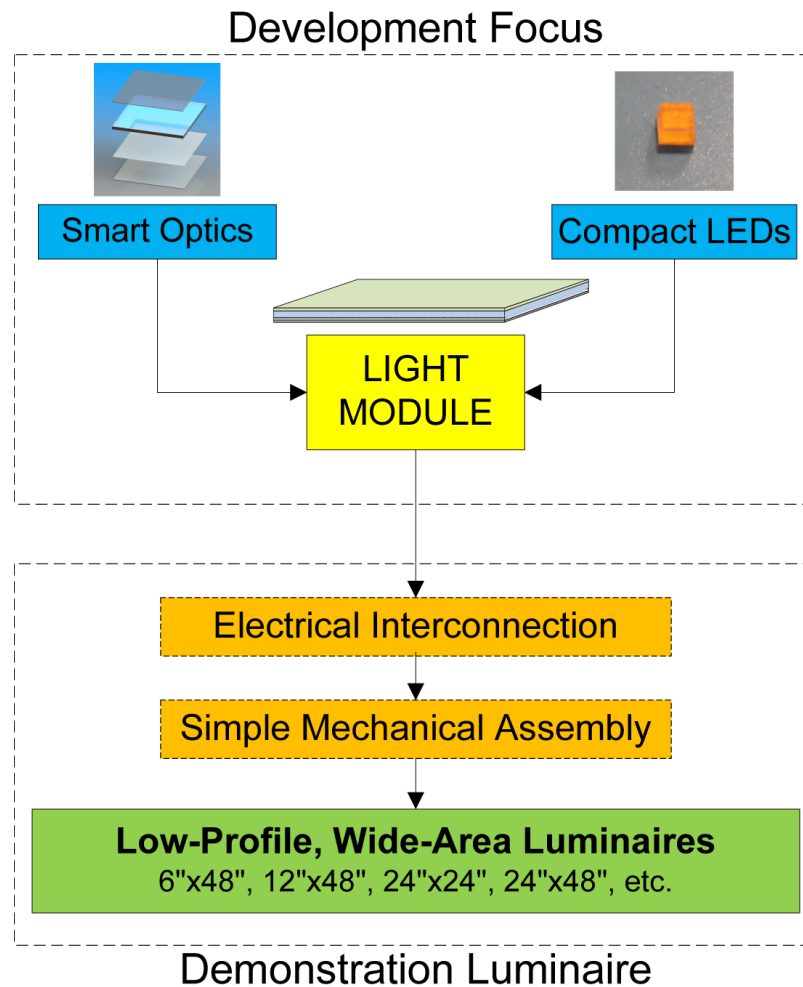


# Scalable Light Module for Low-Cost, High Efficiency LED Luminaires

2015 Building Technologies Office Peer Review



Award #DE-EE0006264

# Project Summary

## Timeline:

Start date: 8/1/13

Planned end date: 7/31/15

## Key Milestones:

1. LED efficacy of >150 LPW at 25°C, 35 A/cm<sup>2</sup>, 3000K CCT, >90CRI [Met by 7/31/14 due date]
2. Identify two or more viable candidate manufacturing processes [Met by 7/31/14 due date]
3. Achieve net Light Module optical efficiency of > 90% [Due 5/15, met ahead of time]

## Budget:

Total Federal funds to date: \$1.95MM

Total future Federal funds: \$305K

CREE Cost Share: **50%**

## Target Market/Audience:

Target Market: high-efficacy, low-cost general illumination with a focus on broad-area luminaires

## Key Partners:

None external to CREE

## Project Goal:

Develop a scalable, versatile **Light Module** architecture which enables high luminaire optical and thermal efficiency. This platform will reduce LED count, result in fewer mechanical piece parts, and simplify integration and assembly. The result is **lower cost per lumen** delivered.

# Purpose and Objectives

**Problem Statement:** despite recent reductions in SSL normalized price (\$/klm), further progress is needed to encourage adoption of this high-efficacy technology.

**Target Market and Audience:** high-efficacy, low-cost general illumination with a focus on broad-area luminaires. For example, linear fluorescents had **2.4B** units installed in 2012, and efficacy values from 50-85 lm/W.

**Impact of Project:** a low-cost, high-efficiency optical architecture applicable to numerous high-efficacy, broad-area LED luminaire form factors

- *By end of Project:*

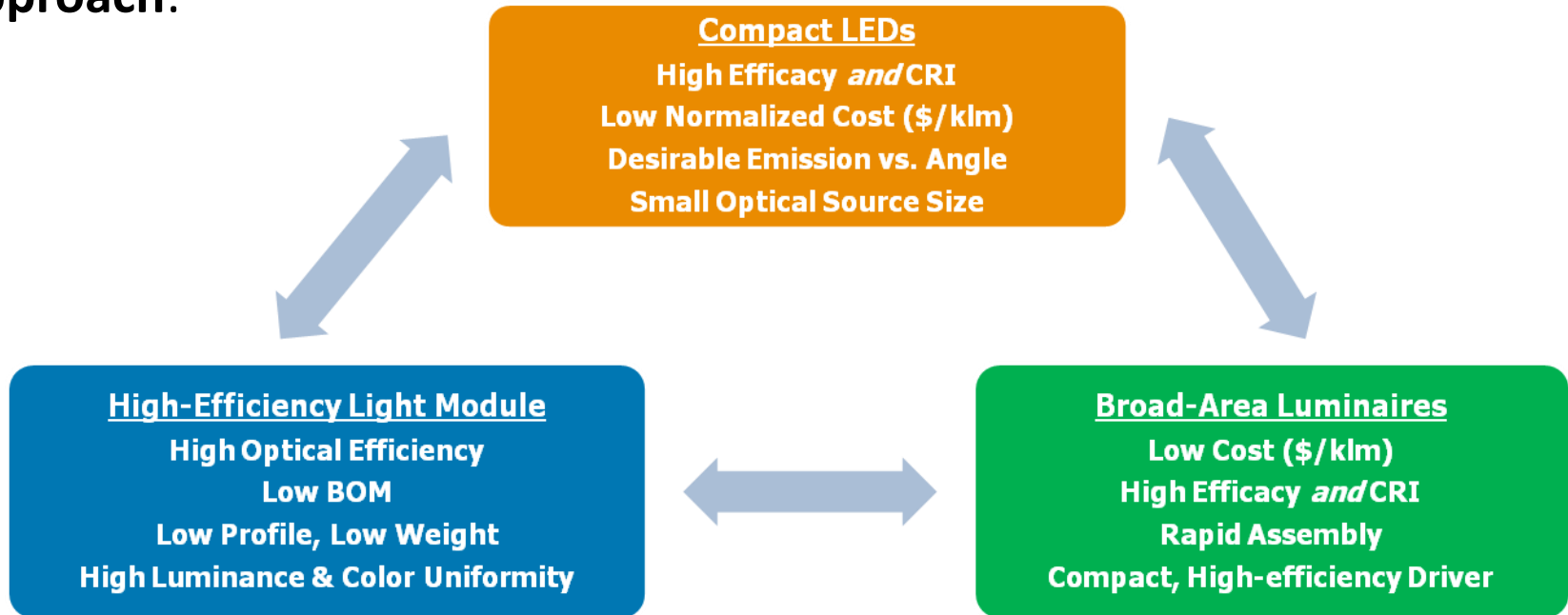
**Demonstration luminaire** with broad area (~24"x48"x0.5"), warm-white (3000K) and high color quality (> 90 CRI) light output at **>116 lm/W**, and an estimated end-user price of **<\$30/klm**

- *1-3 Years after project:*

**Proliferation** into other retrofit/replacement fixtures, as well as development of **novel form factors** enabled by this cost-effective, lightweight architecture

# Approach

## Approach:

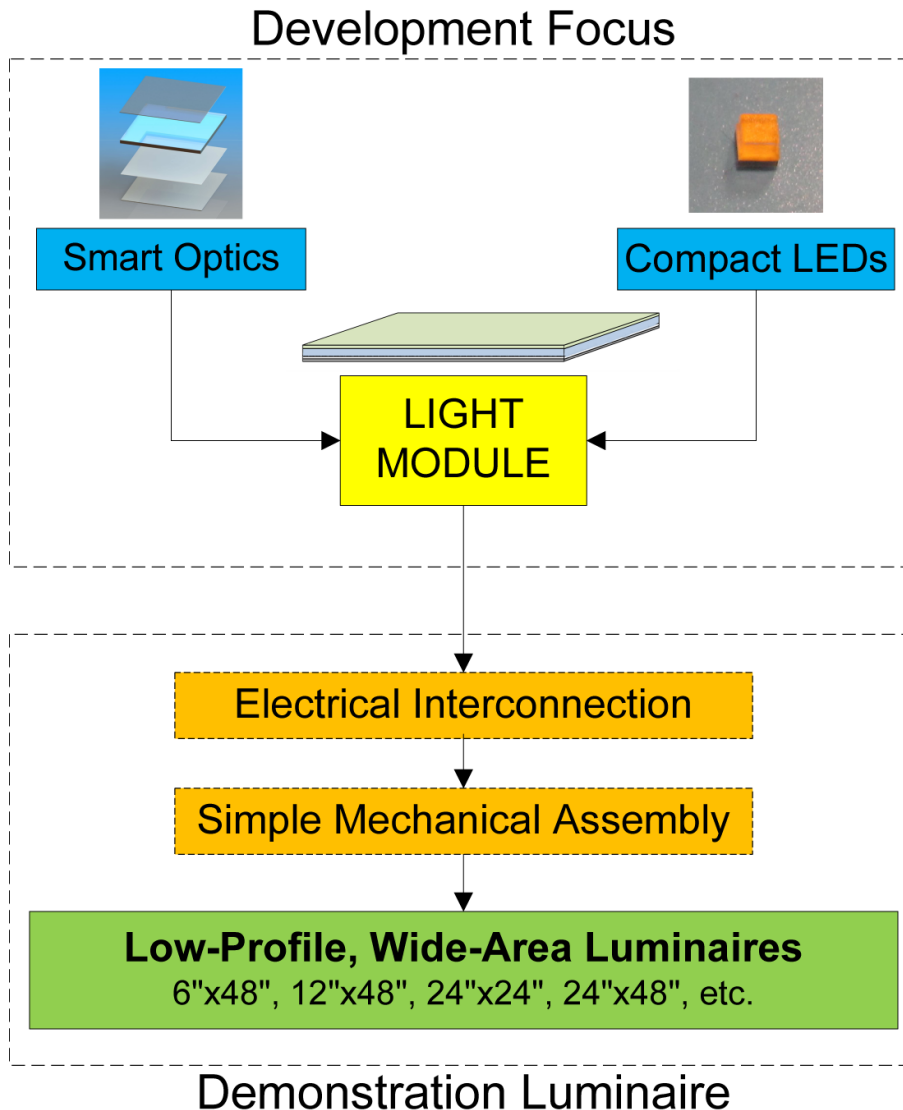


This new Light Module architecture will simultaneously enable:

- High optical, thermal efficiency
- Reduced LED count
- Fewer mechanical piece parts
- Simplified integration and assembly

Lowered \$/klm

# Approach (cont.)

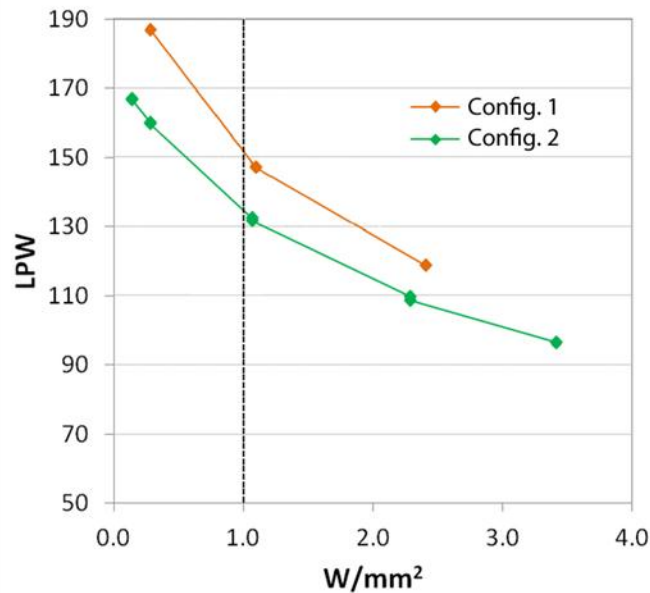
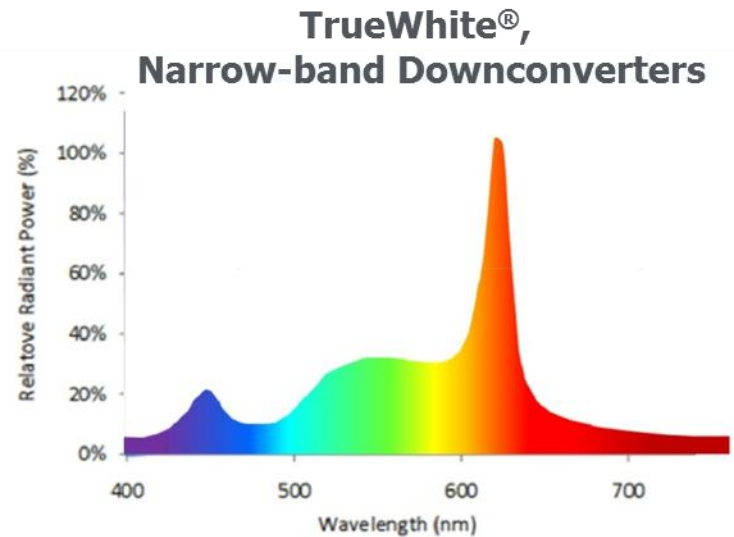
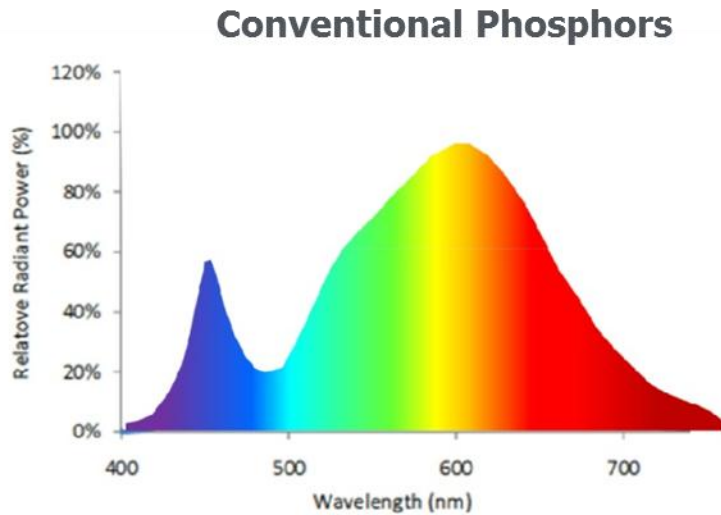


## CHALLENGES

- Compact, high-efficacy *and* high-CRI LED
- LED intensity, color vs. emission angle
- Light spreading, extraction, diffusion
- Achieving > 90% net optical efficiency
- Very low (< 0.5") overall thickness
- Manufacturable fabrication processes
- Low bill of materials, assembly costs
- Low-profile electrical interconnections
- Highly compact > 90% efficient driver
- Minimized handling & number of steps
- Simple, rapid assembly
- Mechanical stability with minimal BOM

# Progress and Accomplishments

LEDs: higher efficacy *and* color quality through spectral engineering



✓ Milestone met: >150 LPW at 25°C, 35 A/cm<sup>2</sup>  
(= 1 W/mm<sup>2</sup>), ~3000K, >80CRI

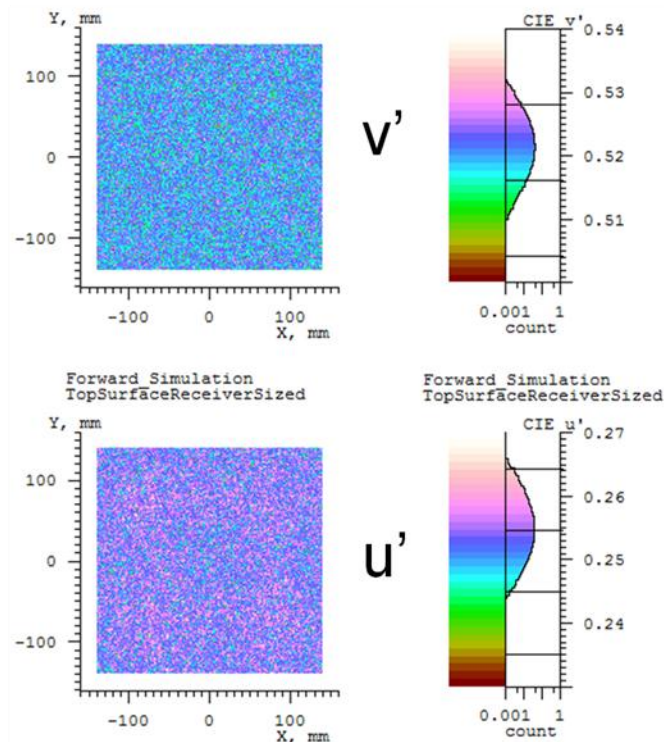
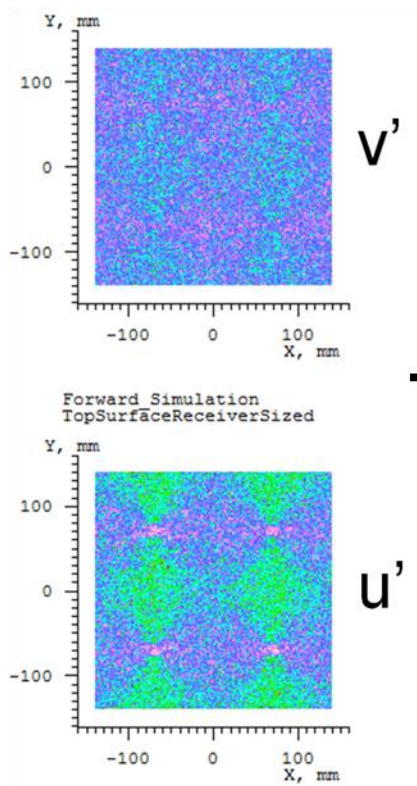
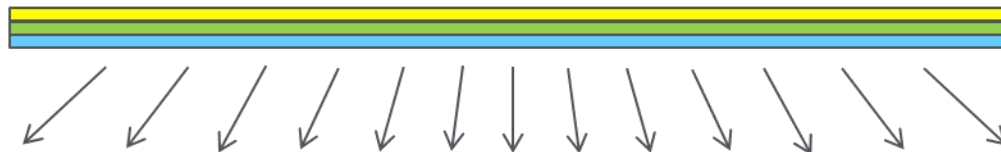
# Progress and Accomplishments (cont.)

Light Module: an optical “repeat unit” that optimally couples and extracts light

Point source



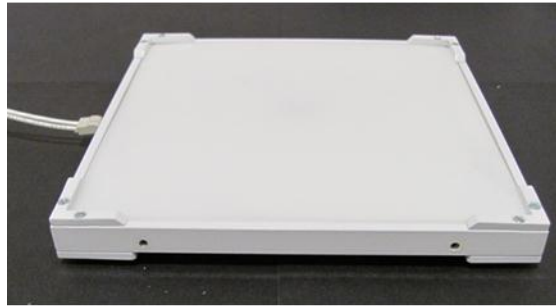
Area Source



✓ Milestone met:  $< 0.005$   $u',v'$  color point variation over the Light Module surface.

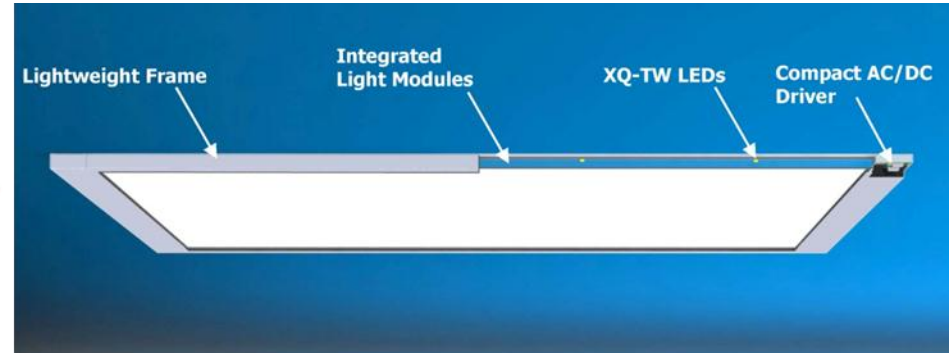
# Progress and Accomplishments (cont.)

Light Module prototypes: verify modeled optical efficiency



6x6" prototype

→  
*Scalable  
fabrication  
methods*



End-of-program 24x48" demonstration

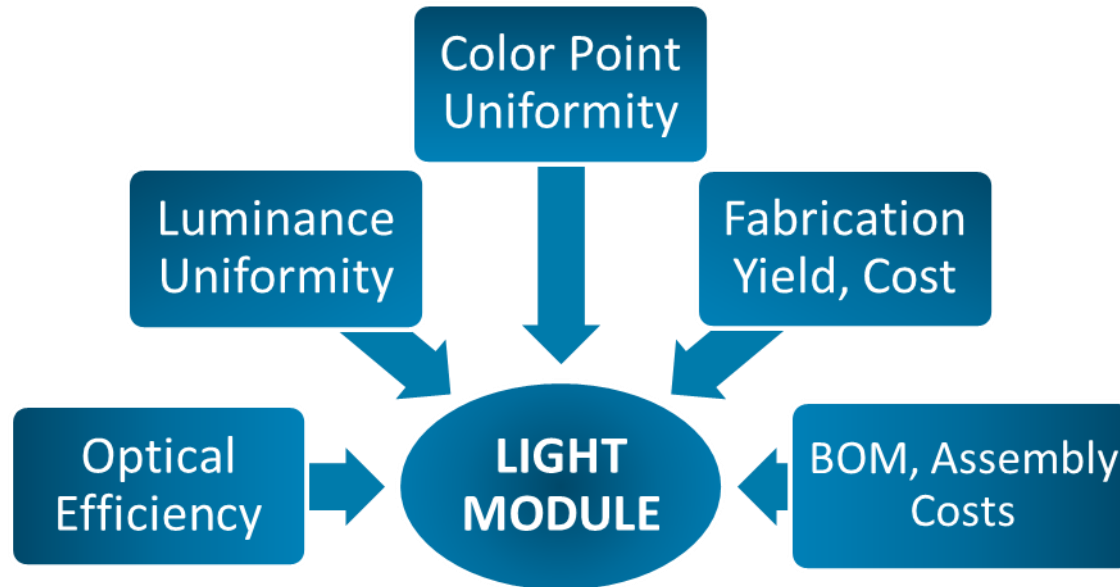
| Description  |                  | LumFlux<br>lm | Relative<br>% | u'     | v'     | CCT<br>K | CRI |
|--------------|------------------|---------------|---------------|--------|--------|----------|-----|
| No Waveguide | LED only         | 105.6         | 100%          | 0.2570 | 0.5268 | 2820     | 80  |
| Waveguide    | Without diffuser | 102.5         | 97.0%         | 0.2560 | 0.5267 | 2843     | 80  |
|              | With diffuser    | 99.3          | 94.1%         | 0.2562 | 0.5270 | 2837     | 80  |

✓ Milestone met: >90% optical efficiency from LED to ambient



# Project Integration and Collaboration

**Project Integration:** CREE SBTC personnel are working closely with CREE R&D and product development groups at all stages of project to ensure viability for commercialization



**Partners, Subcontractors, and Collaborators:** no external partners, but collaborative groups within Cree's R&D and product development teams

**Communications:** project results have been presented at recent DOE SSL Manufacturing and R&D Workshops

# Next Steps and Future Plans

## Next Steps and Future Plans:

- Refine Light Module optical design and fabrication techniques with focus on co-optimizing **uniformity, yield, and cost**
- Assemble and test a **demonstration luminaire** to demonstrate benefits of this new platform
- Continue to work closely with CREE product development groups on transition to **product commercialization**
- **Technology proliferation**: identify new form factors and applications enabled by **lowered \$/klm** offered by this platform

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# REFERENCE SLIDES

# Project Budget

**Project Budget:** \$4.7MM total over two years, with \$2.35MM Federal Share

**Variiances:** none of note.

**Cost to Date:** \$1.95MM in Federal Share to date\*, or 83% of total allocated.

**Additional Funding:** 50% Cree Cost Share (\$2.35MM)

| Budget History             |              |                                 |            |
|----------------------------|--------------|---------------------------------|------------|
| 8/1/13 – 9/30/14<br>(past) |              | 10/1/14 – 2/28/15*<br>(current) |            |
| DOE                        | Cost-share   | DOE                             | Cost-share |
| \$ 1,427,299               | \$ 1,427,299 | \$ 833,714                      | \$ 833,714 |

\* March 2015 spending has not been included in this total, since it has not yet been verified by CREE Accounting.

# Project Plan and Schedule

| Project Schedule   |   |    |    |    |        |    |    |    |        |    |    |    |
|--|---|----|----|----|--------|----|----|----|--------|----|----|----|
| Project Start: 8/1/13  | Completed Work  |    |    |    |        |    |    |    |        |    |    |    |
| Projected End: 7/31/15   | Active Task (in progress work)                        |    |    |    |        |    |    |    |        |    |    |    |
|  | ◆ Milestone/Deliverable (Originally Planned) - Missed |    |    |    |        |    |    |    |        |    |    |    |
|  | ◆ Milestone/Deliverable (Actual)                      |    |    |    |        |    |    |    |        |    |    |    |
|  | FY2013  |    |    |    | FY2014 |    |    |    | FY2015 |    |    |    |
| Task   | Q1  | Q2 | Q3 | Q4 | Q1     | Q2 | Q3 | Q4 | Q1     | Q2 | Q3 | Q4 |
| <b>Past Work</b>   |   |    |    |    |        |    |    |    |        |    |    |    |
| LED efficacy 140 lm/W at 25°C, 35 A/cm <sup>2</sup>  |   |    |    |    |        |    |    |    |        |    |    |    |
| Verify intensity and color mixing capabilities of waveguide/extractor element                    |   |    |    |    |        |    |    |    |        |    |    |    |
| LED efficacy of 150 lm/W at 25°C, 35 A/cm <sup>2</sup> , 90                                      |   |    |    |    |        |    |    |    |        |    |    |    |
| High-throughput, high-yield selective LED phosphor application process                           |   |    |    |    |        |    |    |    |        |    |    |    |
| Down-select package substrate material based on cost, thermal properties                         |   |    |    |    |        |    |    |    |        |    |    |    |
| Achieve substrate reflective coating with >90% reflectivity                                      |   |    |    |    |        |    |    |    |        |    |    |    |
| Verify reliability of prototype LED package  |   |    |    |    |        |    |    |    |        |    |    |    |
| Design and build Light Module optics elements  |   |    |    |    |        |    |    |    |        |    |    |    |
| Model and verify intensity and color mixing capabilities of waveguide/extractor element          |   |    |    |    |        |    |    |    |        |    |    |    |
| Achieve high Light Module optical efficiency with fully optimized compact high-efficacy/high-CRI |   |    |    |    |        |    |    |    |        |    |    |    |
| Develop manufacturing processes for optimized Light Module subsystems                            |   |    |    |    |        |    |    |    |        |    |    |    |
| Define critical feature dimensions and tolerances  |   |    |    |    |        |    |    |    |        |    |    |    |
| Develop low-cost electrical interconnection scheme for low-profile luminaires                    |   |    |    |    |        |    |    |    |        |    |    |    |
| Complete LED substrate die attach and thermal shock reliability testing                          |   |    |    |    |        |    |    |    |        |    |    |    |
| Develop manufacturing processes for optimized Light Module subsystems                            |   |    |    |    |        |    |    |    |        |    |    |    |
| Design and build compact and efficient electrical driver   |   |    |    |    |        |    |    |    |        |    |    |    |
| Design and build lightweight mechanical structure for low-profile, broad-area luminaires         |   |    |    |    |        |    |    |    |        |    |    |    |
| Design and fabricate 6 x 6" or larger Light Module   |   |    |    |    |        |    |    |    |        |    |    |    |

# Project Plan and Schedule (cont.)

| Project Schedule   |   |    |    |    |        |    |    |    |        |    |    |    |   |
|--|---|----|----|----|--------|----|----|----|--------|----|----|----|---|
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|  | FY2013  |    |    |    | FY2014 |    |    |    | FY2015 |    |    |    |   |
| Task   | Q1  | Q2 | Q3 | Q4 | Q1     | Q2 | Q3 | Q4 | Q1     | Q2 | Q3 | Q4 |   |
| <b>Current/Future Work</b>   |   |    |    |    |        |    |    |    |        |    |    |    |   |
| Model and verify intensity and color mixing capabilities of waveguide/extractor element  |   |    |    |    |        |    |    |    |        |    |    |    | ◆ |
| Achieve high optical efficiency with fully optimized compact high-efficacy/high-CRI LEDs |   |    |    |    |        |    |    |    |        |    |    |    | ◆ |
| Define critical feature dimensions and tolerances  |   |    |    |    |        |    |    |    |        |    |    |    | ◆ |
| Develop low-cost electrical interconnection scheme for low-profile luminaires            |   |    |    |    |        |    |    |    |        |    |    |    | ◆ |
| Design and build compact and efficient (>90%) electrical driver                          |   |    |    |    |        |    |    |    |        |    |    |    | ◆ |
| Design and build lightweight mechanical structure for low-profile, broad-area luminaires |   |    |    |    |        |    |    |    |        |    |    |    | ◆ |
| LED efficacy of 162 lm/W at 25°C, 35 A/cm <sup>2</sup> , 90 CRI, 3000K CCT               |   |    |    |    |        |    |    |    |        |    |    |    | ◆ |
| Develop high-throughput, high-yield selective LED phosphor application                   |   |    |    |    |        |    |    |    |        |    |    |    | ◆ |
| Achieve substrate reflective coating with >95% reflectivity                              |   |    |    |    |        |    |    |    |        |    |    |    | ◆ |
| Verify reliability of prototype package  |   |    |    |    |        |    |    |    |        |    |    |    | ◆ |
| Model and verify intensity and color mixing capabilities of waveguide/extractor element  |   |    |    |    |        |    |    |    |        |    |    |    | ◆ |
| Develop manufacturing processes for optimized Light Module subsystems                    |   |    |    |    |        |    |    |    |        |    |    |    | ◆ |
| Assemble and test 2' x 4' demonstration luminaire based on Light Modules                 |   |    |    |    |        |    |    |    |        |    |    |    | ◆ |
| Final estimation of assembled luminaire costs and end-user price                         |   |    |    |    |        |    |    |    |        |    |    |    | ◆ |