Project Summary

**Timeline:**
Start date: October 2011  
Planned end date: September 2014

**Key Milestones**
1. Complete at least two rounds of Accelerated Lifetime Tests (ALT); April 2013
2. Create a refined probabilistic reliability model; Sept. 2013
3. Develop test method for lumen depreciation that reduce test time by 60%; March 2014

**Key Partners:**
- Auburn University
- Cree
- SAS Institute
- PPG Industries
- LED Systems Reliability Consortium

**Budget:**
Total DOE $ to date: $1.33 MM  
Total future DOE $: $370 K

**Project Goal:**
To develop and validate a probabilistic reliability prediction tool and accelerated life testing methodologies to help lighting manufacturers and key stakeholders answer two questions:

- How to ensure the promised reliability for a rapidly changing technology platform?
- What will the usage and maintenance profiles be for a product that lasts 15 years?

**Target Market/Audience:**
Manufacturers and potential users of SSL products looking to justify higher upfront costs
**Purpose and Objectives**

**Problem Statement:** Solid-state lighting (SSL) is touted as providing the dual benefits of high energy efficiency and long lifetime. Initial energy efficiency can be readily verified by testing, but the lifetime of SSL products is generally not known and there are no standard methods of testing.

**Target Market and Audience:** The target audience for this project consists of manufacturers and users of SSL products (e.g., utilities, businesses, and taxpayers) seeking to justify higher first costs for SSL products over less efficient legacy lighting technologies. This group annually consumes ~650 TWh in electricity for illumination, and adoption of SSL technologies can reduce this consumption by ~ 30%.
Impact of Project

This project will provide the target audience with methods to assess the expected lifetime of SSL products

- Increased consumer/end user confidence in energy saving SSL technologies
- Increased market pull for energy efficient lighting
- Potential impact could be 100s MWh per year by 2030

Outputs

- Reliability models and software
- Improved ALT methods
- Information and resources for target market and audience

Approach

System-level approach consisting of both **accelerated life tests (ALT)** and **modeling** of both entire luminaires and key system components such as LEDs, drivers, and optical elements.

Background Literature

Testing

Validation Modeling

6” downlights have been chosen as representative luminaires because they combine several desirable attributes:

- Low cost
- Readily available and widely used
- Multi-generational products
- Incorporate many design features
  - HBLEDs, mid power & hybrid LEDs
  - Remote phosphor & proximate phosphor
Key Issues

- Debate over the intrinsic lifetime of LEDs used in SSL devices
- Other luminaire components (e.g. capacitors) may limit product lifetime
- Accelerating failure modes in SSL products in a meaningful manner is difficult
  - Avoid the “fried egg” syndrome
- Usage environments and product expectations differ greatly between products (e.g. disposable vs. “appliance” luminaires and lamps)
- Public sources of data on SSL luminaire reliability are not available

What is Life?

SSL luminaires do not always fail in a “lights out” fashion as with other lighting sources

Possible SSL failures include:
- **Catastrophic** – abrupt failure
- **Lumen maintenance** – lighting levels reduced below a lower limit
- **Color shift** – Change in color of light
Distinctive Characteristics:

- **System Testing**: Use of 6” downlights and 60 W equivalent lamps for evaluation and root cause analysis.
- **Component Testing**: Separate testing & root cause analysis of key components such as LEDs, phosphors, lenses, etc. provide additional insights.
- **Representative Sampling**: Most tested products are purchased independently, although some manufacturer supplied parts are tested.
- **Virtual Testing**: Use of simulation tools to investigate impacts of degradation of optical or thermal components.
- **Industry Partnerships**: Alliance with LED Systems Reliability Consortium (LSRC) provides access to feedback from the lighting industry.
Lessons Learned

• Creating a universal ALT for SSL luminaires is complicated by different acceleration factors for different luminaire components
  – RTI began testing components separately (e.g. lens, reflector, LED) and building models from these data
• Importance of color stability to the lighting industry has increased and represents a potential impediment to some market opportunities.
• In some cases, power consumption and power factor may change before end of life.
Accomplishments

Market Impact:

• Initial work on the “Hammer Test” was published on the DOE website Dec. 2013 and has been downloaded more than 300 times

• Impact of the project is being accelerated by a close alliance with the LED Systems Reliability Consortium (LSRC) to provide direct access to the US lighting manufacturers industry

• RTI is interfacing directly with relevant standards organizations interested in luminaire reliability

Awards/Recognition:

2012 DOE R&D Achievement Award
Accomplishments

- System-level model for lumen maintenance of SSL luminaires
  - Takes into account changes in optical components, such as lenses and reflectors
  - Paradigm shift from LED-only calculations

- Weibull models for representative luminaires and 60 Watt equivalent lamps in ALTs
  - Demonstrates the wide range of reliability for current products and provides source of information for the industry and stakeholders
Accomplishments

• Performed extensive ALT studies
  – 130 full luminaires
  – 120 bare LEDs
  – 30 60 W equivalent lamps

• Completed all assigned milestones to date (one milestone was moved to Year 3 on agreement with DOE)
• On track to meet future milestones
**Project Integration and Collaboration**

**Project Integration:** Project activities are closely coordinated with an advisory board consisting of key collaborators and the broader lighting industry through the LSRC.

**Partners, Subcontractors, and Collaborators:**

DOE’s LED Systems Reliability Consortium

Auburn University

SAS Institute

Cree Lighting

PPG Industries

**Communications:** This work has been presented at 5 DOE-sponsored workshops, 7 technical conferences, and in 9 technical publications.
Next Steps and Future Plans

• Validate current models for lumen maintenance and driver reliability through additional testing
• Complete extensive failure analysis of catastrophic driver failures and assignment to electrical function of driver circuit
• Complete the study on the impact of particle ingress and dirt depreciation on luminaire performance
• Potentially expand activities to look at color shift
  • LED-level impacts
  • Phosphor impacts
  • Optical systems impacts
• Potentially expand activities to look at Power Management System changes which impact power consumption, electrical efficiency, and power factor
Acknowledgements

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REFERENCE SLIDES
**Project Budget**: DOE total $1.7 M for FY2012 – FY2014  
**Variances**: None  
**Cost to Date**: on schedule at $1.29 to date  
**Additional Funding**: No other funding sources

## Budget History

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Project Plan and Schedule

- Initiation date: Oct. 2011, Planned completion date: Sept. 2014
- Milestones through project include: development of accelerated lifetime tests (ALT) procedures and development of a refined probabilistic reliability model
- Milestone 6 was postponed in order to continue focusing on ALT work