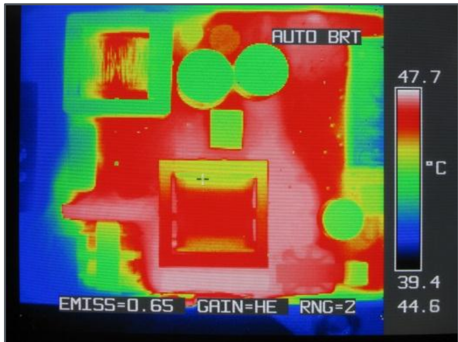
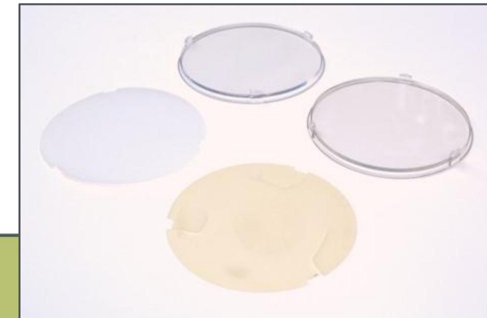
Solid State Lighting Reliability

2014 Building Technologies Office Peer Review





SSL Reliability Management
(luminaire design, components, final assembly and test)

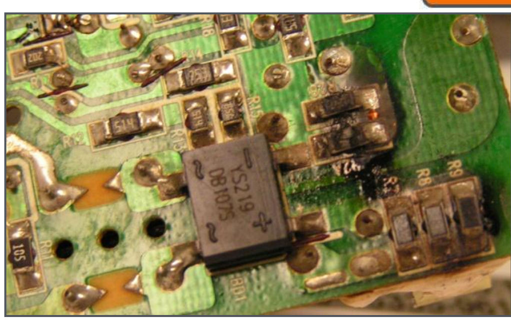
Thermal Management

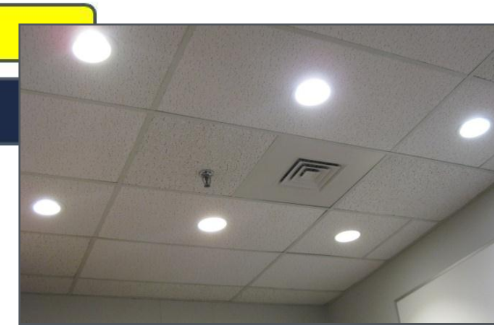
Power → Driver & Control Electronics → LED Light Engine → Optics → Reflector → Diffuser → Light

Power Mgmt

Optical Management

Luminaire Assembly Integrity





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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

Target Market/Audience:

Manufacturers and potential users of SSL products looking to justify higher upfront costs

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?

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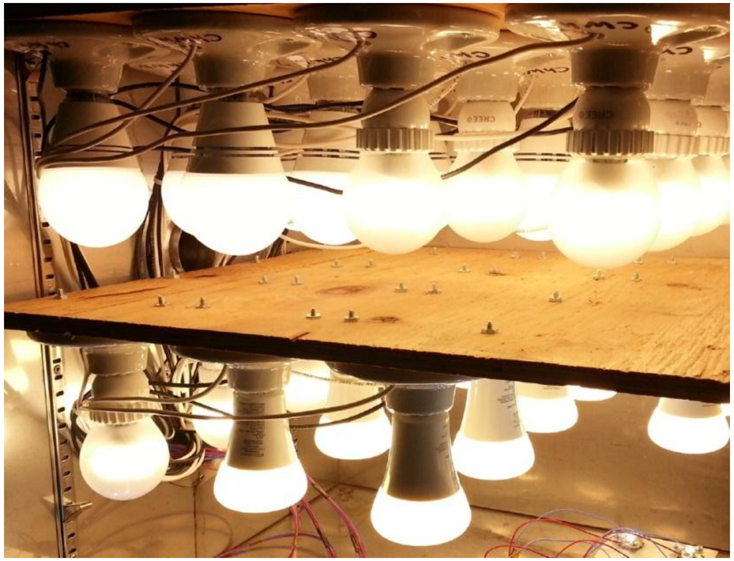
Purpose and Objectives

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%.



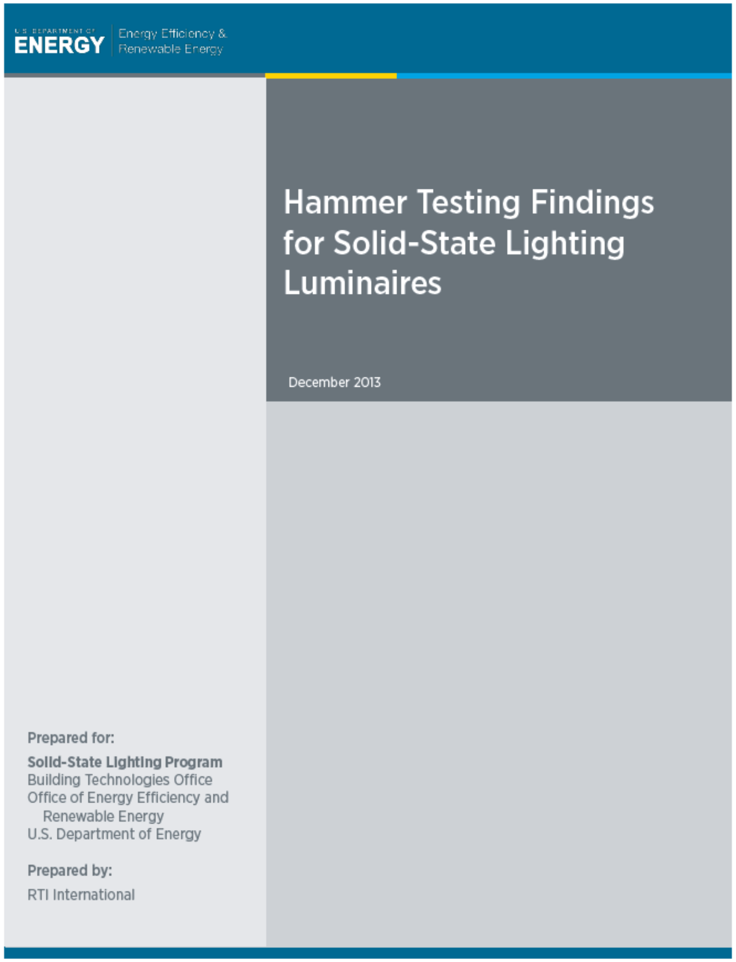
Impact of Project

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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Hammer Testing Findings for Solid-State Lighting Luminaires

December 2013

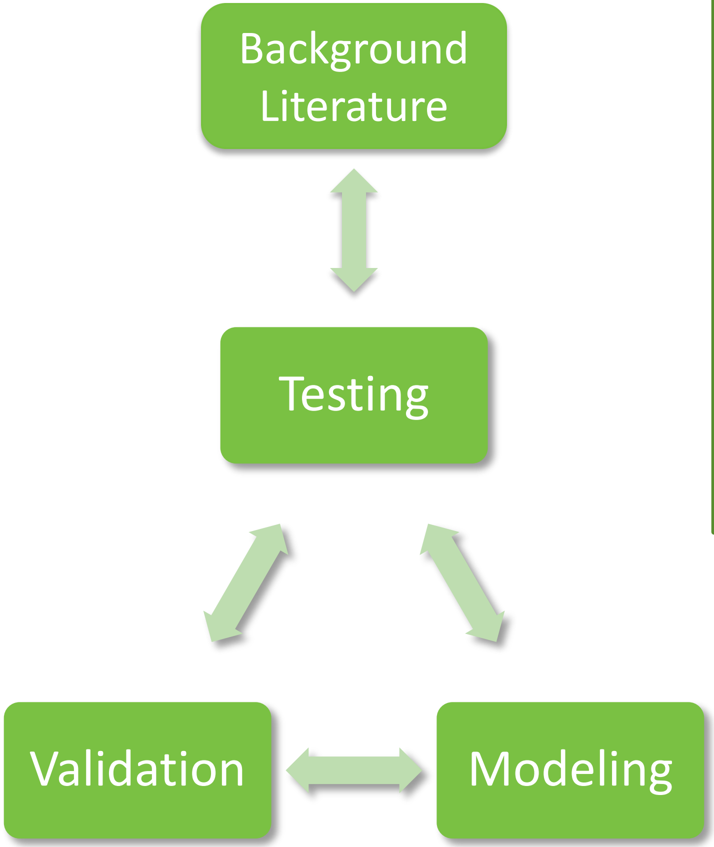
Prepared for:
Solid-State Lighting Program
Building Technologies Office
Office of Energy Efficiency and Renewable Energy
U.S. Department of Energy

Prepared by:
RTI International

http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/hammer-testing_Dec2013.pdf

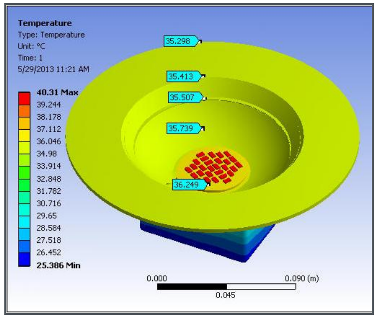
Approach

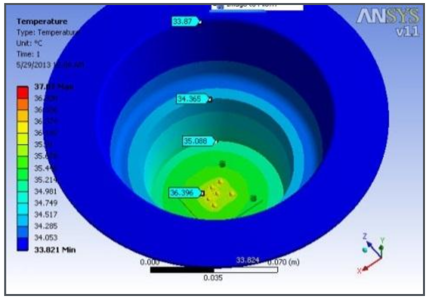
System-level approach consisting of both **accelerated life tests (ALT)** and **modeling** of both entire luminaires and key system components such as LEDs, drivers, and optical elements



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





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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

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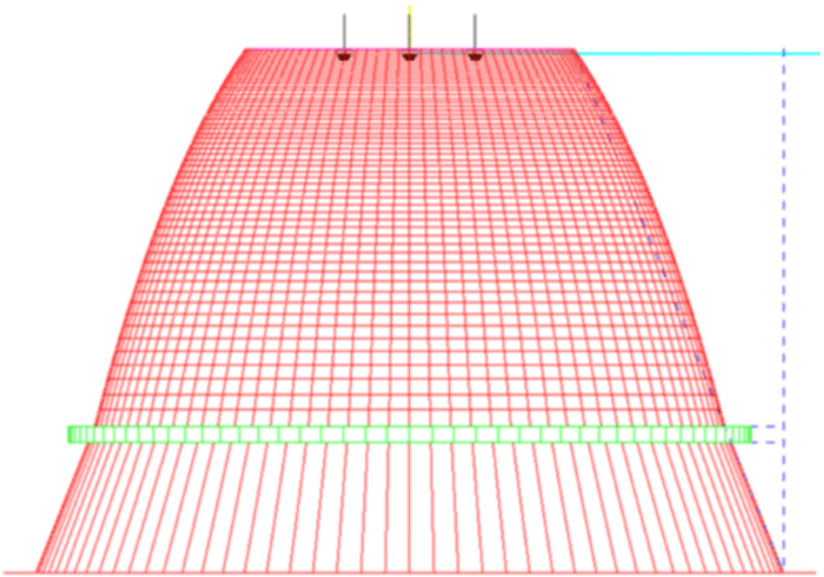
Distinctive Characteristics:

- 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



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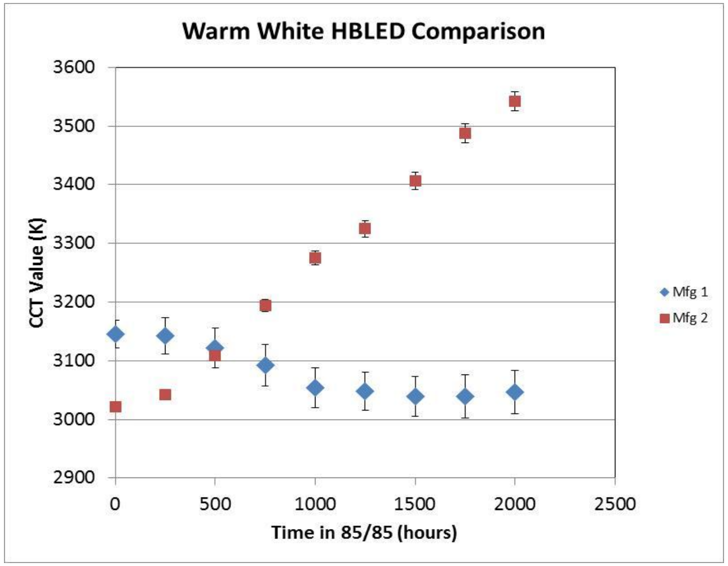
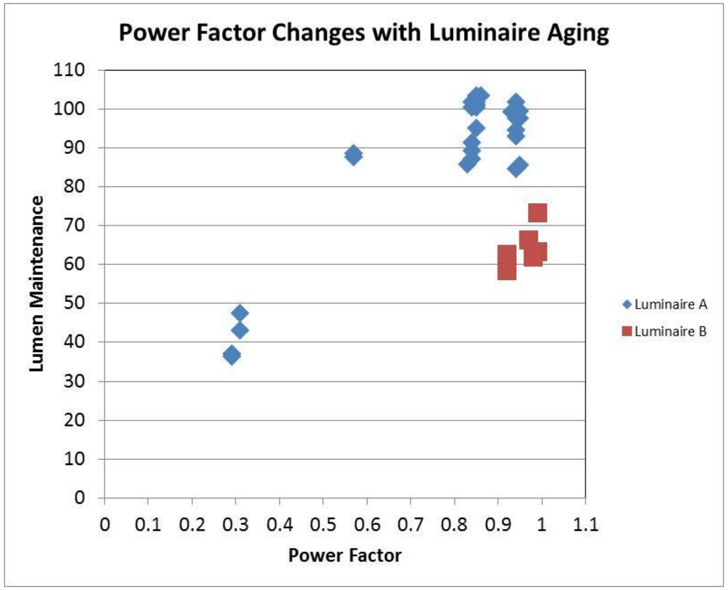
Lessons Learned

- 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.





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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

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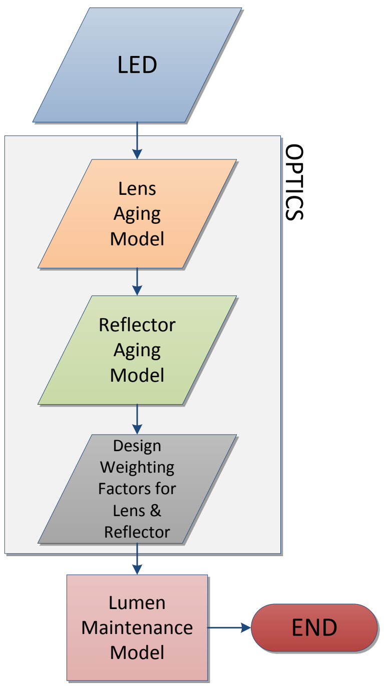
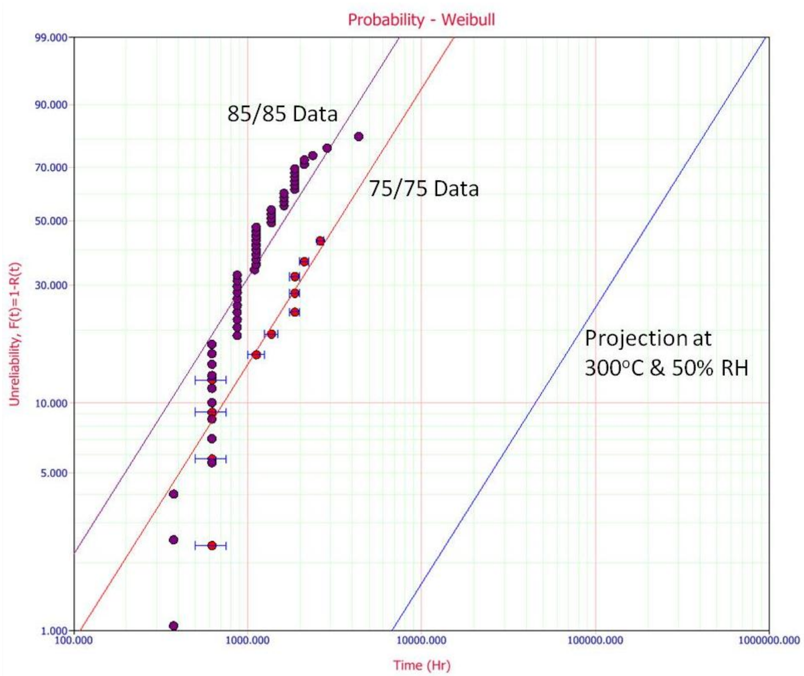
Accomplishments

- 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



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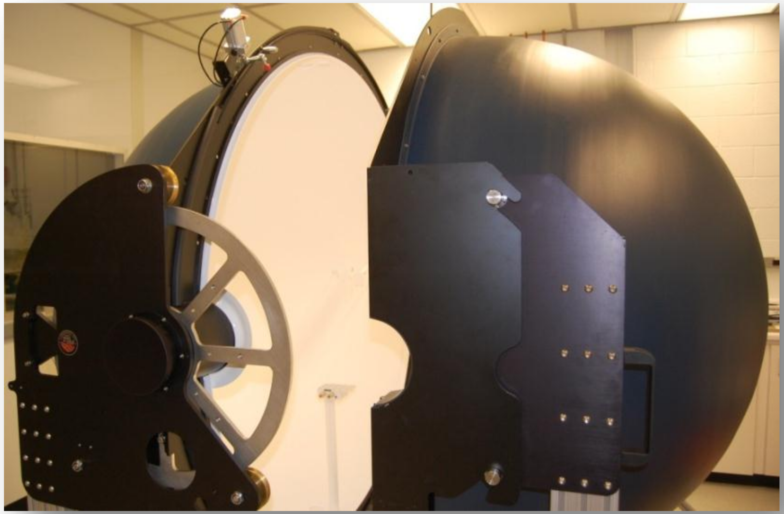
Accomplishments

- 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

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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

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					
FY2012 – FY2013 (past)		FY2014 (current)		FY2014 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$1.105 MM	$276 K	$224 K	$79 K	$594 K	$149 K

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

Project Schedule

Project Start: FY2012		Completed Work
Projected End: FY2014		Active Task (in progress work)
	◆	Milestone/Deliverable (Originally Planned) use for missed
	◆	Milestone/Deliverable (Actual) use when met on time

Task	FY2012 Q1 (Oct-Dec)	FY2012 Q2 (Jan-Mar)	FY2012 Q3 (Apr-Jun)	FY2012 Q4 (Jul-Sep)	FY2013 Q1 (Oct-Dec)	FY2013 Q2 (Jan-Mar)	FY2013 Q3 (Apr-Jun)	FY2013 Q4 (Jul-Sep)	FY2014 Q1 (Oct-Dec)	FY2014 Q2 (Jan-Mar)	FY2014 Q3 (Apr-Jun)	FY2014 Q4 (Jul-Sep)
Past Work												
Task 1: Project Management												
Task 2: Advisory Board	◆											
Task 3: Literature Search & Initial Model		◆		◆								
Task 4: Gap Analysis & Initial ALT			◆									
Task 5: SSL Luminaire Initial Benchmarking						◆						
Task 6 Probabilistic Model Development								◆				
Current/Future Work												
Task 7: Dirt Depreciation Impact								◆			◆	
Task 8: ALT Studies Round 2							◆			◆		
Task 9: Probabilistic Model Optimization								◆				
Task 10: Probabilistic Model Verification											◆	◆