Collaborating for Success: LED Systems Reliability:

DOE SSL R&D Workshop

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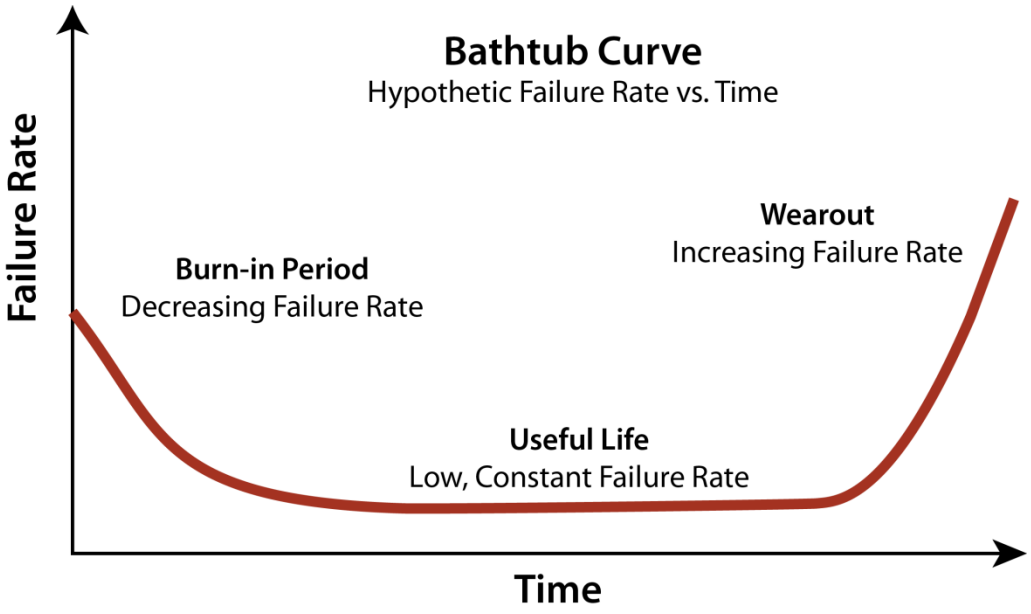
Outline

- Importance of Reliability to the Industry
- NGLIA and DOE Efforts on Reliability
- LED Systems Reliability Consortium
- Some Results to Date
- Conclusions

Luminaire Reliability: An SSL Industry-Wide Concern

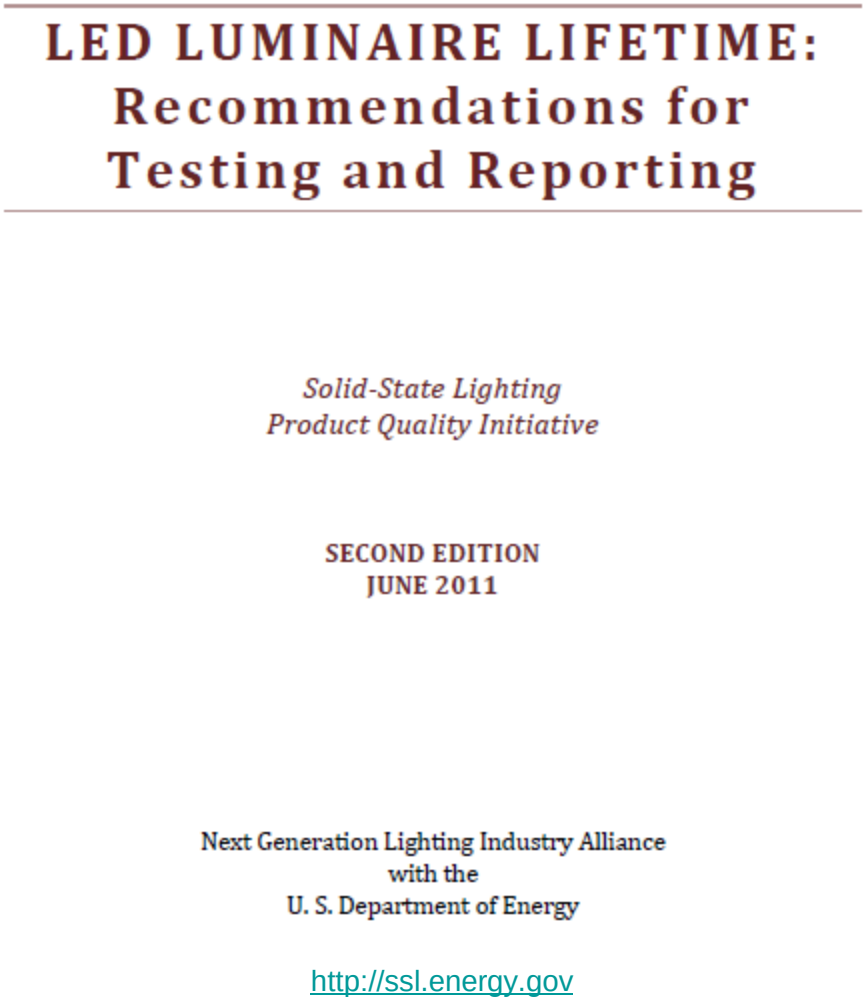
- Lessons learned from the introduction of CFLs emphasize the importance of accurately representing product performance, including lifetime.
  - Failing to meet consumer expectations can slow market penetration.
- Claims of long lifetimes in SSL systems are often based on LED lumen maintenance information alone.
  - May lead to unrealistic expectations with customers
- True reliability of whole integrated LED lighting systems are generally unknown.



A model of luminaire reliability would aid the SSL luminaire manufacturers and end users.

NGLIA and DOE Sponsored Efforts

- Provides recommendations for reporting and demonstrating luminaire product lifetime.
- Clarifies that the loss of lumen output could be for *any reason*
  - *Many failure modes can cause light loss, not just LEDs*
- Emphasizes that LM-80 source data with TM-21 projection *is not a proxy for lifetime*
- Provides options for interim specifications and for the treatment of color shift
- Issues a call for industry collaboration to "understand the issues surrounding true lifetime and reliability."


LED LUMINAIRE LIFETIME:
Recommendations for
Testing and Reporting

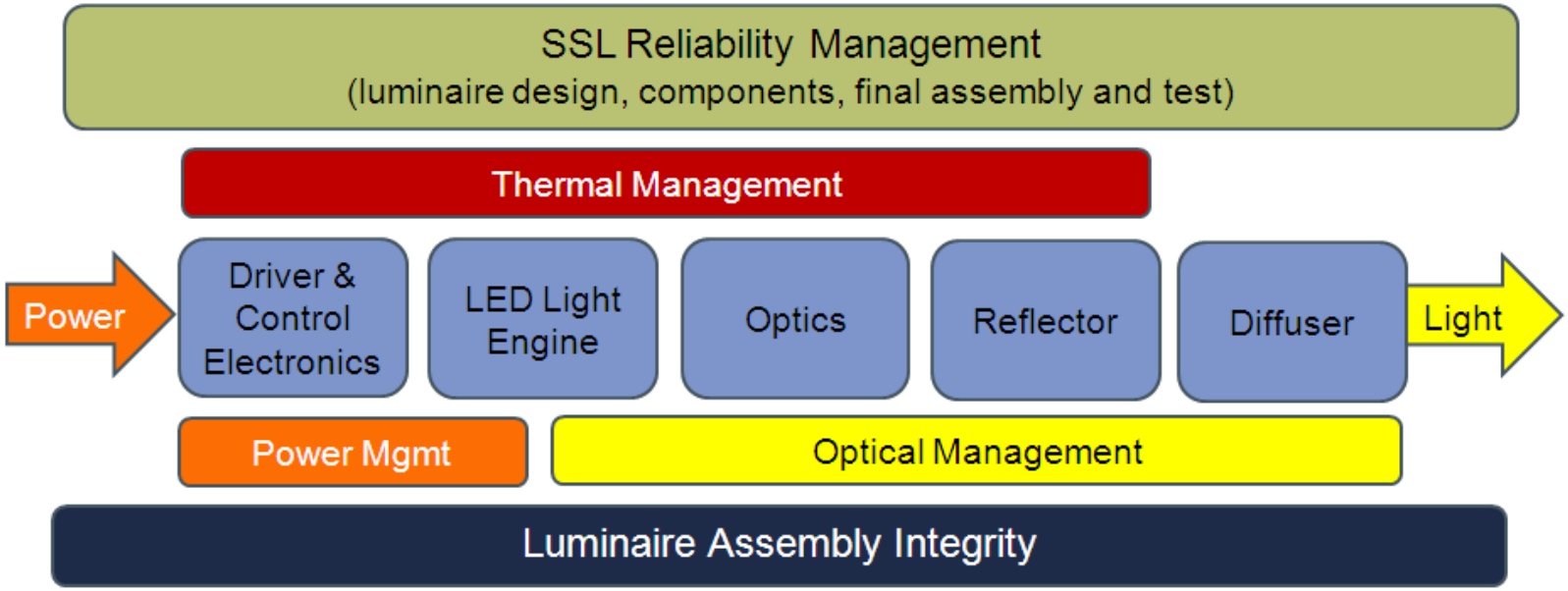
Solid-State Lighting
Product Quality Initiative

SECOND EDITION
JUNE 2011

Next Generation Lighting Industry Alliance
with the
U. S. Department of Energy

http://ssl.energy.gov

SSL Luminaire System Reliability



Source: Appalachian Lighting Systems, Inc.

FAILURE OUTCOMES

- **Catastrophic failure**—Complete failure of the device to produce light.
  - Associated mainly with power management components
- **Lumens maintenance**—Ability of a device to produce acceptable light output above a predetermined unacceptable level (e.g., L_{70}) for 50% of the population (B_{50}).
  - Associated mainly with optical management components
- **Color shift**
- **Reduced energy efficiency**

LED Systems Reliability Consortium (LSRC)

- Began work in October 2011.
- Membership includes:
  - Luminaire manufacturers
  - Research organizations
  - Universities
  - National Labs
  - DOE
- Purpose
  - Create a library (database) of reliability characteristics for individual components and subsystems for use in the model
  - Develop an accelerated test program to provide the inputs for that model
  - Develop a modeling tool to use to predict lifetime of luminaires, light engines, and lamps

The modeling tools and testing program are intended to be made freely accessible and widely useable at the end of the consortium's efforts.

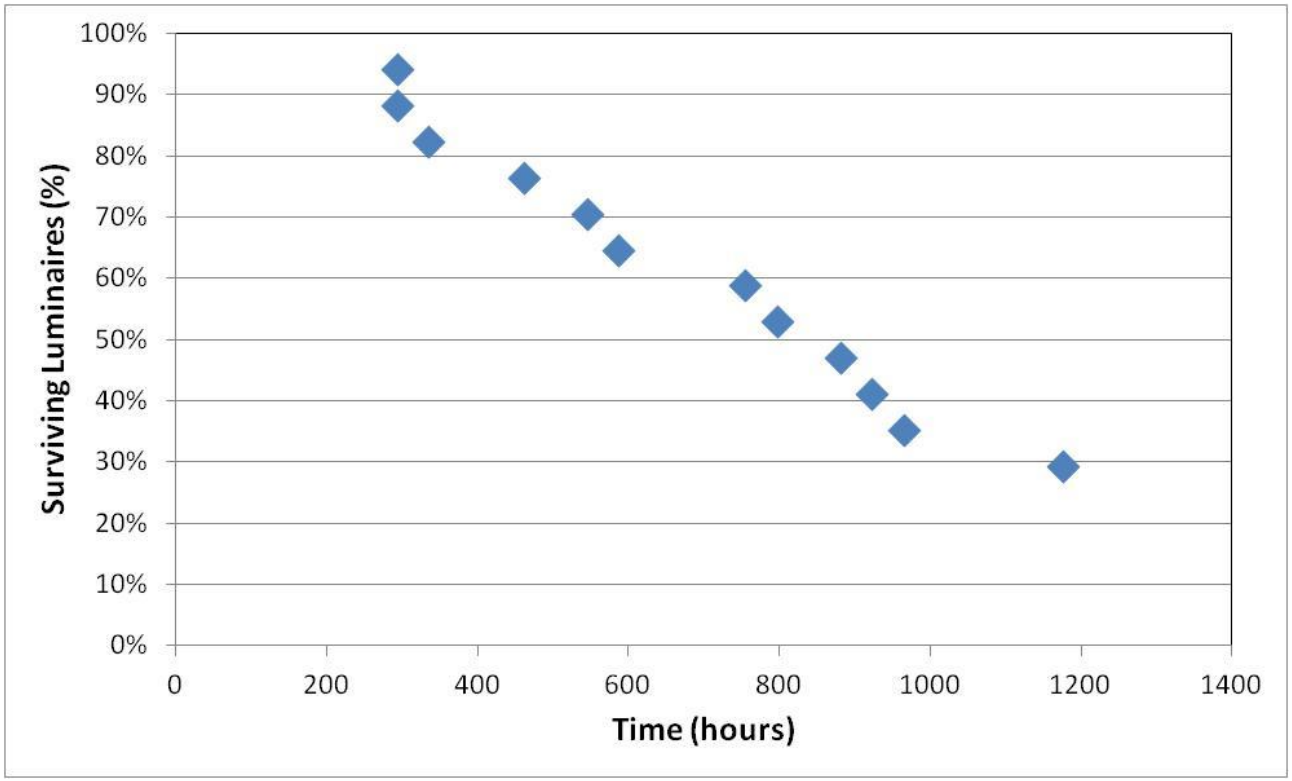
First Steps

- Identify specific initial test examples and solicit samples from members.
- Develop "test to failure" protocol for these samples, and begin
  - Hammer Test protocol developed in collaboration between Univ. of Maryland, Lamar University, and RTI
  - Test samples provided by five luminaire manufacturers
    - 6” downlights and one 2’x2’ troffer
- Companies may also submit their own data on these or related examples.
- Share and discuss initial data and results of testing, and refine protocols

Hammer Test

- The low field failure rate for LED luminaires suggests that overstress testing will be required to induce failures in a reasonable period of time.
- LSRC setup a team to develop a “Hammer Test” to accelerate failures
  - Abhijit Dasgupta – University of Maryland
  - Xuejun Fan – Lamar University
  - Lynn Davis – RTI International
- Hammer Test protocol consists of
  - 6 hours of 85°C and 85% RH
  - 15 hours of temperature shock (-50°C to 125°C)
  - 6 hours of 85°C and 85% RH
  - 15 hours of 125°C
  - Electrical power cycled during testing
  - Performance checked after every test loop
- Five luminaire manufacturers agreed to provide luminaires for testing

Hammer Test Results



- LED luminaires are robust even under the harsh conditions of hammer test.
- All failures were in the driver circuit. Common failure modes:
  - Components
  - Circuit boards including interconnects and solders

Hammer Test (cont.): LEDs and Lumen Depreciation

- A total of 611 LEDs have been through Hammer Test.
- Total exposure time of these LED is 972,000 hours.
- Only four LEDs failed during hammer test
  - One solder fatigue. LED feel off of board.
  - Two failed apparently due to board level issue, possibly corrosion
  - One unknown
- Additional public data (e.g., LM-80 and L-Prize lamps) have demonstrated that the failure rates of LEDs is low, especially when proper thermal management practices are applied.

Lumen Maintenance in Hammer Test

- Lumen maintenance for luminaires in Hammer Test was good, despite the extreme conditions.

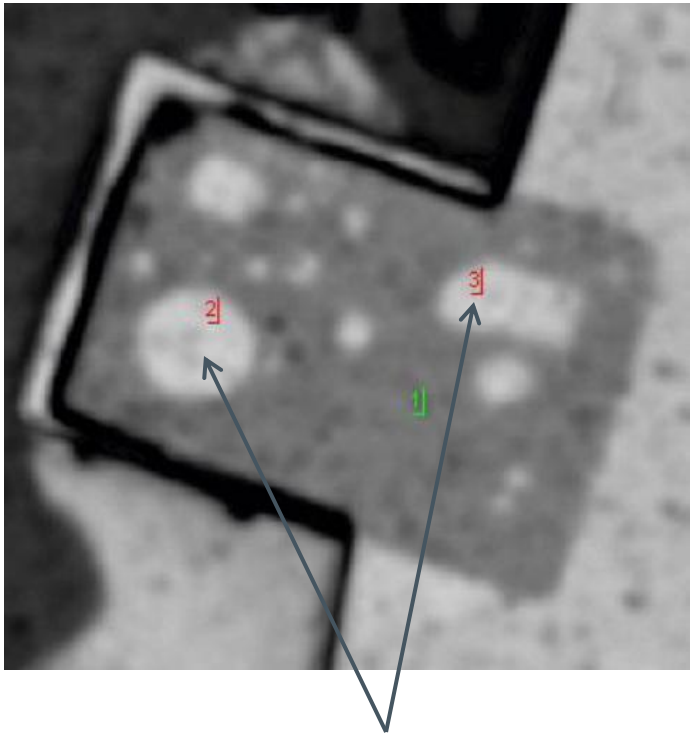
- Observed lumen depreciation can be attributed to a number of system-level factors including:
  - LED depreciation
  - Aging of lenses (e.g., yellowing and increase opacity)
  - Aging of other optical surfaces (reflectors, paints, etc.)
  - Aging of solder masks (yellow and delamination)

- Lumen depreciation in Hammer Test tracks results in 85°C and RH% RH

Luminaire No.	No. of Hammer Test Loops	Lumen Maintenance at End of Test	Predicted Lumen Maintenance Based on 85/85
6	35	88.9%	89%
7	29	86.3%	
11	32	84.8%	
12	11	95.1%	94%
15	23	73.4%	
16	17	91.3%	92%
17	17	92.7%	92%

Another Collaboration Example: Impact of Soldering Voiding on LEDs

- Acoustical microscopy examination of solder joints from Hammer Test samples revealed the presence of voids (< 20%) in the interior of the joint.
- Potential impact
  - Reduced heat transfer rate from LED?
  - Decreased mechanical strength of solder joint
- After discussion with the LSRC membership, John Pan (Cal Poly) provided data indicates that the effect of voiding on solder thermal performance is negligible for void volumes < 25% and weakly correlated for void volumes > 25%.



Voids in solder joint

Conclusions

- The reliability of LED luminaires should be considered from a systems perspective. The “weak link” determines reliability.

  LED luminaire reliability involves more than the LEDs

- Even under overstress conditions, LED luminaires exhibit a high level of robustness.
- There have been several collaborative efforts among industry participants to share information on this critical issue.

  Collaborative efforts continue to gain momentum

- Still an opportunity for additional voices from the industry to help “understand the issues surrounding true lifetime and reliability.”