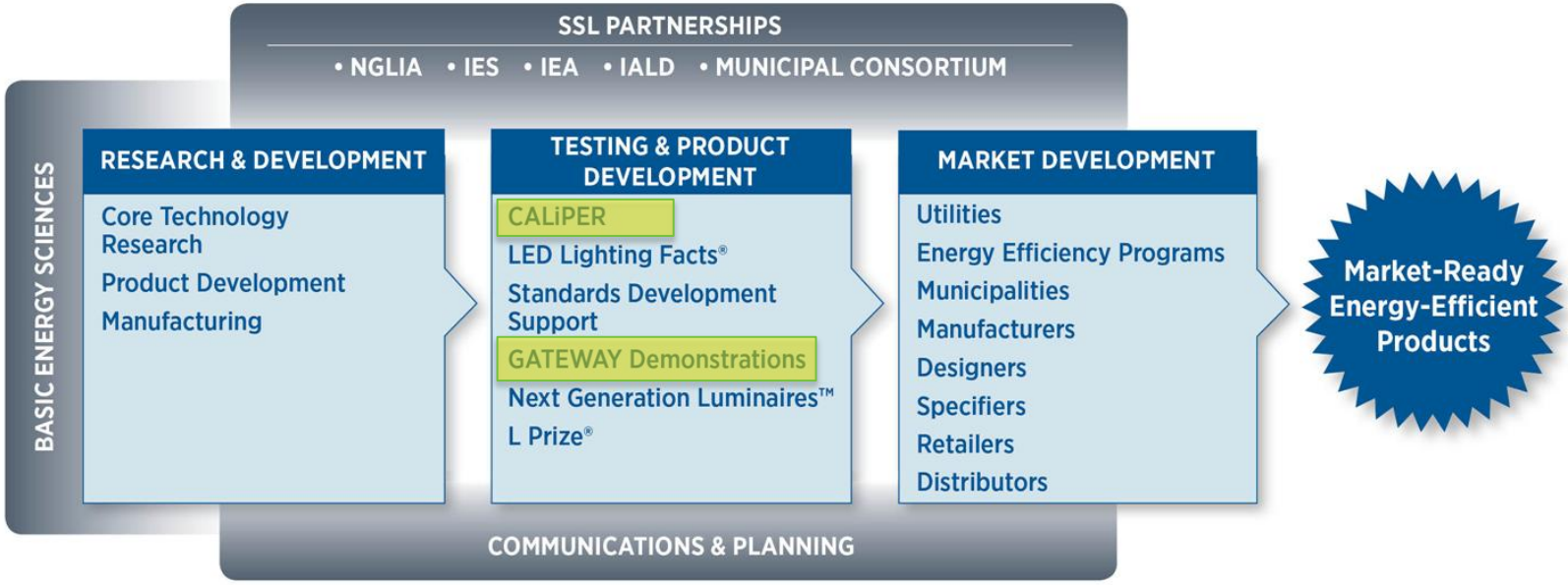
Solid State Lighting: GATEWAY & CALiPER



Solid State Lighting: GATEWAY & CALiPER

Marc Ledbetter

Pacific Northwest National Laboratory

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April 3, 2013

GATEWAY Problem Statement

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

GATEWAY includes Muni Consortium

Multi-Year Market Development Support Plan

- IDs 5 key market barriers. Most relevant to GATEWAY are:
  - Lack of information for buyers and lighting professionals
  - High transaction costs
- IDs 10 key market needs. Most relevant to GATEWAY are:
  - Well-documented case studies
  - Objective, widely available technical information from a credible source
- GATEWAY part of plan states:
  - "Though SSL is successfully penetrating some parts of the market, much unfamiliarity remains among mainstream user groups who have questions about reliability, performance, and cost effectiveness."

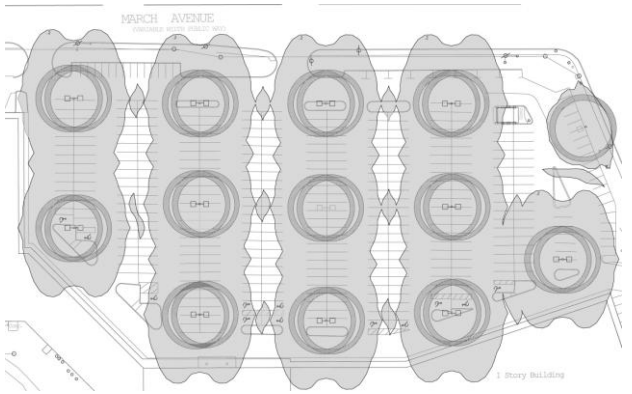
Potential Impact of GATEWAY

Real-world demonstrations provide:

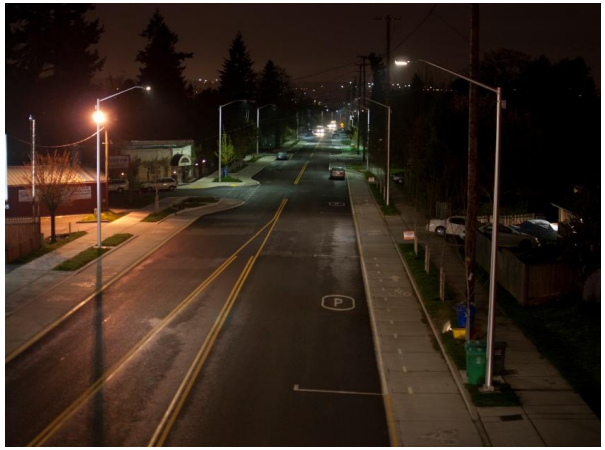
- Data to help defuse myths and hype
- Rising level of knowledge for all users
- Feedback loop for issues needing to be addressed by DOE (R&D and other market support programs) and by manufacturers for product improvements

Collaboration with Muni Consortium members provides:

- More rapid learning among members
- Better selection of products; less wasted money; more energy savings
- Early identification of issues of most importance to members, e.g., controls



TJ Maxx Parking Lot, Manchester, NH



Cully Blvd, Portland, OR

GATEWAY Focus and Approach

BTO Goals & Priorities Alignment

- BTO goal: "…*In the area of solid state lighting, the program goal is to achieve lighting technologies with double the efficiency of today's most efficient lighting sources*"
- SSL is one of the top BTO priorities

Approach to Demonstrations

- Focus on general illumination lighting applications where LEDs are competitive or are otherwise important
- ID a project and form a team (e.g., host, utility, manufacturers, etc.)
- Conduct pre-analysis to confirm opportunity, leading to go/no go decision
- Pre- and post-installation measurements and user evaluations
- Conduct analysis and widely share results
- Discuss identified product weaknesses with manufacturers and R&D team for potential product improvements

Measuring the color on five areas of two photographs in Getty Exhibit Gallery
- Getty Conservation Institute

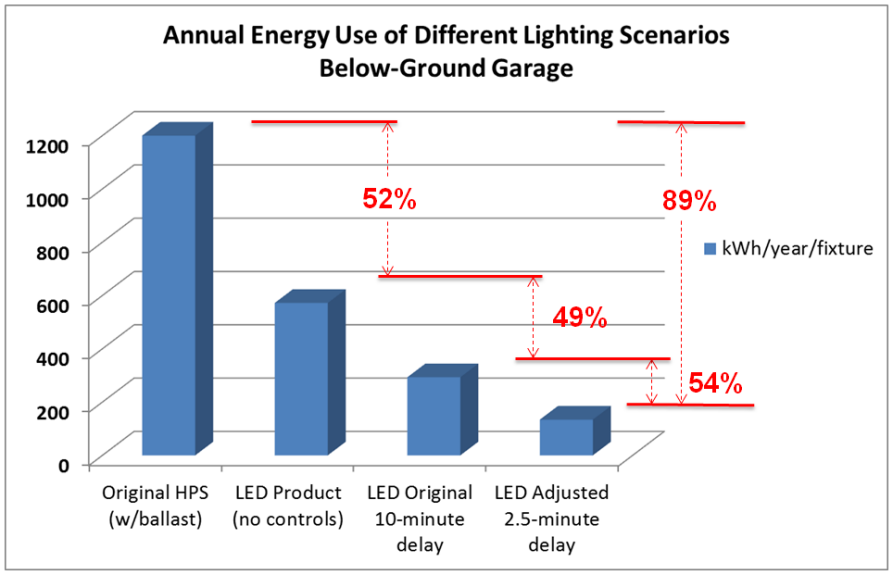
GATEWAY Approach – cont'd

Municipal Solid-State Street Lighting Consortium (MSSLC)

- ID information gaps and project needs via workshops & comm. mtgs.
- Prepare information, tools, and projects
  - Focus on priority issues, e.g., controls, side-by-side comparisons with advanced conventional sources
  - Specifications, e.g., luminaire and controls
  - Computer tools, e.g., financial analysis tools
- Share/Network/Educate
  - Regional workshops (typically ~100 attendees)
  - Webcasts (typically ~500 attendees and sometimes many more)
  - Presentations at multiple other venues
    - IES Street and Area Lighting Conference
    - Strategies in Light, LightFair International, US Conference of Mayors
    - DOE SSL Workshops
- Solve member problems, e.g., provide analyses and advice

Key GATEWAY Issues Currently Being Addressed

- Change in chromaticity for color sensitive applications
- High lumen output applications
  - E.g., roadway, high-bay, roadway tunnels applications are just becoming competitive; represent high use applications for SSL
- Outdoor lighting control systems
  - Exterior lighting, in particular, has largely not benefited from controls due to incompatibility with previous technologies



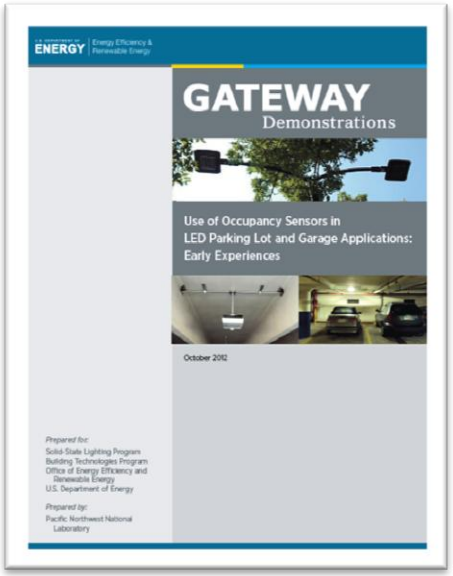
Delay refers to the time setting after which an occupancy sensor reverts to low state

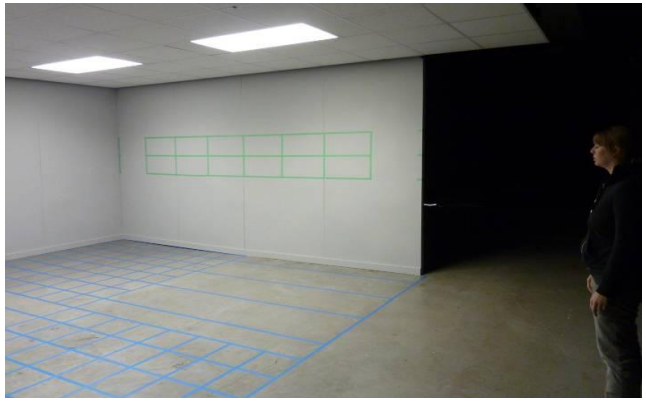
Department of Labor Headquarters Parking Garage, Washington, DC

Distinctive GATEWAY Characteristics

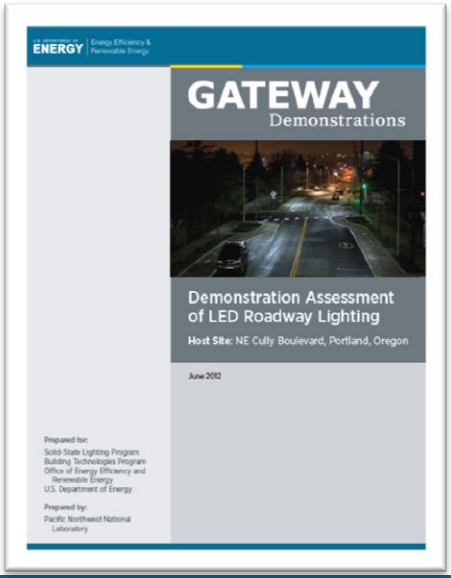
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

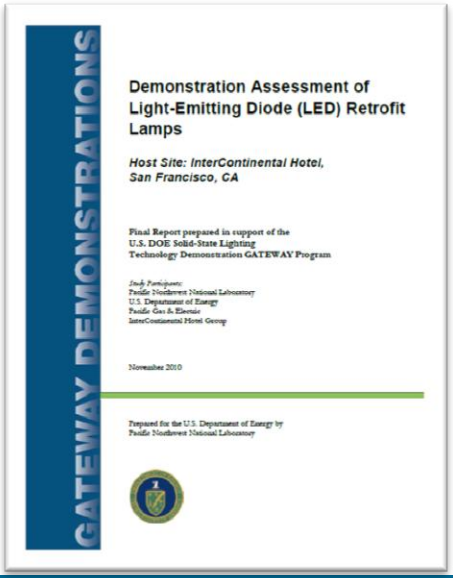
- Objective, third-party analysis and reporting from recognized authority
- Thorough evaluations; nationally recognized subject matter *experts* on staff
- Widespread dissemination of results
- Tight feedback loop with other DOE program elements, (e.g., R&D, CALiPER, etc.) and manufacturers
- Close integration with streetlight buyers and operators
- Muni Consortium provides salesman-free environment for unencumbered information exchange





LED Tube Investigation in collaboration with Lighting Design Lab, Seattle, WA



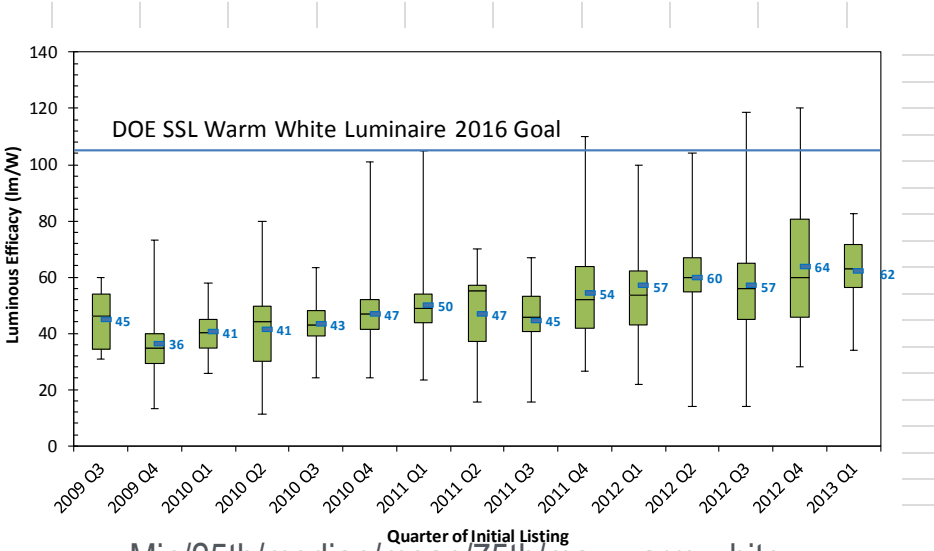


Recent Important GATEWAY Accomplishments

- Eight evaluations published in FY12
  - Sites included Getty Museum, CA; Central Park, NY, Golden Gate Bridge, CA; City of Philadelphia, PA; four others
- Project findings incorporated into Getty publication, “Guidelines for Using SSL in Museums,” related to preservation of precious artifacts, January, 2012
- Identification of chromaticity shift problem through collaboration with Smithsonian and Getty Museums, 1st Q, FY13
- “LED Lighting in Today’s Museums” Conference on March 1, 2013; 300 attended
- U.S. Conference of Mayors adoption of LED Street Lighting Resolution at the June, 2012 annual meeting
- Public release of MSSLC Model Controls Specification in March 2013
- Completion of study monitoring long-term performance of occupancy controlled parking garage SSL luminaires, March 2013

GATEWAY Progress on Goals

- Long-term goals are for integrated SSL Market Development Support Program
  - **By FY16:** Induce manufacturers to introduce warm white, 85 CRI, LED luminaires achieving at least 112 lm/W; cool white, 75 CRI, achieving at least 131 lm/W
  - **By FY16**: Achieve electricity savings of 21 TWh/year
  - **Desired End State**: > 20 ea. 200+ lm/W luminaires or lamps sold widely by major manufacturers
- Still far from goal but making good progress
- Issued RFP for third party evaluation of DOE program; final report before end of this FY (postponed from last FY due to mid-year budget cut)



Min/25th/median/mean/75th/max warm white luminaire efficacy in LED Lighting Facts vs. DOE 2016 goal, by quarter of initial product listing

GATEWAY Recognition

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

"The available resources were essential in facilitating the process on behalf of these communities. . . the model specification, and guidance of key personnel at the DOE Municipal Solid-State Street Lighting Consortium played a critical role in our process." – Jonathan Roberts, Iowa Association of Municipal Utilities, in reference to a joint purchase of LED street lighting for 15 small Iowa municipalities

DOE has both motivated and supported my efforts to develop more energy efficient lighting solutions. I am grateful for all the resources and leadership DOE provides.

Scott Rosenfeld, LC, IESNA
Smithsonian American Art Museum

It is highly recommended that cities begin networking with other cities who have installed LED street lights as early as possible in the process to help confirm the desired objectives and avoid the pitfalls. A good starting place is the Municipal Solid State Street Lighting Consortium (http://www1.eere.energy.gov/buildings/ssl/consortium.html). The MSSLC is funded by the U.S. Department of Energy and is simply a consortium of communities who share experiences and best practices pertaining to LED street lighting. They hold regular workshops throughout the United States and are an excellent resource for technical information.

Source: "A Municipal Guide for Converting to LED Street Lighting," Leotek Inc. (accessed via web)

GATEWAY Project Plan & Schedule

- Program Initiation: FY08 Target Completion: TBD

FY13 Deliverable	Due date(s)	Progress
2 white papers addressing outdoor lighting controls	Jun; Sep 2013	1 completed; 2nd on schedule
1 follow-on GATEWAY report on the Cully Blvd installation in Portland	Mar 2013	Delayed due to control system manufacturer planned software upgrade
1 new GATEWAY report involving roadway lighting	Apr 2013	On schedule
2 GATEWAY demonstration reports on indoor lighting projects	Feb; Jul 2013	Both delayed due to project host delays in purchasing products; new deliverable dates are expected as September, 2013
MSSLC Model Controls Specification, Version 1.0	Jan 2013	Completed in March. Additional time needed to address 600 stakeholder comments
Financing Strategies component of the MSSLC Website	Jun 2013	On schedule
3 webcasts and 1 national MSSLC meeting	Periodic; Sep 2013	2 webcasts completed, 3rd scheduled; national in-person meeting to be co-located with IESNA Street and Area Lighting Conference

Note: Deliverables list does not include all work products

GATEWAY Project Budget

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

Budget History								
FY10			FY11		FY12		FY13	
DOE	Cost-share	ARRA	DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$676K	**	$795K	$835K	**	$1535K	**	$1095K	**

*** In-kind, on a per-project basis*

GATEWAY Integration & Collaboration

FY13 Subcontractors

- Seattle City Light (Director of MSSLC) - $320K

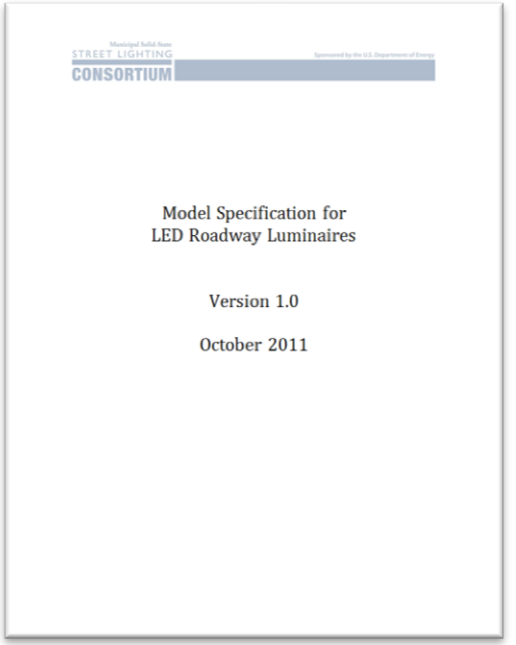
FY13 Collaborators to Date

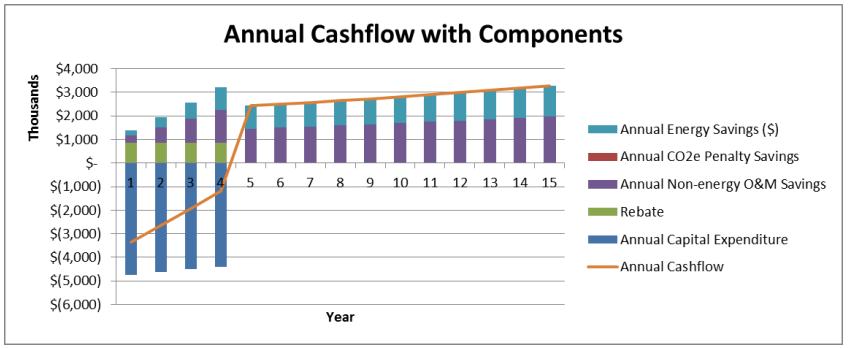
- Smithsonian Museum of American Art
- Pacific Gas & Electric
- Applied Materials, Inc.
- University of Florida
- Burden Iron Works Museum
- C&K Markets
- LED Power, Inc.
- Finelite, Inc.
- Idaho Power / Idaho DOT
- Minnesota DOT
- PETCO
- National Association of City Transportation Officials
- Approximately **400 members** of the MSSLC (numerous projects are ongoing within that organization) – NYC, Phil, Chicago, GA Power, etc.

Muni Consortium Members

GATEWAY Market Impact

- Muni Consortium is by far the most important source of information and activity on SSL streetlighting
- Muni Consortium has attracted 400 member organizations; having direct influence on purchases
  - E.g., IAMU, Portland solicitations using luminaire specification
- GATEWAY reports presenting original research
  - Examp.: I-35 Bridge lumen maintenance study is first public long term (5 years) SSL field lumen maintenance data
- Collaborating with many major cities, e.g., LA, NYC, Philadelphia, Seattle, Portland, San Jose
  - Projects include luminaires, controls, and large installations
- Collaborating with major lighting manufacturers
  - Virtually all of them participated in workshops to help finalize the luminaire specification: GE, Philips, Cree, Acuity, etc.
- Great interest in specs and tools
  - 20,000 visits and 3,500 downloads of luminaire spec in FY12
  - More than 1,200 downloads of Financial Analysis Tool in FY12





GATEWAY Communications

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

- Successful Selection of LED Streetlight Luminaires Webcast, March 6, 2013
- LED Street Lighting Workshop, Boston, MA, August 2–3, 2012
- LED Street Lighting Workshop, Los Angeles, CA, April 19-20, 2012
- MSSLC Retrofit Financial Analysis Tool Webcast, April 3, 2012
- LED Street Lighting Workshop, Dallas, TX, March 15–16, 2012
- Kinzey BR. 2013. "Lighting Controls in the Field: Exterior Applications Bring New Challenges." DOE Solid-State Lighting R&D Workshop, Long Beach, CA. PNNL-SA-93161.
- Miller NJ. 2012. "GATEWAY Demonstrations: What Have We Learned About LED Performance and Cost Effectiveness? " Lightfair 2012, Las Vegas NV. PNNL-SA-87797.
- Poplawski ME. 2012. "Status of Specification and Performance Standards for LED Streetlights." Smart Lighting Partnering Summit, Santa Clara, CA. PNNL-SA-87013.
- Poplawski ME. 2012. "MSSLC Model Specification for Adaptive Control and Remote Monitoring of LED Roadway Luminaires." LightSavers Canada. PNNL-SA-92458.
- Tuenge JR. 2012. "The Meaning of Equivalency." IES Street and Area Lighting Conference, Miami, FL. PNNL-SA-89961.
- Poplawski ME. 2012. "Insights from Installations." DOE Solid-State Lighting R&D Workshop, Atlanta, GA. PNNL-SA-86241.

GATEWAY Next Steps and Future Plans

- Initiate Muni Consortium efforts on roadway lighting in collaboration with U.S. DOT(high interest verified at Dep. Asst. Secretary level)
  - 26 million roadway lights in the U.S.
- More focus on High Lumen Output Applications, e.g., tunnels and high bay
- Increase efforts on Exterior Lighting Controls (improved specs, guidance, and demo projects
  - Adaptive lighting, other control strategies on roadways bring a host of new questions/issues
- Investigate issues that become evident after long-term operation
  - Return to previous sites for measurement, analysis and reporting
  - Provide direct feedback to users, specifiers, manufacturers, and the R&D community
- Work more with purchasing alliances, especially for smaller cities
  - Iowa Association of Municipal Utilities
  - Bay Area Climate Collaborative
  - Northwest Energy Efficiency Alliance / Bonneville Power Administration

CALiPER Problem Statement

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

Multi-Year Market Development Support Plan

- IDs 5 key market barriers. Most relevant to CALiPER are:
  - Lack of information for buyers and lighting professionals
  - Low product quality and performance
- IDs 10 key market needs. Most relevant to CALiPER are:
  - Independent performance test results
  - Support for development of industry standards and test procedures
  - Independent investigations of key SSL issues
- CALiPER part of plan states:
  - "The testing conducted to date has already revealed important technical issues, including power consumption by LED luminaires in the off state, and the need for […] standardized procedures for rating the performance of individual LED packages. Issues identified through the testing program will feed into the standards development process."

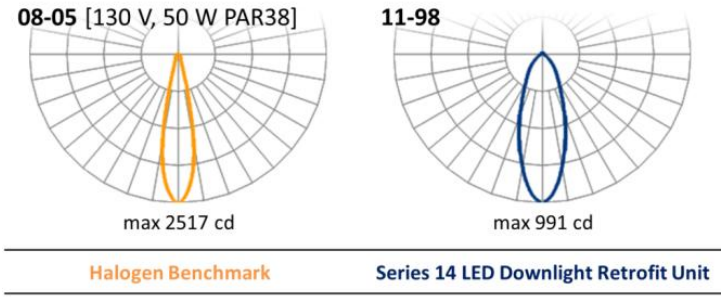
Potential Impact of CALiPER

Independent test results provide:

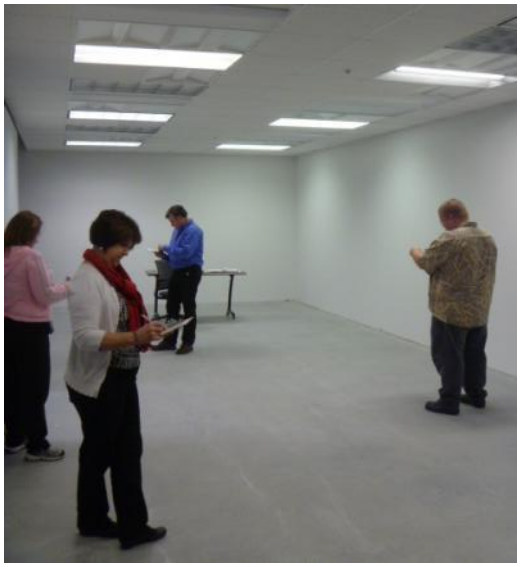
- Pressure on manufacturers to report performance accurately (was critical in early CALiPER years)
- Rising level of knowledge for all users
- Feedback loop for issues needing to be addressed by DOE and standards groups

CALiPER exploratory studies provide:

- Detailed data and analysis on specific technical issues, e.g., flicker, dimming compatibility
- Technical data and input to standards bodies, e.g., lumen maintenance extrapolations, in situ LED measurements
- Qualitative evaluations by industry experts, e.g., designers evaluation of luminaires



CALiPER Report 14: LED Downlight Retrofits. LED compared to benchmark.



Experts evaluate LED troffers

CALiPER Focus and Approach

BTO Goals & Priorities Alignment

- BTO goal: "…*In the area of solid state lighting, the program goal is to achieve lighting technologies with double the efficiency of today's most efficient lighting sources*"
- SSL is one of the top BTO priorities

Approach to CALiPER Testing

- Focus on commercially available products, purchased through normal market channels, i.e., retail, electrical distributors, on-line
- Use accredited, independent photometric test laboratories and industry standard procedures
- Perform testing of benchmark products
- Analyze and summarize test results, compare LED to benchmark products; identify product weaknesses and strengths
- Publish detailed and summary reports

Products procured and tested for CALiPER Application Report 20: PAR38 Lamps

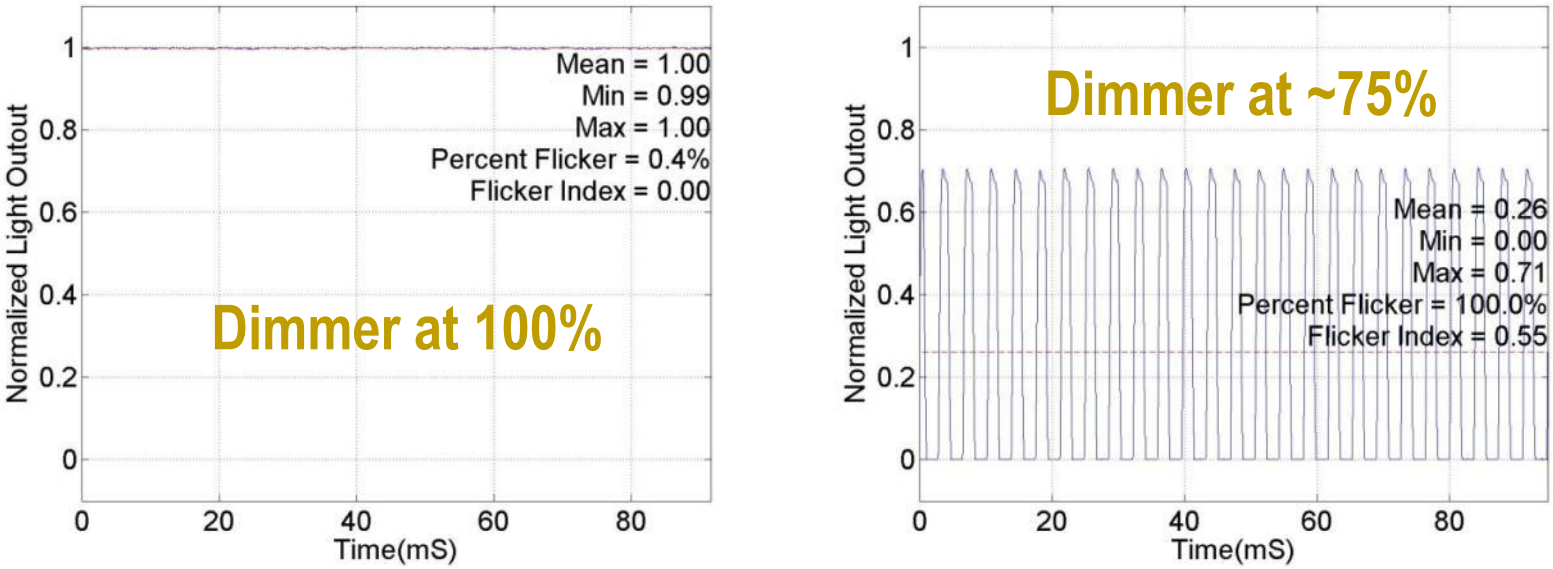
CALiPER Approach – cont'd

CALiPER Exploratory Studies:

- ID topics through industry roundtables, annual workshops, and knowledge of key barriers faced by SSL industry
- Investigate specific issues, e.g.:
  - LED lamp performance when operated on dimmer switch
  - Performance of LED replacements for common office fluorescent fixtures
  - Performance of LED reflector lamps operated in a simulated retail setting
- Conduct measurements and expert evaluations, e.g.:
  - Photometric and electrical testing
    - In-house testing at PNNL contributes to development of new industry standard test procedures
  - Mock-up installations with evaluation by PNNL and external experts
- Share results with standards bodies, energy efficiency sponsors, lighting designers & specifiers, manufacturers, etc., through presentations, reports, conference papers, journals, trade press

Key CALiPER Issues Currently Being Addressed

- Dimming performance of LED products
- Visible flicker produced by LED products
- Quality and performance of LED office/classroom lighting

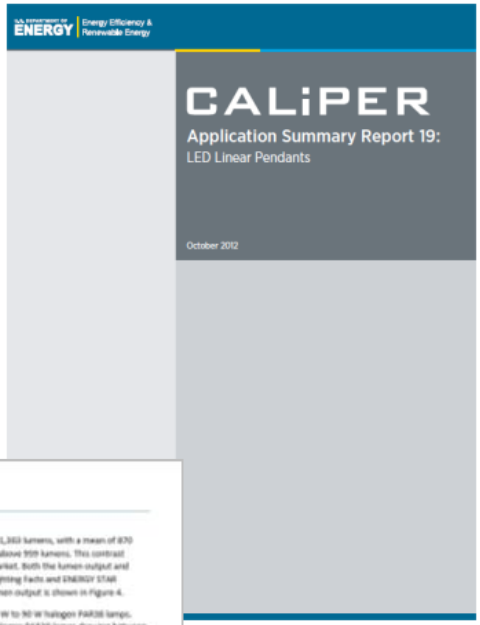


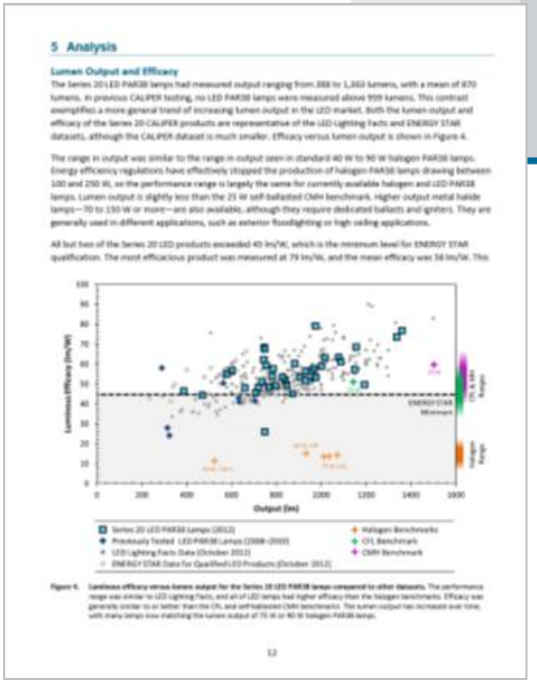
Flicker wave forms of LED troffer fixture operated on a dimming control

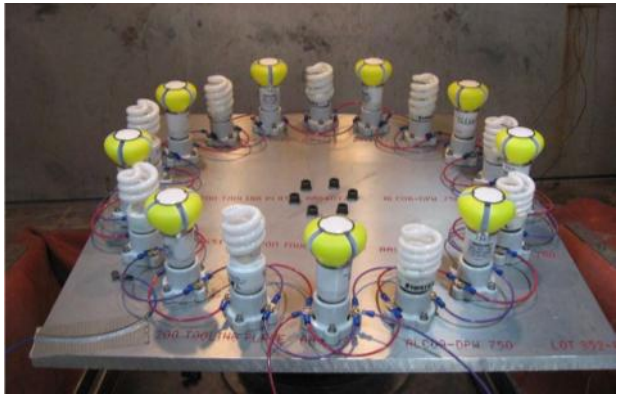
Distinctive CALiPER Characteristics

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

- Anonymous purchase of commercially-available LED products – no “gold plated samples”
- Comparative analysis puts LED performance in context of overall lighting industry and benchmark technologies
- Tight feedback loop with other DOE program elements, e.g., R&D, Standards, Lighting Facts, and others
- CALiPER Roundtable (forum for testing lab and measurement standards issues)
- Very strong brand name in SSL industry







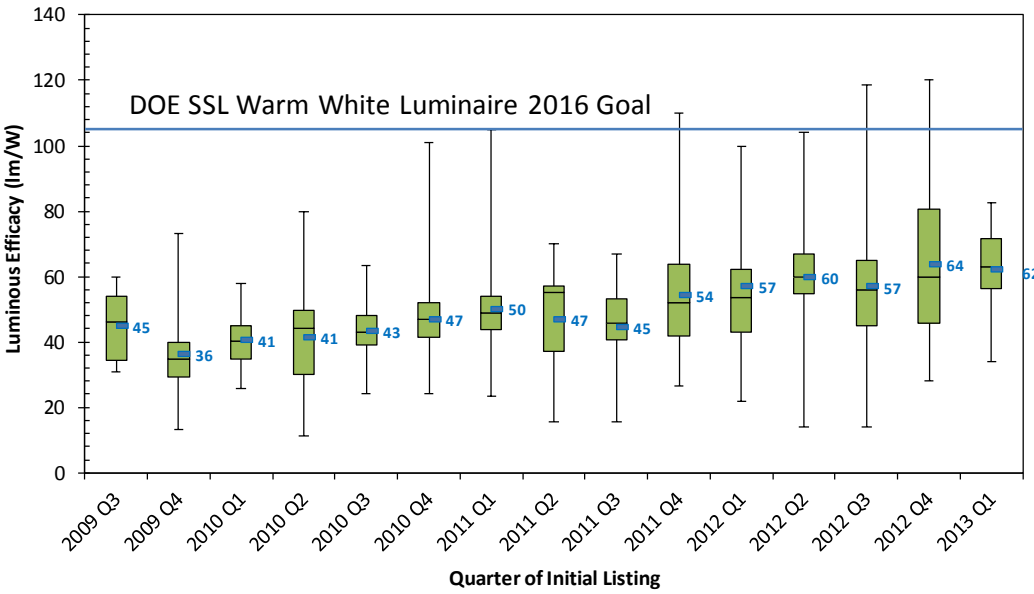
Stress testing of LED replacement lamps

Recent Important CALiPER Accomplishments

- Five Application Summary reports + one Retail Replacement Lamp Study published in FY12 + three application Summary reports in FY13 to date
  - Nearly 200 products tested and reported in last year
- 6th annual CALiPER Roundtable (March 2012) attended by ~30 representatives from industry, independent test laboratories, and key standard setting groups including IES, NIST, NEMA, ANSI, IEEE
- CALiPER Exploratory Study on Office/Classroom Lighting completed
  - Focused on LED overhead troffer fixtures, retrofit kits, and replacement tubes
  - Compared LED to fluorescent benchmarks
  - Evaluated dimming, flicker, glare
  - Brought in lighting designers, specifiers, and other experts for qualitative evaluations
- Significant progress integrating CALiPER and LED Lighting Facts databases and web tools
  - Largest publicly available database of independently verified LED product performance data

CALiPER Progress on Goals

- Long-term goals are for integrated SSL Market Development Support Program
  - **By FY16:** Induce manufacturers to introduce warm white, 85 CRI, LED luminaires achieving at least 112 lm/W; cool white, 75 CRI, achieving at least 131 lm/W
  - **By FY16**: Achieve electricity savings of 21 TWh/year
  - **Desired End State**: > 20 ea. 200+ lm/W luminaires or lamps sold widely by major manufacturers
- Still far from goal but making good progress
- Issued RFP for third party evaluation of DOE program; final report before end of this FY (postponed from last FY due to mid-year budget cut)



luminaire efficacy in LED Lighting Facts vs. DOE 2016 goal, by quarter of initial product listing

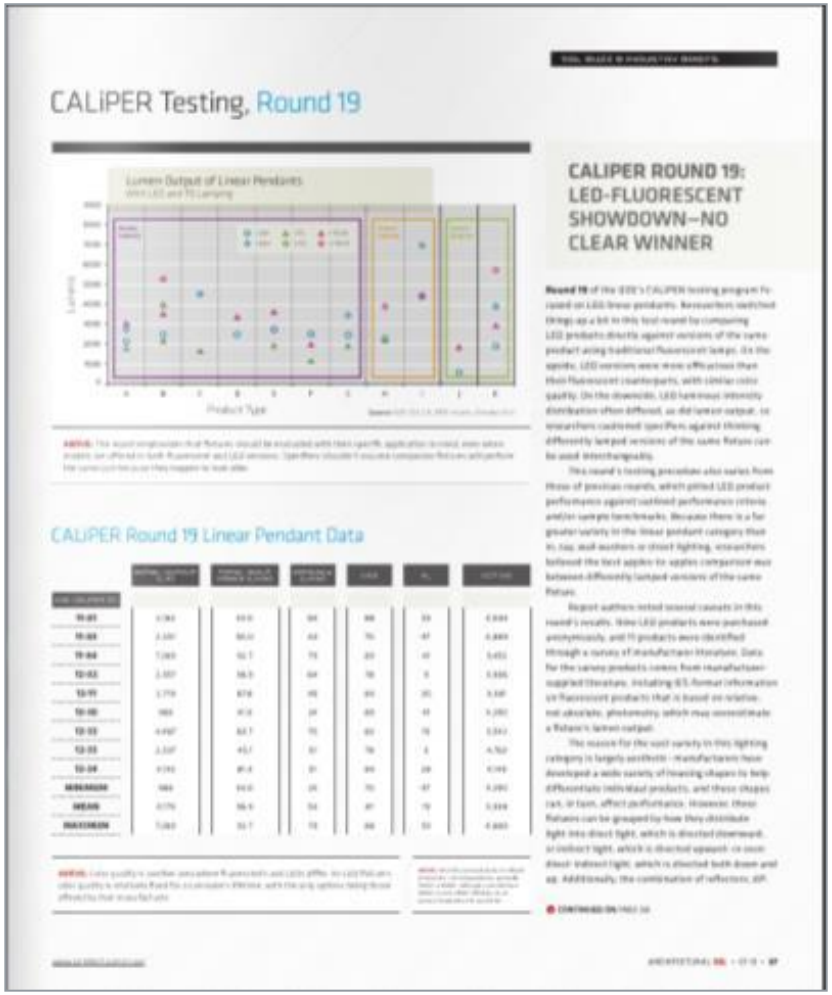
CALiPER Recognition

I have to thank you for setting the CALiPER [roundtable]. I think we got more done on LM-79 thoughts in that 4-hour window than we have in the last 6 months.
– Cameron Miller, National Institute of Standards and Technology and Chair, IES Technical Procedures Committee

CALiPER put manufacturers around the world on notice. People cite this program as a motivation for improving their products.
– Vrinda Bhandarkar, Strategies Unlimited

CALiPER testing program has been fundamental in driving the industry to higher quality and performance standards.
– Jeff Bisberg, Albeo Technologies

– CALiPER has become a common SSL industry term (and verb)


CALiPER Testing, Round 19

CALIPER ROUND 19: LED-FLUORESCENT SHOWDOWN—NO CLEAR WINNER

CALiPER Round 19 Linear Pendant Data

Architectural SSL magazine features CALiPER reports in virtually every issue

CALiPER Project Plan & Schedule

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

- Program Initiation: FY07 Target Completion: TBD

FY13 Deliverable	Due date(s)	Progress
Two Industry Snapshot Reports	Mar 2013 Sep 2013	1 completed; 2nd on schedule
Two Application Performance Reports	Dec 2012 Mar 2013	Three reports completed to date
Report and presentation on Office/Classroom Lighting Study	Feb 2013	Completed
Study plan for new Special Investigation	Mar 2013	Completed
CALiPER/Standards Roundtable	Apr 2013	Scheduled for April 8-9 in Portland

Note: Deliverables list does not include all work products

CALiPER Project Budget

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

	Budget History								
	FY10			FY11		FY12		FY13	
	DOE	Cost-share	ARRA	DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
CALiPER	$656K	*$0*	$645K	$961K	*$0*	$811K	*$0*	$953K	*$0*

CALiPER Integration & Collaboration

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

CALiPER is integrated and collaborates with:

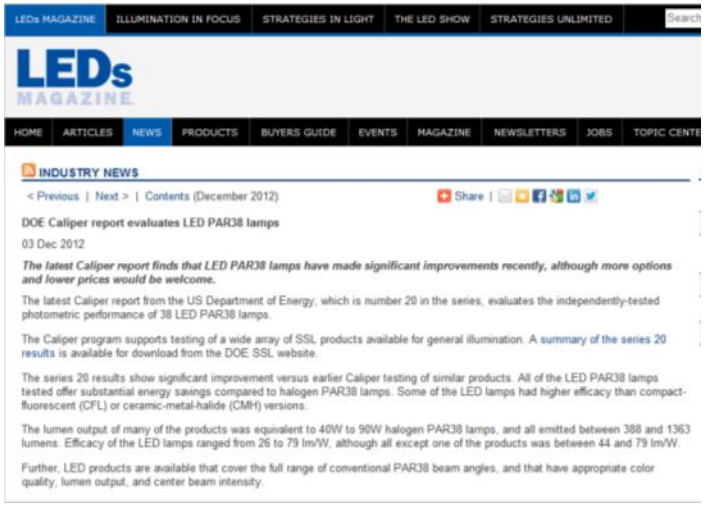
- LED Lighting Facts program
  - Developing shared database & testing
- Industry standards bodies
  - Direct participation in committee meetings and annual CALiPER Roundtable
- DOE EE programs: FEMP, BBA
- DOE SSL R&D: issues and results fed directly back to DOE SSL R&D team
- Utility and energy efficiency programs
  - Solicit topics for investigation; provide data and guidance
- Independent testing labs via shared problem solving and CALiPER Roundtable
- Lighting professional organizations, e.g., IES, IALD

CALiPER/Standards Roundtable 2012

CALiPER Market Impact

- Critical role in development of LM-79 test procedure
  - Contributed data
  - Round-robin testing; significant hand-holding with labs at every step
  - NVLAP accreditation process
  - Measurement repeatability tests
- Great market interest in reports and data:
  - more than 10,000 hits to the category search page in FY12
  - more than 4,600 copies of CALiPER Summary, Benchmark, and Exploratory Reports downloaded in FY12
  - Each summary report covered by trade press: LEDs Magazine, Architectural SSL, LD+A, others
  - Frequent CALiPER references in presentations by industry, academic, and utility representatives
- CALiPER is by far the most important independent SSL Testing source of information

Integrating spheres used in LM-79 testing



CALiPER story in LEDs Magazine

CALiPER Communications

Reports and Publications:

- Application Summary Report 20 - LED PAR38 Lamps (Nov 2012)
- Application Summary Report 19 - LED Linear Pendants (Oct 2012)
- Application Summary Report 18 - LED Recessed Wallwasher Luminaires (Oct 2012)
- Retail Replacement Lamp Testing, 2011 (Apr 2012)
- CALiPER 2012 Year in Review Report (Dec 2012)

Webcasts:

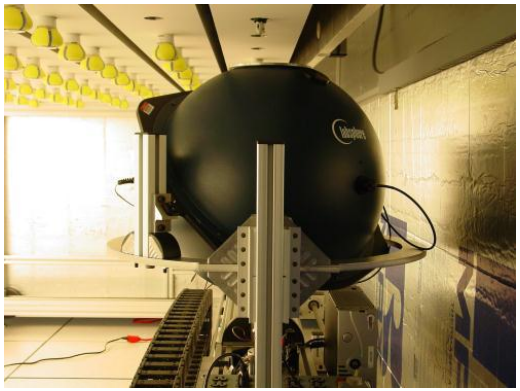
- Results of the LED Replacement Lamp Study Webcast, March 15, 2012
- DOE's 2012 CALiPER Reports in Review Webcast, January 22, 2013

Conference Presentations:

- LED Replacement Lamps Testing Results: A Sampling of Products from Major Retailers Strategies in Light, Feb. 2012 – Royer
- CALiPER: How Well Do LED Products Perform in the Lab? DOE Market Introduction Workshop, July 2012 - Taylor
- Troffers, Kits, and Tubes: LEDs challenge fluorescent in the Office Lighting Olympics, Strategies in Light, 2013 - Miller

CALiPER Next Steps and Future Plans

- Additional Exploratory Studies
  - Supplemental evaluations of T8-replacements for office exploratory
  - Retail display lighting
  - PAR 38 elevated temp lumen and chromaticity maintenance
  - Data analysis and synthesis of LED Lighting Facts data
  - LED lamp dimming performance and PQ characterization
- More application reports with emphasis on specific applications and design scenarios, going beyond LM-79 testing
- Continued support for standards groups including flicker, dimming, power quality, and long term performance testing



PNNL Test Apparatus for long term testing of LED replacement lamps