U.S. Department of Energy Solid State Lighting Program Market Effects Evaluation Report

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Executive Summary

DOE SSL Program

As described in its 2012–2016, five-year,[1] U.S. Department of Energy's (DOE) Solid State Lighting (SSL) Program seeks to speed the market introduction and adoption of SSL products through a variety of program efforts to achieve the following objectives:

1. Affect the types of SSL general illumination products adopted by the market, emphasizing high-performance products likely to reduce energy use and to satisfy users.
2. Accelerate commercial adoption of these products.
3. Support appropriate application of these products to maximize energy savings.

By FY 2016, the SSL program seeks to induce market introduction of: general illumination SSL warm white products that achieve 112 lumen per Watt (l/W); and cool white products that achieve 131 lm/W (luminaire or replacement lamp efficacy) and achieve 21 terawatt hours (TWh) annual energy savings.

DOE's 2012–2016, five-year plan intends that the market for high-performance SSL products in the United States will achieve a state that DOE believes will eventually be self-sustaining; therefore, DOE can justify the conclusion of its SSL market development support efforts upon meeting the following end-state conditions:

1. Products Brought to Market: offering at least 20, 200+ lm/W, (luminaire or replacement lamp efficacy), warm or cool white general illumination products for sale by major manufacturers (and, in most major markets, through normal lighting equipment sales channels).
2. Market Adoption of Products: the above products constitute 15% of annual luminaire and replacement lamp sales in the United States.
3. Energy Savings: annual SSL-derived electricity savings in the United States reach 122 TWh per year.

To foster the market for high-performance SSL products, DOE tasked the Pacific Northwest National Laboratory (PNNL) to manage an integrated set of technology commercialization activities, called *key program elements,*[2] in support of DOE's SSL program. These DOE's SSL program elements are:

- LED Lighting Facts
- Next Generation Luminaries Design Competition (NGL)
- GATEWAY Technology Demonstrations
- Commercially Available LED Product Evaluation and Reporting (CALiPER)
- Technology Prize Competitions (L Prize)

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1 http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl_5year-plan_2012-16.pdf

2 *SSL Multi-Year Market Development Support Plan.* May 2012.

- Technical Information and Evaluation and Market Studies, including the Technical Information Network for Solid State Lighting (TINSSL)
- Standards and Test Procedures Support
- Coordination and Leadership

Evaluation Goals and Approach

Evaluation Goals and Researchable Questions

PNNL contracted with Cadmus to conduct an evaluation of the SSL program for FY 2006 through FY 2012. The evaluation seeks to achieve the following primary goals:

1. Determine DOE's SSL market introduction support program's effectiveness and progress toward achieving the program's objectives, and
2. Assess the impact the SSL program has had on the development of the SSL market in the United States.

Key researchable questions addressed in this study include:

1. What are the program's key objectives, activities, outputs, and intended outcomes, and how do these align with DOE's desired end state?
2. From the perspective of program managers/staff, how does the program's design and implementation address the defined market needs and market barriers?
3. Who are the key market actors targeted by the various program elements? Must additional market actors be targeted?
4. How instrumental have the activities been in addressing each of the defined market barriers?
5. What overall impact has the SSL Program had on the SSL market's development in the United States?
6. To date, how successful have the SSL Program efforts been to date in influencing progress toward the goals set by the program?
7. Do industry, energy-efficiency and lighting consumer groups view the SSL Program as offering valuable, independent, and objective information on SSL technologies and markets?

Evaluation Approach

To determine the program's effectiveness and the progress toward achieving the SSL program objectives, Cadmus reviewed program achievements, interviewed program staff, and conducted in-depth interviews with representatives of the targeted market actors to obtain feedback on the effects and effectiveness of the program's diverse components. The evaluation activities included:

- Cadmus started by collecting secondary data on the program and available market research studies pertaining to the SSL market, including market characterization studies on SSL products.

- To initiate and guide the evaluation, Cadmus conducted three in-depth group interviews with DOE and PNNL SSL program managers and program leads to understand the SSL program and the implementers' perspectives on the program.
- Cadmus created an initial program theory and logic model (PTLM) to design and guide the evaluation.
- To gather market actor perspectives and feedback on the program, Cadmus selected a market actor interview sample and conducted in-depth interviews with 26 market actors in the SSL market.

To assess the program's effects on market adoption of SSL products, Cadmus conducted an analysis, based on the inputs of an expert panel. This included applying its web-based Market Adoption Tool (MAT) with a Delphi process to solicit expert inputs on how the market would have evolved without the program.

- The Cadmus MAT assumes market adoption over time can be characterized using an exponential diffusion curve (the Bass S-shaped curve).
- Cadmus recruited 10 key market actors of 26 interviewed as part of the primary interview process to participate in the market adoption estimation process.
- Cadmus aggregated products into three SSL product groups, based on LED types: indoor lighting, indoor luminaires, and outdoor lighting.

Major Findings

Program Implementer Views

In its 2012–2016 five-year plan,[3] DOE identified the following, five, primary, near-term market barriers:

1. High costs relative to competing technologies.
2. Limited Industry standards and test procedures for SSL general illumination products.
3. Lack of information for buyers and lighting professionals.
4. High transaction costs in terms of product specifications to unfamiliar buyers and specifiers.
5. Low product quality and performance.

The program theorizes that meeting specific needs will help overcome the market barriers, as follows:

- Meeting specific market needs can collectively reduce costs by expanding market opportunities for high-performance SSL, which, in turn, generates revenue for SSL manufacturers to invest in research and development and lower production costs.

[3] *SSL Multi-Year Market Development Support Plan.* May 2012.

- Meeting these market needs will help build a widely recognized and used industry-standard and test procedure infrastructure, allowing manufacturers to characterize their products in terms clearly understood by potential buyers.
- Meeting these market needs will help equip lighting industry professionals, program sponsors, consumers, and other market actors with the information needed to make appropriate purchasing decisions and to properly apply this new technology.

While the program has targeted segments of commercial customers, such as facility managers in large commercial buildings and federal buildings, by design, the program has not targeted the residential consumers directly. However, through its programmatic activities targeting the up-and mid-stream supply side, the program has attempted to address consumers in all market sectors, including the residential sector.

When asked to discuss the program theory, program leads agreed that the program objectives accurately depicted their efforts in accelerating adoption of quality SSL products in the market. They further emphasized that the program targets reliable, high-performance products likely to reduce energy use and to satisfy users. Program staff suggested defining long-term outcomes in terms of market transformation goals or end-state goals.

When asked what the program had yet to accomplish to meet DOE's desired end-state goals, program staff cited the following significant needs:

- Build market confidence in products to increase market adoption:
  - Further educate the end-user community, better informing them about quality SSL products and viable applications.
  - Facilitate product introduction through L-Prize and NGL design competitions.
  - Continue program efforts towards supporting industry standards and test procedures; so product performance can be accurately presented and evaluated.
- Expand collaborations with more professional and trade groups:
  - Reach out to installers and electricians, which typically do not attend webinars, check websites, or read fact sheets.
  - Make SSL products easy to specify and install.
- Engage with residential consumers to substantially move the market.
- Explore new delivery channels for information already produced.
- Shift focus to adopting SSL technologies using properly-applied controls.

Market Actor Perceptions and Feedback

Cadmus conducted in-depth interviews with 26 individuals, representing market actors in SSL manufacturers, trade organizations, big-box retailers, volume buyers, distributors, as well as, representatives involved with setting industry standards and testing procedures, and sponsors and managers from energy-efficiency programs and initiatives.

More interviewees knew of and became involved with CALiPER and the general information components, such as workshops, and knew the least about or became involved in standard and test procedures and NGL.

According to interviewees, manufacturers serve as the key market actors or decision makers influencing the type and quality of SSL products available in the United States, followed by DOE and other organizations developing qualified product lists.

SSL Market Challenges and Barriers

Respondents identified the following challenges as key factors currently affecting the availability and adoption of quality of SSL products:

- *Cost* was cited as the primary challenge facing the wide adoption of SSL technologies in all market segments.
- *Consumers' awareness and trust* was the second most cited challenge facing adoption of SSL products. Commercial customers were characterized as more aware of SSLs than residential customers. Factors contributing awareness and trust barriers included:
  - Consumers' misconceptions about the technology due to stigma associated with CFLs;
  - Concerns about the product's look and feel;
  - Uncertainty and distrust in product performance claims; and
  - Lack of understanding of the added benefits of SSL products and how to choose and evaluate SSL products.
- Product technical and performance characteristics were the third most cited barrier or challenge. Some of the technical issues cited included:
  - Controllability, specifically around dimming;
  - Color inconsistency and low light output;
  - Appropriate applications of quality SSL products; and
  - Compatibility and integration with existing controls and fixtures.
- Production capacity, supply, and demand also presented key challenges Contributing factors included:
  - The development pace and lag time between production and consumer availability;
  - Inaccurate claims of product performance;
  - Rapid change of types of SSL technologies offered with little time adapt; and

- Difficulties keeping up with increasing demand for SSLs.

Program Effectiveness

Interviewees were asked to identify how the program has addressed the market barriers and challenges, and were asked to rate DOE's SSL program overall in specific categories.

Effects on Knowledge and Awareness

The interviews provided the most information on how the program affected market actor knowledge and awareness about SSL products. Overall, responses indicated the program has successfully communicated useful information about product performance, quality, and appropriate applications. Details follow:

- Several respondents indicated the major benefits of the SSL program including increased communication and collaboration among market actors, such as:
  - Manufacturers and lighting designers;
  - Provision of a process to bring together diverse stakeholders, especially at the technology's development stage;
  - Provision of a clear pathway and milestones to technology development; and
  - Overcoming an older perception of the DOE's role as more of an adversary than a partner.

Remarks made by respondents include:

- Several respondents noted the benefits of SSL program outreach activities, especially those conducted through TINSSL, in enhancing awareness and knowledge through increased communication and collaborations among stakeholders.
- One respondent stated that without DOE's program, the information flow would not occur, and another highlighted the value of timely information provided by the program.
- Another respondent noted that DOE provided a positive platform for information flow, speeding the adoption of SSL technologies to consumers.
- DOE's main role to include a leadership position, and, without such leadership, SSL adoption would have taken longer (which relieved some of the burden on manufacturers).

The majority of respondents found the various types of information provided by the program to be very helpful and said they applied the information in various ways in their respective organizations:

- The majority of respondents from the energy-efficiency programs and initiatives group replied that the information they received proved useful in improving their understanding of quality SSL products, guiding their technology selections, and developing minimum specifications for programs.
- Respondents from standards and test labs used the program SSL information in a variety of ways. One noted using it to understand customers' needs and to develop testing procedures and services aligned with those needs.

- Another respondent stated that all of the program's venues and channels proved very helpful as they played different, complementary roles.
- Another respondent considered the information DOE provided useful as it helped limit the introduction of cheap and low-quality products into the market.

Two effects commonly noted by respondents included:

- Accessibility of quality information (from an unbiased, independent, and trusted source) that could be used by various market actors; and
- Availability of information to benchmark quality products, therefore decreasing the likelihood for poor products to exist in the market.

Cadmus interviewed respondents about how DOE's SSL program affected the market through the quality of information the program offered to end-users and customers. A general consensus emerged that the program had less impact on the market in this particular area, and opportunities existed for the program to increase its educational and outreach activities to consumers and end users.

Effects on Product Quality and Performance

Cadmus asked respondents to describe how DOE's SSL program affected the quality, performance, and pace of development for SSL products. Overall, respondents awarded the program very high marks in these areas:

- Interviewees from all groups indicated the quality and performance of the SSL products increased due to DOE's SSL program.
- One interviewee stated that the program's focus on quality led to advances in three years that could have taken 10 years; the combined efforts of SSL program elements "pushed people to understand what a quality product is and support that."

Effects on SSL Product Cost

Cadmus asked interviewees to describe their views on how the DOE SSL program affected the SSL market by addressing the cost of SSL products relative to competing technologies. Mixed views and uncertainties resulted regarding the program's effects on the cost of SSL products:

- One-half respondents among the manufacturer and trade organization group observed that DOE activities accelerated the cost-competitiveness of SSL products, particularly during the technology's introduction phase.
- Other respondents noted SSL products remain costly, and work remains to bring down costs.

Two respondents found the program led to higher costs for SSL products (than would have otherwise occurred). One respondent thought the program's efforts may have increased costs as it promoted higher-quality products than might be in the market without the program.

Program Opportunities and Recommendations Identified by Market Actors

Most interviewees agreed significant opportunities exist to accelerate adoption of SSL products. The following highlight market actors' responses:

- *Enhancing market actors' engagement and coordination*, in particular among the designer community, architects and manufacturers, retailers, and utilities.
- *Educating the demand side of the market and increasing awareness*. Notably, respondents suggested: providing enhanced training for designers, specifiers, and end users about controls and SSL compatibility; encouraging more involvement by designers; and providing outreach to commercial real-estate developers and to specifiers and purchasers.
- *Reducing initial costs and improving product performance.* Respondents most often cited increasing rebates and incentives to consumers as opportunities. Cost reductions could be made through improving efficiency in chip manufacturing. Respondents also cited smart and integrated controls as ways to reduce costs.

Recommendations from Market Actors

Market actors provided numerous recommendations addressing ways to improve DOE's SSL program to accelerate the availability and adoption of quality SSL products. Respondents offered the following key recommendations:

- Maintain the current program activities on all fronts, including: support for development of quality standards and test procedures; and collaboration between stakeholders to ensure a cohesive SSL market introduction process.
- Enhance outreach, education, and training targeted to consumers and end-users, especially through mainstream media, such as National Public Radio and newspapers, to increase knowledge and awareness and set realistic expectations on product performance as well as selection of quality SSL technologies for appropriate applications.
- Enhance collaboration efforts in multiple dimensions, including: industry and consumers; ENERGY STAR (maintaining consistency in information and decreasing confusion among users); and other standards organizations and rating systems.
- Increase the focus on product applications while improving the products' efficacy.
- Enhance and enforce quality check and quality assurance procedures during the early stages of product development to ensure production of high-quality products and accurate claims regarding product attributes (such as longevity).
- Include more information through TINSSL on results from GATEWAY and CALiPER.
- Increase market surveillance efforts to obtain intelligence on consumers' attitudes and practices in the SSL market, and use this information to design and target outreach.
- Increase marketing efforts and engage more manufacturers and utility programs, through DOE's programs, such as the NGL and L Prize that will lead to an increase in support of the winning

products. Promote L Prize winners and NGL competition winners more broadly beyond lighting industry groups to ensure the products succeed when entering the marketplace.

Respondents also provided recommendations for addressing the technical challenges presented by quality products. Key recommendations included the following:

- Ensure the use of quality metrics and thresholds (such as color quality comparable to incandescent) to ensure customer acceptance; include color information in LED Lighting Facts.
- Include product lifetime data as a requirement in the LED Lighting Facts program.
- Include price competitiveness criteria in the L Prize competition to decrease product costs of the winning products.
- Enhance the judging criteria used in NGL competition to include more objective criteria, rather than subjective criteria, such as style and aesthetics.
- Provide incentives to winners exceeding the L Prize competition minimum requirements to drive manufacturers to produce higher-quality products.
- Expand and disseminate more demonstrations studies from CALiPER, such as the troffer study.
- To establish market trends, develop annual reports on types of SSL product performance and application as well as energy consumption.
- Increase staffing levels and availability in the Municipal Solid State Street Lighting Consortium to articulate the technology's benefits and policy-related issues to municipalities without background information on these subjects.
- Maintain successful program support in the development of credible industry standards and testing procedures, and expand work with ANSI, similar to the program's successful work with the IES.

Estimates of Program Effects on SSL Market Adoption

To assess the program's effects on the market, Cadmus asked panelists to use the MAT to provide their estimates of what market adoption, in terms of installed lighting, would have been for each group of SSL products had DOE not engaged in the program's SSL activities. The difference between the market adoption estimated with MAT and actual market adoption provided an estimate of the program market effect. While the web-based application allowed panelists to estimate market adoption for 2005 to 2025, Cadmus targeted the analysis on the years with estimates of actual market adoption (2009–2012)[4] and, in Round 2, asked panelists providing estimates to focus on these years when providing their input.

[4] Navigant. *Adoption of Light-Emitting Diodes in Common Lighting Applications.* U.S. Department of Energy. April 2013. Available online: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/led-adoption-report_2013.pdf

Cadmus interpreted the results as follows:

- An average market adoption counterfactual estimate less than actual market adoption indicated panelists thought the program had a *fostering* effect on the market for SSL products;
- An average market adoption counterfactual estimate greater than actual market adoption indicated panelists thought the program had a *dampening* effect on the market.

Table 1 summarizes actual market adoption values for three SSL product categories (indoor lamps, indoor luminaires, and outdoor luminaires), and estimates of market adoption without the program, based on the panelists' input (2009–2012).

Table 1. Summary of Actual and Estimated Market Adoption of SSL Products

Year	Average Panelist Estimates	Actual Market Adoption	Average Panelist Estimates	Actual Market Adoption	Average Panelist Estimates	Actual Market Adoption
	Indoor Lamps		Indoor Luminaires		Outdoor Luminaires	
2009	0.11%	0.02%	0.05%	0.00%	0.17%	0.03%
2010	0.17%	0.08%	0.07%	0.03%	0.26%	0.35%
2011	0.26%	0.40%	0.10%	0.12%	0.38%	0.93%
2012	0.42%	0.91%	0.15%	0.37%	0.57%	1.71%

Generally, panelists attributed a market fostering effect to DOE SSL program activities and contributed many positive comments. Panelists' estimates indicated the program increased adoption by a factor of two to three times by 2012. The effect was especially large for outdoor lighting, where an estimated three-fold increase occurred. Estimates for indoor lamps showed the least degree of consensus, given the input of one expert who believed the program's quality and testing requirements slowed market adoption slightly. Panelists noted:

- "GATEWAY reports…have provided information that has assisted municipalities to specify LED roadway luminaires much more quickly than if they had to do individual demonstrations and write individual specifications…."
- "…without DOE SSL Municipal SSL Consortium adoption would be more haphazard and uncoordinated. In addition…larger numbers of poor quality products would likely be installed in cities and towns, turning other local governments away from the technology."

Program Impacts and Progress towards Goals

Program Impacts

Based on this study's findings, DOE's SSL market introduction support program has produced the following four key impacts on the SSL market:

1. **Impacts on knowledge and awareness regarding quality SSL products and performance characteristics.**

   Based on the market actors' interviews and on the amount of information developed and disseminated by the program, strong evidence exists that DOE's SSL market introduction support program directly resulted in increasing *technical knowledge and awareness*. Specifically, program impacts emphasized the attributes of quality SSL products, specifications, and performance characteristics, and the understanding of benefits from quality products among key market actors in the supply side up- and mid-stream.

   Results produced moderate evidence that DOE's SSL program directly increased knowledge and awareness regarding the *benefits of quality SSL products* among market actors in the demand side, including consumers and end users. Results based on responses from the majority of interviewees indicated these effects directly linked to the program information dissemination activities, including model specifications targeting large-facility managers and federal entities. The effects on consumers and end-users indirectly linked the program through information dissemination efforts by supply-side market actors.

2. **Impacts on the availability of quality SSL products.**

   Based on the market actors' interviews, strong evidence exists that DOE's SSL market introduction support program directly increased the *pace of development of the quality and performance of SSL products*.

   Moderate evidence exists that DOE's SSL program directly increased the *availability of quality products in the market*.

3. **Impacts on the cost of quality SSL products.**

   Based on the market actors' interviews, weak evidence exists that DOE's SSL market introduction support program directly *decreased the cost of quality SSL products*. In addition, the high cost of the winning products (such as L Prize products) affected competition in the market, as there criteria did not address the cost in the competition.

4. **Impacts on the adoption of quality SSL products and resultant energy savings.**

   The *adoption rates of SSL products* increased significantly since 2006, but still represent a very small share of the installed lighting market (less than 1% in 2012). Cadmus' analysis suggested the program led to a two- to three-fold increase in adoption of indoor luminaires and outdoor SSL lighting products by 2012, although the SSL products' share of installed lighting remained very low (less than 1% in 2012).

Given that SSL technologies remain in their early stages of market development and introduction, and based on the analysis of results from the market actors' interviews, weak evidence exists that DOE's SSL program directly *increased the magnitude of sales and adoption of quality SSL products among end users*, and consequently had low impacts on the *resultant energy savings*. The program's limited effect on market adoption could be partially attributed to:

- Limited outreach and marketing to consumers and end-users;
- Limited engagement of key market actors, such as lighting designers and end-users;
- Limited available information on sales and savings of quality products; and
- Limited availability and high cost of the winning SSL products (such as those from DOE's competition programs), compared to incumbent technologies.

Program Progress towards Goals

Evidence exists that DOE's SSL market introduction program has very effectively accelerated development and production of quality SSL products in the following ways:

- Providing objective, reliable and unbiased information regarding quality characteristics, performance, and appropriate applications of SSL products.
- Lowering the transaction cost among buyers and specifiers of accessing valuable information on the specifications and appropriate applications of quality products.
- Pushing the market towards developing and manufacturing quality SSL products.
- Increasing the visibility and credibility of product performance claims.
- Supporting the development of new and updated standards and testing procedures.

While the program has made great strides on the market's supply-side, ample opportunity remains for the program to increase its impacts on increasing adoption of SSL products by consumers and end users. Current market data shows the market offers high quantities and types of quality SSL products, but adoption rates remain very low. This could be the result of a lack of information and awareness among consumers as well as the high costs of SSL products relative to competing technologies. Savings associated with quality SSL products can only be realized upon wider adoption of these technologies.

Progress towards Quality Goals for SSL Products

Market data[5] on SSL efficacy indicate that high-efficacy warm-white products available in the market, although in much lower quantities than cool-white products, have exceeded DOE's SSL FY 2012 program efficacy goals by at least 53% in 2012, and have exceeded FY 2013 goals by at least 28% in 2013. In 2012, the average efficacy values for cool-white products exceeded the DOE's SSL FY 2012 targets by at least 10%, but were lower than FY 2013 program goals by at least 17%, in 2013.

[5] Data is based on DesignLights Consortium (DLC) Quality Product List (QPL), which only provides quality information on SSL products in the commercial sectors; there is no information available on the market share of these products.

DOE's SSL program efficacy goals were increased by 35% for warm-white and by 47% for cool-white products, in FY 2013 compared to FY 2012 goals; whereas, the goals were increased by 22% for warm-white and by 2% for cool-white products, in FY 2016 compared to FY 2013 goals. In contrast, the pace of efficacy improvement for SSL products in the market (with similar quality specifications as those in the program's goals) was much lower. The average efficacy values for the most efficacious (top 10th percentile) of products in the DLC QPL have only increased by at about 17% and 6% for warm-white and cool-white products, respectively, in 2013 (as of May 2013) compared to 2012.

If the pace of improvement in efficacy for SSL products in the market continues at the same rate as that between the years 2012 and 2013, there is a high likelihood that warm-white products in the market will meet or exceed the program's FY 2016 efficacy goals; however, there is less likelihood that cool-white products will reach the FY 2016 efficacy goals.

Given that currently there are low quantities of SSL products (especially warm-white products), with characteristics that match those of DOE's SSL FY 2016 efficacy goals; there is a market need for an increase in the volume of production of these high efficacy products. While pushing the market to produce high-quality products is important, there is also a need for market pull strategies to increase the demand for affordable quality SSL products.

Progress towards Energy Savings Goals for SSL Products

When comparing the market forecasted data on electricity savings from LED to the DOE's SSL program goals, in 2012, the energy savings realized from LED (in three categories) were about 36% of DOE's SSL FY 2012 energy savings targets. If the full potential of energy savings from these products were realized, the energy savings in 2012 would have exceeded the program's targets. There were no published data on energy savings estimates for SSL products for 2013. Due to the limited information available, it is hard to estimate the magnitude of energy savings that could be realized by 2016; however, there is large remaining potential of energy savings from SSL products that could be gained if market penetration increased.

Recommendations

Program SSL Quality and Savings Goals

Given the slow rate of market development of high efficacy SSL products, Cadmus recommends that DOE's SSL program revise its FY 2016 efficacy goals for cool-white products, to reflect the current status of SSL quality characteristics in the market.

Given the lack of information on market adoption and energy savings of DOE's targeted quality SSL products, we recommend that DOE conduct longitudinal national studies to assess market adoption, in-terms of installed units, and determine the actual efficacy levels and quality metrics, as well as energy savings of the adopted products. These studies could be commissioned every three to five years to assess the progress in adoption rates of the type/quality of products adopted and their energy savings.

The results from these studies can inform setting future realistic and achievable goals regarding market sales and energy savings targets of quality SSL products.

Measurement of Program Achievements

We recommend that the program establish program performance metrics and market indicators to track and report program achievements annually. The program performance metrics should measure the direct outputs from the program. For example, the number of tests, the number of demonstration projects, the number of publications and technical reports, workshops, conferences etc. The market indicators should measure the outcomes of the program, for example, the quantity of quality SSL products manufactured, market sales of quality products, adoption rates, amount of energy savings, increase in technical knowledge among market actors, increase in awareness and acceptance among consumers etc. By developing a tracking and reporting system, to keep a record of these metrics and indicators, future evaluations of the program's success and measurement of program achievements will be more effective and informative.

Program Impact on Adoption of SSL Products

For the program to accelerate market adoption of quality SSL products by consumers and end-users, we recommend that the program expand its outreach activities to end-users, including residential consumers, to increase the awareness and acceptance of SSL products. This could either be directly implemented by the program or indirectly through influencing market actors, including utility program implementers, to address this issue. One possibility is for the program to sponsor a national campaign utilizing main stream media to assure that the information reaches a wider-audience. Another possibility is that the program produces user-friendly marketing materials and guides, which could be used by other market actors, such as energy efficiency programs and retailers, to distribute to their customers. Increasing the number of demonstrations through scaled-field placements at targeted consumers' sites, such as chain stores, restaurants, universities and colleges, is another opportunity that the program could pursue to enhance the visibility of these products among wider audiences.

The program should maintain its successful efforts in coordination and collaboration with various market actors and decision makers. Those efforts will ensure the continuous feedback from industry professional and implementers on the status of the technology. There is a possibility that the program could increase its impacts on the adoption of quality products by incentivizing manufacturers to reduce the initial cost of the products. That could be achieved through the various program efforts in increasing the competition between manufacturers and providing grants to support the research and development of these technologies. In addition, through DOE's leadership, nationally coordinated efforts among utilities and energy efficiency program sponsors could be pursued to provide more incentives on quality SSL products.

Introduction

DOE SSL Program Overview

Program Goals

The U.S. Department of Energy's (DOE) Solid State Lighting (SSL) Program seeks to speed the market introduction and adoption of SSL products through a variety of program efforts. These efforts have been designed to aid in appropriate applications of SSL products, to avoid buyer dissatisfaction, and to preclude delays in market acceptance.

DOE[6] adopts the following roles:

- Help customers, businesses, and government agencies differentiate high-quality SSL products and applications;
- Widely distribute objective technical information;
- Coordinate SSL market development activities among federal, state, and local organizations; and
- Communicate performance targets to industry.

DOE's SSL market-based program activities initiated in fiscal year (FY) 2006, with the program continually evolving. In May 2009, DOE developed a five-year SSL Market Development Support plan, covering the FY 2008–2012; following that, in February 2012, DOE updated the program activities and goals covering FY 2010 and FY 2013; and, more recently (in May 2012) published a five-year plan for FY 2012–2016,[7] which included the following program objectives:

1. Affect the types of SSL general illumination products adopted by the market, emphasizing high-performance products likely to reduce energy use and satisfy users.
2. Accelerate commercial adoption of these products.
3. Support appropriate application of these products to maximize energy savings.

Per the 2012–2016 plan, the market development support activities targeted the following goals:

> "By FY 2016, induce market introduction of general illumination SSL warm white products that achieve 112 lm/W and cool white products that achieve 131 lm/W (luminaire or replacement lamp efficacy), and achieve 21 TWh annual energy savings."

The 2012–2016, five-year plan aims for the market for high-performance SSL products in the United States to achieve a state that DOE believes will eventually be self-sustaining; therefore, DOE can justify the conclusion of its SSL market development support efforts, upon meeting the following end-state conditions:

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6 http://www1.eere.energy.gov/buildings/ssl/market.html

7 http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl_5year-plan_2012-16.pdf

1. Products brought to market: offering at least 20, 200+ lm/W (luminaire or replacement lamp efficacy), warm or cool white general illumination products for sale by major manufacturers (and in most major markets through normal lighting equipment sales channels).
2. Market adoption of products: the above products constitute 15% of annual luminaire and replacement lamp sales in the United States.
3. Energy savings: annual electricity savings in the United States from SSL reach 122 TWh per year.

Program Elements

To foster the market for high-performance SSL products, DOE tasked the Pacific Northwest National Laboratory (PNNL), operated by the Battelle Memorial Institute, to manage the following integrated set of technology commercialization activities—called *key program elements*[8]—in support of DOE's SSL program:

- **LED Lighting Facts®**

  The LED Lighting Facts program showcases LED products for general illumination, produced by manufacturers that commit to testing products at accredited laboratories and accurately reporting performance results according to industry standards. For lighting buyers, designers, and energy-efficiency programs, the LED Lighting Facts label and online searchable database provide information essential to evaluating products and to identifying the best lighting usage options.

  LED Lighting Facts consists of:

  - A dynamic, searchable web database of LED product performance data;
  - An energy-efficiency program resource enabling utilities and other energy-efficiency sponsors to enter the specific requirements of their incentive programs and search the entire LED Lighting Facts database for qualifying products; and
  - A host of resource and educational materials for various market actors, including manufacturers, distributors, large retailers and national chains, lighting professionals, and utilities.

- **Next Generation Luminaries Competition™**

  The Next Generation Luminaires (NGL) Design Competition seeks to encourage technical innovation and to recognize and promote excellence in the design of energy-efficient LED luminaires for commercial, industrial, and institutional applications.

  Activities include:

  - Developing and implementing NGL design competition requirements;
  - Organizing judging and award ceremonies; and
  - Promoting results through industry trade press and other information dissemination venues.

[8] *SSL Multi-Year Market Development Support Plan.* May 2012.

- **GATEWAY Technology Demonstrations**

  GATEWAY demonstrations showcase high-performance LED products for general illumination in a variety of commercial and residential applications. Demonstration results provide real-world experience and data on state-of-the-art SSL product performance and cost-effectiveness. These results provide buyers with reliable data on product performance.

  Two main components make up the program: (1) Demonstrations; and (2) the Municipal Solid State Street Lighting Consortium (MSSSLC). Program activities include: investigating field installations (evaluating light quality, energy savings, economic performance, and other performance parameters) and administering the MSSSLC.

- **Commercially Available LED Product Evaluation and Reporting (CALiPER)**

  DOE's CALiPER program supports testing of a wide array of SSL products available for general illumination, using industry-approved test procedures. CALiPER test results:

  - Help guide DOE planning for SSL research and development (R&D) and market introduction activities;
  - Support DOE GATEWAY demonstrations and performance specification development activities;
  - Provide objective product performance information to the public;
  - Help buyers and specifiers achieve confidence that new SSL products will perform as claimed; and
  - Guide the development, refinement, and adoption of credible, standardized test procedures and measurements for SSL products.

- **Technology Prize Competitions (L Prize)**

  The L Prize is the first government-sponsored technology competition designed to spur lighting manufacturers to develop high-quality, high-efficiency SSL products that set leading-edge performance benchmarks for industry. The competition seeks to substantially accelerate America's shift from inefficient, dated lighting products to innovative, high-performance products. Program activities include testing and evaluating entries in DOE-sponsored technology competitions for advanced SSL products, arranging field tests, and developing product specifications.

- **Technical Information and Evaluation and Market Studies**

  This group of program activities includes developing fact sheets, design guides, presentations, product performance specifications, and webcasts to educate lighting and energy-efficiency professionals and increase awareness on SSL technology, performance, and appropriate applications. Efforts related to planning and dissemination of this technical information channel through the Technical Information Network for Solid State Lighting (TINSSL). TINSSL members include representatives from regional energy-efficiency organizations and program sponsors, utilities, state and local energy offices, and other stakeholders.

- **Standards and Test Procedures Support**

  Program standards and testing activities include: working with industry standards organizations on new and revised SSL standards and test procedures; providing supporting analysis; and identifying and communicating user needs.

- **Coordination and Leadership**

  Coordination and leadership activities fall into two main categories:

  1. Facilitating and coordinating local and regional efforts to promote the deployment of programs supporting the market introduction of SSL technologies. DOE holds annual SSL Market Introduction workshops to bring together a wide variety of key market actors in the SSL market, including manufacturers, utilities, regional efficiency organizations, lighting designers and specifiers, state and local government officials, facility managers, retailers and others.
  2. Federal government leadership, where the program works with DOE's Federal Energy Management Program (FEMP) and General Service Administration (GSA) among others to collaborate on demonstration projects; provide educational seminars, meetings, and conferences; and develop and distribute technical materials designed specifically for the federal sector.

Evaluation Goals

PNNL contracted with Cadmus to evaluate the SSL program. This study sought to achieve the following primary goals:

1. Assess the impact of the SSL Program on development of the SSL market in the United States; and
2. Determine the effectiveness of DOE's SSL market introduction support and progress toward achieving the program's objectives.

The scope of work covered under this study spans FY 2006 to 2012.

To determine the program's effectiveness and progress toward achieving the SSL program objectives, Cadmus reviewed the program's achievements throughout the period covered under this study, interviewed program staff, and conducted in-depth interviews with representatives of the targeted market actors to obtain feedback on the effects and effectiveness of the program's diverse components.

To specifically assess how the program has affected market adoptions of SSL products, Cadmus conducted an analysis based on inputs provided by an expert panel. We applied Cadmus' web-based tool, using a Delphi process for soliciting and analyzing experts' inputs on how the market would have evolved had the program not existed.

Evaluation Approach

This chapter provides details on the research conducted to complete this evaluation.

To address the study's primary goals, Cadmus performed the following tasks:

- Develop a research framework and compile initial information;
- Prepare interview instruments and conduct in-depth market actor interviews;
- Solicit market actor estimates of program market effects; and
- Analyze data, and present findings and recommendations.

The key researchable questions addressed in this study include:

1. What are the key program objectives, activities, outputs, and intended outcomes, and how do they align with DOE's desired end state?
2. From the perspective of program managers/staff, how is the program designed and implemented to address the defined market needs and market barriers?
3. Who are the key market actors targeted by the various program elements? Are there additional market actors that must be targeted?
4. How instrumental have the activities been in addressing each of the defined market barriers?
5. What has been the overall impact of the SSL Program on the development of the SSL market in the United States?
6. To date, how successfully have SSL Program efforts influenced progress toward the goals set by the program?
7. Do industry, energy-efficiency, and lighting consumer groups view the SSL Program as offering valuable, independent, and objective information on the SSL technology and markets?

Evaluation Tasks

Develop Research Framework and Compile Initial Information

To initiate and guide the evaluation, Cadmus sought to understand the SSL program and the implementers' perspectives on how program components were intended to achieve the program's goals. The process began by collecting secondary data on the program and available market research studies pertaining to the SSL market, including market characterization studies on SSL products.

Through this research, the evaluation team defined key market indicators to characterize the SSL market and its changes for FY 2006–2012. Key indicators used in this study include: changes in SSL sales and saturation levels over time; and changes in efficiency levels and energy savings over time.

In addition, Cadmus conducted three in-depth group interviews with DOE and PNNL SSL program managers and program leads. This activity sought: to better understand, from the program managers'

and staff's perspectives, the program's design and implementation to address market barriers and market needs (as articulated in the program plans); and to identify key market actors targeted by the various program elements.

To utilize this information and to guide the research, Cadmus created an initial program theory/logic model (PTLM). Program theory and logic models serve as key tools to make certain an evaluation and program implementation team come to a shared understanding of a program and the intended outcomes of the program activities.

Typically, PTLMs are used to document program activities and how these activities interrelate to address market barriers and produce outputs and short-, mid-, and long-term outcomes. PTLMs are structured to present the program theory in textual description, while the logic model provides a graphical representation of the program theory, showing the flow between program activities and anticipated outputs and outcomes. In addition, PTLMs identify key performance indicators associated with program theory that could be used to assess program progress towards specified goals.

Using a PTLM, a program's expected outcome, as perceived by program staff, can be used to design and guide an evaluation, compared to findings from the study to test the plausibility of the program theory, and to provide insights on improvements to recommend.

For example, for the SSL program, the management team may believe that by outputting commercially available product performance information, CALiPER may encourage manufacturers to report more accurate performance information on their products and help buyers better understand the actual performance of SSL products and product categories.

Cadmus developed a preliminary logic model, based on the background materials reviewed and the implementer interviews. This model then informed subsequent data collection and analysis. After completing the evaluation, Cadmus constructed a more complete logic model (presented later in this report) that more accurately and comprehensively captured the relationships among program elements, activities, outputs, and expected outcomes.

Conduct Market Actor Interviews

To gather market actor perspectives and feedback on the program, Cadmus prepared interview instruments and selected a market actor interview sample. Cadmus used the secondary market data and program implementer interviews to develop interview instruments. We also used this information to summarize key program activities and outputs to provide background information to the market actors selected for interviews.

Cadmus conducted in-depth interviews with 26 market actors in the SSL market, including interviewees representing manufacturers, trade-organizations, energy-efficiency program managers and sponsors, distributors, big-box retailers and large buyers, and individuals from industry standards setting bodies and testing laboratories. These interviews sought to achieve the following three objectives:

1. Obtain feedback from market actors regarding how they perceived the effects from the various program efforts to date, including how the program addressed defined market barriers, and overall program impacts on the SSL market development.
2. Determine the effects of program activities on the types of SSL general illumination products *brought* to the market.
3. Determine the effects of program activities on the types of SSL general illumination products *adopted* by the market.

Cadmus prepared an interview guide addressing these interview goals (included as Appendix A).

Delphi Method

In addition, Cadmus created a web-based data collection tool (the Cadmus' Market Adoption Tool) to obtain market actor estimates to be used for assessing the program's effect on the market adoptions of installed SSL products. The study recruited 10 key market actors of the 26 interviewed as part of the primary interview process to participate in the market adoption estimation process. Participants were directed to the website, where they input their market adoption estimates for three product categories under the counterfactual case, in which the SSL program did not exist.

Cadmus used this data collection tool in combination with a Delphi process,[9] which allowed the market actor experts to provide the rationale for their estimate and to review inputs of the other experts and revise their estimate, if desired. The study used market actor inputs to estimate the effect of the SSL program on market adoptions of three SSL product categories.

Analyze Data and Present Findings and Recommendations

To address the study goals, Cadmus analyzed the information gathered through the secondary and primary data collection.

The study team analyzed information collected through program staff interviews, market actor interviews, and the market adoptions analysis to assess program effectiveness and outcomes. We used the initial PTLM to assess the expected program's outcomes from the market perspective, in comparison with program staff expectations.

The analysis included drawing findings from the market actors' interviews to determine the effects of the program activities on the types of SSL products brought into the market and the products adopted by the market. Cadmus used the market adoptions analysis to quantify the program's effects on progress toward meeting DOE's desired end state goals.

To assess the SSL Program's impact on development of the SSL market in the United States, Cadmus performed a qualitative analysis of the full set of data collected for the study in a preponderance of

[9] H. A. Linstone, and Murray Turoff. *The Delphi Method: Techniques and Applications*. Reading, Mass.: Addison-Wesley. ISBN 978-0-201-04294-8. 1975. Also available online http://is.njit.edu/pubs/delphibook/

evidence process. This entailed reviewing the evidence regarding whether the program has affected the market and determining the effects in terms of overall market development.

In addition, Cadmus drew recommendations based on study findings and feed-back from the market actors' interviews regarding possible improvements on program activities, outreach, and targeted market actors. Furthermore, we provided recommendations on which metrics could be tracked and reported to measure future program impacts on the market development activities.

Program Implementers' Perceptions of the Market and Expected Outcomes

From Cadmus' review of program documents, the study team identified the market barriers and needs addressed by the program, using these to structure our program implementer interviews. We conducted group interviews with the implementation team to collect responses regarding: program objectives and outcomes; how the program addresses the identified market barriers and market needs; and how success is measured. We conducted interviews with DOE's SSL program managers and other program leaders, organized as follows:

1. The first interview group included seven high-level program leaders and managers.
2. The second interview group included six program leads, responsible for management of specific program elements, such as the Gateway demonstration program, LED Lighting Facts, the NGL Design Competition, and the TINSSL information and outreach element.
3. The third interview group included three staff members working with lighting standards and test procedures; these individuals also worked with program elements such as CALiPER, technical information, and factsheets.

Market Barriers and Market Needs

In its 2012–2016 five-year plan,[10] DOE identified the following, five, primary, near-term market barriers:

1. High costs relative to competing technologies.
2. Limited Industry standards and test procedures for SSL general illumination products.
3. Lack of information for buyers and lighting professionals.
4. High transaction costs in terms of product specifications to unfamiliar buyers and specifiers.
5. Low product quality and performance.

DOE also identified the following 10 key SSL market needs to guide DOE's SSL program planning and market development support activities:

1. *Effective product purchasing guidance:* to guide buyers to products that will likely perform well. Target market actors include: retailers, facility managers, other large-volume buyers, consumers, and other agents acting on their behalf (such as lighting specifiers and electric utilities).
2. *Market visibility for high-performance, commercially available products:* to educate the market about the technical potential of using the technology in well-designed products.
3. *Well-documented case studies of SSL general illumination installations:* to inform the market about product application issues, energy performance, and cost-effectiveness.

[10] *SSL Multi-Year Market Development Support Plan.* May 2012.

4. *Market introduction support from energy-efficiency program sponsors*: to help SSL manufacturers build sales volumes for high-performance products, thereby increasing the demand for high-performance products and driving down technology costs.
5. *Independent performance test results on commercially available products:* to counter exaggerated performance claims made by vendors; encourage manufacturers to use industry-standard test procedures as a basis for performance claims; and provide a high-quality dataset on product performance that can be used to analyze trends and product performance issues.
6. *Objective, widely available technical information from a credible, respected source*: to help fill information gaps and increase understanding of the technology, its attributes, and its limitations.
7. *Support for the development of industry standards and test procedures for SSL general illumination products*: to enable basic market infrastructures.
8. *Coordination of local, regional, and federal SSL market development activities:* to maximize the effect of invested public and ratepayer money.
9. *Independent investigations from a credible source of key issues affecting SSL market adoption*: to provide up-to-date information on SSL market development for DOE and for industry planning and analysis purposes.
10. *High-visibility technology competitions:* to spur innovation by reducing the risks of developing and selling very high-performance, state-of-the-art SSL products.

The program theorizes that meeting the identified market needs can collectively reduce costs by expanding market opportunities for high-performance SSLs, which, in turn, will generate revenue for SSL manufacturers to invest in R&D and lower production costs.

In addition, program theory holds that meeting these market needs will help build a widely recognized and used industry-standard and test procedure infrastructure, allowing manufacturers to characterize their products in terms clearly understood by potential buyers. Further, program theory assumes that meeting these market needs will help equip lighting industry professionals, facility operators, lighting specifiers, energy-efficiency program sponsors, retailers, and consumers with the information required to make appropriate purchasing decisions and to properly apply the new technology.

To overcome the identified barriers and to achieve the program goals, DOE plans to complete the following:

- Use lessons learned from past emerging technology introductions (such as compact fluorescent lamps [CFLs]) and current market research to minimize the likelihood that the SSL market will repeat the mistakes that greatly delayed market adoption of earlier emerging technology market introductions.
- Closely coordinate with lighting industry organizations (such as NGLIA, IES of North America, and the International Association of Lighting Designers) and other government and utility programs seeking to improve lighting energy efficiency.

- Assist buyers and their agents to improve buyers' satisfaction with SSL products.
- Provide timely and appropriate information on quality product performance and specifications to key market actors.
- Enhance market opportunities, and seek to reduce the risks and costs for manufacturers of SSL products to sell good quality, high-performance products to motivated buyers.

While the program has targeted segments of commercial customers, such as facility managers in large commercial buildings and federal buildings, by design, the program has not targeted the residential consumers directly. However, through its programmatic activities targeting the up-and mid-stream supply side, the program has attempted to address consumers in all market sectors, including the residential sector.

Cadmus discussed program barriers, articulated in the five-year program plans with the program leads. Of five listed program barriers—(1) high cost; (2) limited industry standards and test procedures; (3) lack of information; (4) high transaction costs; and (5) low product quality and performance—program staff agreed that high costs and high transaction costs associated with acquiring information on SSL products, present the primary market barriers.

One program lead identified another barrier related to high transaction costs: risk aversion. The respondent noted that, as technology changes so rapidly, specifiers fear selecting the wrong product. Program managers clarified that the definition of high transaction costs reflected not just a consumer's intellectual costs of learning about SSL products, but also for professionals trying to specify SSLs.

This presents an especially challenging market barrier, given the complexity of SSL technology, and the amount of time required to learn about product quality and performance for those not already familiar with the technology. Program leads remarked that the challenge lies in addressing public inertia and unwillingness to change as well as their aversion to risk.

The group also noted that product availability remains a primary barrier, and program staff sometimes found it difficult to obtain products selected for testing through CALiPER. In addition, respondents cited the stigma surrounding new technologies as a barrier.

The program has addressed these market barriers by using responses received from market actors, such as lighting designers and practitioners, to inform its research and development program activities. This program facet proves very important and unique, as developers or researchers normally do not receive such direct feedback about market barriers and product performance issues. For example, program staff discovered early on that dimming performance presented a problem. They raised this issue with the standards organizations and product developers at program workshops. Staff noted that products recently introduced into the market possess much better dimming capabilities.

Interviewees also noted use of trade press and published research as primary information sources used to inform their knowledge of market barriers. For example, research conducted by Southern California Edison regarding the stigma surrounding CFLs has been helpful in this regard.

Other cited information sources included competitions, which provide feedback on product quality and performance. Additionally, the SSL program organizes special purpose roundtables with groups such as lighting designers, electric utilities, manufacturers, large facility operators, national retailers, and office building developers, seeking to procure feedback about program activities that work well as well as suggestions for future program directions.

These roundtables provide effective feedback on product performance and changes as well as on market barriers faced by specific user groups. For example, in response to barriers identified for selecting and installing products used in street lighting, DOE established the MSSSLC. This group provides information and resources to municipalities and other street lighting owners regarding how to successfully apply SSL street lighting products and technologies. MSSSLC, with more than 500 members, has worked so effectively that DOE plans create a new consortium for indoor SSL users.

DOE's internal Strategy Committee serves as the primary vehicle for addressing and responding to feedback about issues raised in workshops and through other activities. The program also uses many other communications methods for obtaining feedback from the SSL community, including:

- DOE's SSL website;
- An electronic newsletter with more than 6,000 subscribers;
- Workshops held three times a year;
- Weekly e-mail updates;
- Webcasts;
- Conference presentations; and
- Exhibits at Light Fair.

Views on Program Objectives and Outcomes

When Cadmus interviewers asked PNNL program leads to discuss the key program objectives, activities, outputs, and intended outcomes, and how these align with DOE's desired end state, the program leads agreed the program objectives accurately depicted their efforts in accelerating adoption of quality SSL products in the market. They further clarified that the program's first objective in the 2012–2015 plan ("affect the types of SSL general illumination products adopted by the market, emphasizing high-performance products likely to reduce energy use and satisfy users") focused on affecting not only the efficacy of products, but also the quality attributes, such as high-performance and product reliability.

Regarding the program's second objective ("accelerate commercial adoption of these products"), the interviewees concurred that the program's goal includes achieving widespread and rapid adoption of

quality SSL products. A respondent cited that a better measure of adoption of quality products would focus on the fraction of lumens provided by SSL products as opposed to focusing on units of total sales.

Respondents also remarked that, by supporting the appropriate application of these products (the program's third objective), the program influenced the installation of products in the appropriate applications, subsequently avoiding wrong applications and poor experiences by end-users: "Happy, satisfied users lead to faster market adoption."

Cadmus discussed the program outcomes and DOE's desired end-state goals for the SSL market with the program leads. Program managers argued that, in this program, distinctions between short-, mid-, and long-term outcomes proved arbitrary, and outcomes occurred in more of a continuous process over time. One program manager highlighted that one potential effect on manufacturers would be the influence on the quality of their products and how manufacturers characterized these products. Another interviewee suggested that long-term outcomes should be defined in terms of market transformation goals or end-state goals.

Managers of program elements suggested a desired mid-term outcome would be seeing more incentives offered to appropriate products and eliminating the need for incentives in the long term.

Respondents from the standards and test procedures support group clarified that the point of supporting the standards and test procedures elements have been to produce the most trusted information in the market. Respondents also noted the importance of developing and implementing standards in a timely fashion. While the development of standards could provide guidance in the early stages of market development, it is important to allow technologies to achieve their maturity prior to implementing standards that could have negative consequences, such as stifling creativity in the early stages for technology development.

When asked what the program could yet do to meet DOE's desired end-state goals, respondents cited the following:

- Create conditions in the marketplace that support introduction of high-efficiency products. Interviewees noted that some efficient technologies, currently under research and testing, and have yet to enter the market.
- Facilitate product introduction through L-Prize and NGL Design Competition.
- Make SSL products easy to specify and install.
- Explore new delivery channels for information already produced.
- Expand collaborations with more professional and trade groups.
- Reach out in the field to installers and electricians, who typically do not attend webinars, check websites, or read fact sheets.
- Further educate the end-user community, better informing them about quality products.

- Build market confidence in products, thus increasing market adoption. Program staff have found it necessary to conduct multiple demonstrations to reassure potential users that products will work in their specific applications.
- Shift focus to adopting SSL technologies using properly-applied controls.
- Engage with residential consumers. By design, the program traditionally has precluded focusing on the residential sector, but eventually will need to engage with it to substantially move the market.
- To better accomplish the end state, continue program efforts to support industry standards and test procedures.

Views on Assessment of Program Success

The program does not employ formal annual measures of success. DOE informally measures success every year in a qualitative way by continuously engaging designers, utilities, facility managers, and consultants, certain segments of commercial consumers (but not residential consumers) to obtain feedback by distributing feedback forms at meetings and workshops and by engaging in personal interactions with industry group decision makers. Additionally, program managers track references to their programs and materials through the trade press.

Program managers stressed that they took feedback seriously. Typically, they received responses from 20% to 30% of workshop and meeting attendees, and program managers modified workshop formats in response to feedback received.

Feedback enabled program staff to adjust the program to better meet participants' needs. For example, DOE changed the program's direction regarding product testing when manufacturers expressed concerns about the high costs of complying with testing requirements.

In response, DOE program managers met with industry representatives to arrive at a modified testing approach, which allowed manufacturers to group products into families and to test single products within a product family. This enabled manufacturers to continue testing products while reducing the financial burden of testing to a more acceptable level.

The program obtains feedback on SSL market development needs of utility and energy-efficiency providers by working with them via TINSSL. The Utility and Efficiency Program Roundtable, held in April 2012, uncovered a number of potential enhancements to DOE SSL market development efforts, many of which were incorporated into the FY13 Program Plan.

Program staff reviews the program and the SSL lighting market every six months to identify market needs and to determine if their actions have addressed them.

Program managers reported achieving a sense of accomplishment regarding program activities to date. One program manager pointed to the SSL market report produced by Strategies Unlimited as evidence that the United States has successfully managed the SSL market. The report contrasted market adoption

of outdoor SSL products in China with that in the United States. The report noted that, in China, while a surge in sales of SSL products initially occurred, the lack of emphasis on product quality and subsequent product failures soon collapsed sales. In the United States, DOE's emphasis on product quality led to a more slowly growing market, which did not experience a market collapse.

Program managers highlighted the efforts of LED Lighting Facts, where the number of products listed has steadily increased, and the efficacy of products submitted have moved closer each year to past L-Prize program targets. Program managers feel that informing market actors that someone will check their product claims helped improve the quality of the products. Utilities have set up their programs, based on data from LED Lighting Facts, and have stated that they want all information sources to be presented in a manner similar to DOE's LED Lighting Facts.

Program team members stated that the CALiPER testing program has proved instrumental in holding manufacturers accountable. In the early years of the SSL product introduction, manufacturers made overly optimistic and unsubstantiated claims concerning product quality and lifespans.

DOE introduced the CALiPER program, which anonymously purchases and tests products, and provides publically-available reports of test results. This quickly caught the industry's attention. One program manager noted that a manufacturer described CALiPER as "DOE's tough love to the industry," and praised DOE for holding manufacturers accountable. Lately, CALiPER has evolved to not only encompass testing of individual products, but also to exploration of issues common to SSL lighting products in general, such as dimming.

Program staff also spoke of the success of the DOE booth at the lighting industry's annual conference, Light Fair International. DOE's booth featured revolving, 30-minute presentations about program components, such as Gateway, CALiPER, the NGL, and LED Lighting Facts, and provided copies of TINSSL fact sheets.

Staff also noted that materials and testing results from DOE's program were considered unbiased, objective information sources. Other industry groups cited and linked to materials produced by DOE (including the museum industry, where CALiPER studies proved instrumental in quelling the controversy about whether LED lighting destroyed artwork). Control specifications that DOE helped develop have been used internationally. Respondents noted that DOE brings expertise to the table and is considered a unifying entity.

Respondents spoke to the interactive nature of the various program elements. An example that was given by a respondent was that, program elements with objectives other than supporting the development of test procedures and/or standards, such as CALiPER and GATEWAY technology demonstrations, provide information that helps identify the need for testing procedures and standards. This information is then used by the standards and test procedures support program to further address those identified needs.

The variety in market actors proved a critical element in this cooperative success. SSL lighting brought in many new companies, such as semiconductor manufacturers, which were not traditional lighting companies and knew little of the lighting market, but were willing to be guided through the process.

Program managers also cited the important role that energy-efficiency programs have played across the country. They noted that where regulated utilities could work to advance emerging technologies without the restrictions of meeting cost-effectiveness requirement, their efforts succeeded, and utilities could test and demonstrate SSL products.

Program staff considered the following indicators of program success:

- Standards developed and published, and observing their effectiveness;
- Data collected through CALiPER and subsequently used by standards bodies;
- Increasing the number of submissions to the NGL design competition;
- Light industry's or trade publications' use of fact sheets and other materials published through the program; and
- Lighting designers stating they trusted information drawn from the NGL design competition more than information from other competitions.

Market Actor Perceptions and Feedback

Market Actor Interviewees

Cadmus conducted in-depth interviews with a representative group of market actors involved with the development and deployment of SSL technologies through various capacities. These included: 26 in-depth interviews with representatives from SSL manufacturers, trade organizations, big-box retailers, large buyers, distributors, representatives involved with setting industry standards and testing procedures, and sponsors and managers from energy-efficiency programs and initiatives. Table 2 shows entities represented in the interviews.

Table 2. Market Actor Groups Interviewed

Market Actors Category	Sample Frame (n=26)	Entities Interviewed
Manufacturers and Trade Organizations	6	Philips, Acuity Brands, General Electric (GE), Cree, American Lighting Association (ALA), and National Electrical Manufacturers Association (NEMA).
Big-box Retailers, Large Buyers and Distributors	4	General Services Administration (GSA), The Home Depot, Grainger, and CBT Development Consultants.
Industry Standards Bodies and Testing Labs	5	American National Standards Institute (ANSI), Intertek, Underwriters Laboratories (UL), International Commission on Illumination (CIE), and the Illuminating Engineering Society (IES).
Energy-Effiency Program Sponsors/ Utilities	11	Pacific Gas and Electric, Midwest Energy Efficiency Alliance, Sacramento Municipal Utility District, National Grid, Optimal Energy, Northeast Energy Efficiency Partnerships, New York State Energy Research and Development Authority, Southern California Edison, Energy Trust of Oregon, Efficiency Vermont, and Franklin Energy.

Market Actors' Description and Roles

Manufacturers and Trade Organizations

This section describes manufacturers and trade organizations Cadmus targeted for interviews:

- Philips Lighting of North America's seeks to introduce innovative end-user-driven and energy-efficient solutions and applications for lighting, based on a thorough understanding of customer needs, both in a public and private context.
- GE manufactures appliances, lighting, power systems, and other products worldwide. GE plays an active role in SSL product development, serves as a member of the NGLIA, and has previously received a DOE R&D grant.
- Cree is one of the market-leading innovator and manufacturer of SSL in the United States, with its primary focus on the advancement of LED technology, from chip to luminaire levels. Cree has

worked closely on many DOE SSL program aspects with its LED bulbs the first included in GATEWAY Technology demonstrations. Additionally, Cree produced some of the first LED bulbs to include LED Lighting Facts labels.

- A manufacturer, Acuity Brands Lighting delivers lighting solutions to improve the quality of schools, workplaces, and public places. One of the largest manufacturers of luminaires in the lighting industry, Cree focuses on developing new outdoor products: 100% of its new product development is in SSL.
- A trade association representing the lighting industry, the ALA membership includes: lighting, fan, and dimming control manufacturers; retail showrooms; sales representatives; and lighting designers dedicated to providing the public with proper applications of quality residential lighting. The ALA has supported the annual Lighting for Tomorrow Lighting Fixture Design Competition since its beginning 11 years ago. The Competition seeks to increase the number of efficient, practical, and saleable residential LED lighting fixtures in the market and available to consumers.
- A trade organization, NEMA serves as an association of electrical equipment and medical imaging manufacturers. NEMA is a participant of the NGLIA—a DOE-designated industry partner for the program. With the NGLIA, NEMA strongly participates in many of DOE's SSL Program activities.
- An international standards setting organization, CIE (also known as the CIE from its French title, the Commission Internationale de l´Eclairage) participates in worldwide cooperation and the exchange of information on all matters relating to the science and art of light and lighting, color and vision, photobiology and image technology. ISO recognizes CIE as an international standardization body. CIE also has worked with accrediting bodies to establish energy-efficient lighting programs, ensuring the quality application of the standards by testing laboratories. As part of that work, CIE developed and implemented a Measurement Assurance Program for SSL products, in which over 90 laboratories— domestically and internationally—have participated.

Big-Box Retailers, Large Buyers and Distributors

- A distributor, Grainger's focus in the SSL market includes LED lamps, A-line lamps, reflectors, and fixtures, and has worked with DOE for about six years in SSL technology development efforts. Much of its DOE connection occurs through D&R International, which supports DOE SSL program efforts, including implementation of the LED Lighting Facts program, as a subcontractor to PNNL.
- CBT Development Consultants focuses on design services and implementation of SSL products for property owners. Early on, CBT emphasized LED lighting technologies.
- An independent Federal entity, the GSA helps manage and support the basic functioning of federal facilities. To reduce operational costs and to work towards sustainable alternatives, GSA tests new products to determine their performance in real-world conditions.

- A major retailer of lighting products in the United States, the Home Depot's products include incandescent, halogen, LED, and fluorescent products. The company has played a significant role in introducing LED products to consumers, including those eligible for utility rebates.

Industry Standards and Testing Laboratories

Cadmus interviewed individuals involved in the development of standards and test procedures, and with broad experience and involvement in this area:

- A third-party test lab, Intertek provides SSL customers with reliable testing and certification for regulatory approval, conducting testing to industry specifications. Along with UL, Intertek was among the first CALiPER test labs.
- ANSI has served in its capacity as administrator and coordinator of the United States private sector voluntary standardization system for more than 90 years. ANSI works with a variety of stakeholders and organizations to set industry standards, guidelines and specifications on SSL.
- UL, a safety science company, works on safety solutions in electricity, renewable energy, and nanotechnology by providing various services including: certification, validation, testing, inspection, audits, and training. UL's Luminaire Testing Laboratory (LTL) has participated in DOE's efforts related to the SSL industry since its inception. LTL became involved in early product evaluation for DOE through PNNL, and served as the first CALiPER laboratory.
- IES is an organization that is composed of a diverse membership with focus on lighting; membership includes lighting manufacturers, lighting designers and architects, as well as, consultants, electrical and building contractors, distributors and wholesalers, representatives from utilities and energy services and governmental and educational affiliates. IES provides effective lighting education in various forms, publishes recommended practices in lighting, initiates and develops high quality standards, promotes lighting research, and collaborate with various market actors and expansive memberships to influence actions and policies to advocate for quality lighting.

Energy Efficiency Programs and Initiatives

- Midwest Energy Efficiency Alliance (MEEA), a collaborative network, advances energy efficiency in the Midwest to support sustainable economic development and environmental preservation. MEEA plays a large role in advancing the SSL market. Its activities include: conducting workshops; leading a collaborating network of efficiency program administrators involved in SSLs; training and outreach; disseminating information on vendor and product selection; and publishing annual surveys on regional plans and perception by stakeholders addressing the SSL market.
- Northeast Energy Efficiency Partnerships (NEEP), a non-profit organization, focuses on advocacy, and collaborates on and educates about energy-efficiency practices. As an organization, NEEP has implemented residential lighting programs. NEEP founded and administers the Design Lights Consortium and its SSL Qualified Products List.

- National Grid works with its stakeholders to promote development and implementation of energy solutions and has incented SSL technologies since 2006.
- Franklin Energy implements energy-efficiency and renewable energy programs for utilities and states. Franklin Energy participates and regularly engages in various elements of DOE's SSL program.
- Optimal Energy provides consulting services to utilities, program administrators, state and federal energy offices, regulatory commissions and other entities to promote and support energy-efficiency programs.
- Pacific Gas and Electric (PG&E) is the largest combined natural gas and electric utility in the United States. In conjunction with San Diego Gas and Electric and Southern California Edison, PG&E develops product line road maps for products and technologies, with SSL as a major focus. PG&E's lighting portfolio transitioned from fluorescent lighting to LEDs, including replacement lamps and fixtures. PG&E's has been examining the introduction of SSLs into their programs.
- Sacramento Municipal Utility District (SMUD) conducts multiple activities involving innovative technologies. SMUD operates a program piloting emerging technologies in real-world applications. The program testing results provide SMUD with information on whether specific products qualify for rebates and incentives. SMUD provides this information to manufacturers for performance improvements.
- New York State Energy Research and Development Authority (NYSERDA), a government research organization, focuses on energy supply and efficiency. A member of the DLC, NYSERDA has sponsored the group since its inception.
- Southern California Edison (SCE), one of four investor-owned electric utilities in California, particularly focuses on SSL's technological efficiency. SCE supports other incentive or resource-based programs helping to transform the market for more energy-efficiency lighting technologies, and actively participates in the lighting road map process.
- Efficiency Vermont, an energy-efficiency utility in Vermont, develops programs to reduce energy consumption. A statewide group, Efficiency Vermont provides energy-efficiency services for the commercial and residential sectors. Efficiency Vermont's focus on lighting strategies in the commercial sector; utilizing DOE's information on SSL products, it designs and develops programs, promoting LEDs, since 2008.
- Energy Trust of Oregon, an independent nonprofit organization, designs and operates energy-efficiency programs for utility customers in Oregon. Energy Trust of Oregon has worked closely with PNNL to shape the approach and strategy for LED introduction. Its' staff often speak at utility roundtables and rely on PNNL for advice on issues like LEDs and dimming.

Findings from Market Actor Interviews

This section presents findings from the market actor interviews, beginning with their feedback regarding their levels of awareness and participation in the program, and their insights into market actors perceived to have the greatest effect. The section then discusses the interviewees' views on challenges and barriers in the SSL market, followed by an examination of their views about the program's impacts on the market. The section concludes with a discussion of remaining opportunities, and recommendations market actors identified for methods DOE and PNNL can use to enhance this market.

Market Actors' Engagement with DOE's SSL Program

The individuals interviewed engaged with DOE's SSL program in various capacities. The majority of respondents knew of the various program elements and activities. In addition, a large group of interviewees participated in various program elements and activities. It is important to note that not all program elements are relevant to all market actors interviewed, and that not all categories of market actors were interviewed as part of this study. For example, standards organizations are not engaged or targeted in NGL design competition, and designers, the primary target audience for NGL were not a stakeholder category interviewed as part of this study.

Table 3 shows the percentage of individuals aware of the program's various elements and activities as well as the percentage of individuals participating in those program aspects. Interviewees knew the most about and participated in CALiPER and the general information components (such as workshops) and knew the least about and participated least in standard and test procedures and NGL.

Table 3. Market Actor SSL Program Awareness and Participation

Program Elements/Activities	Awareness (n=26)	Participation (n=26)
Technical Information Network for Solid-State Lighting (TINSSL)	85%	65%
Municipal Consortium, Fact Sheets and Market Studies, Postings, and SSL Updates	77%	62%
Workshops, Meetings, Roundtables, and Webinars	96%	81%
LED Lighting Facts	85%	69%
NGL Design Competitions	73%	50%
L Prize	88%	62%
CALiPER	100%	85%
GATEWAY Technology Demonstrations	85%	58%
Standards & Test Procedures Support	73%	42%

Influential Market Actors

Interview subjects, asked to identify key market actors or decision makers influencing the type and quality of SSL products available in the United States, most often cited manufacturers, followed by DOE and other organizations developing product performance specifications, as shown in Table 4. The "other" category shown in the table includes designers, distributors, specifiers, architects, and large-buildings owners and managers.

Table 4. Influential Market Actors in SSL Market

Influential Market Actors	Respondents (n=26)
Manufacturers	62%
Organizations developing product performance specifications and product lists, such as DOE, NEEP and EPA	46%
Big box and large retailers	27%
Energy-efficiency programs	27%
Standards setting bodies & testing labs	23%
Other market actors	31%

Manufacturers

Most respondents cited manufacturers (especially those producing chips) play key market roles, with large impacts on the performance and quality level of LED products. Manufacturers cited by respondents included: Philips, CREE, Cooper, Acuity, and Sylvania. One respondent specifically noted that manufacturers develop new types of SSL products and recognize quality as a requirement for success and participation in efficiency programs.

Organizations Developing Product Performance Specifications

Multiple respondents cited DOE, through its various programs, such as CALiPER and LED Lighting Facts, NEEP, through its DLC QPL, and EPA through the ENERGY STAR programs, as key market-actors influencing the type and quality of SSL products available in the market. One respondent remarked that DOE has played a critical role as a credible third party, and another noted that DOE has played a major role in maintaining consistent requirements that suppliers must meet, along with proper testing for LED standards. Another respondent identified specific individuals in the DOE program for their important roles in advancing quality SSL products and their work in areas such as CALiPER and GATEWAY and due to their expertise in outdoor luminaires and indoor luminaries.

One respondent cited the important role that NEEP plays in developing the DLC qualified product list. One respondent pointed out DLC's influential role due to manufacturers' participation. Another respondent cited other influential groups, such as the Lighting Research Center of Rensselaer Polytechnic Institute.

Big Box and Large Retailers

Multiple respondents cited big box retailers such as The Home Depot, Lowes, Wal-Mart, and Target as major players, due to their direct influence of product availability and consumers' adoption of SSL products. One respondent noted key market actors include large retailers (because they carry the products and educate customers). Another respondent noted that, in retail, merchants drive the quality of products, based on benchmarks of product quality. One respondent specifically mentioned the importance of large retailers, as they conduct large-scale retrofits.

Energy-Efficiency Programs

Five respondents cited energy-efficiency programs and utilities as important market actors due to the influence of their incentives programs. One respondent noted the influence of program delivery entities in specifying which technologies they will support at a given time.

Industry Standards-Setting Bodies and Testing Laboratories

Three respondents reported that industry standards-setting bodies—such as IES and NEMA—and testing laboratories play an instrumental role in establishing specification requirements and testing criteria for SSL products.

Other Market Actors

Three respondents included customers as key market actors. One respondent cited hospitals, such as the Mayo Clinics, while another specified large property managers or developers as significantly influencing SSL stocks and quality due to purchasing lighting for numerous properties. Two respondents cited designers, specifiers, architects, and distributors as influential because they push for quality products. One respondent reported that a combination of distributors and manufacturers, in conjunction with DOE, would serve as the best market actor.

Challenges and Barriers

Interviewees were asked to identify the primary challenges and barriers facing the availability of quality SSL products in the market; and to identify the primary challenges and barriers involving adoption, in terms of customer acceptance, of these products in the residential, commercial, and industrial markets.

Major Challenges and Barriers

Respondents identified the following challenges as key factors currently affecting the availability and adoption of quality of SSL products:

- Cost
- Consumers' awareness and trust
- Technical and performance characteristics of SSL products
- Production capacity, supply, and demand

In addition, when interviewees were asked to identify future challenges facing the SSL market, the challenges were similar to the current challenges, with the addition of compatibility and appropriate

applications. One of the respondents remarked that the greatest challenge in the years to come will be continuing to manage and reduce the initial cost for the end user. Another respondent mentioned that the greatest challenges facing SSL in the future are keeping costs low, reaching consumers effectively to increase adoption, maintaining quality of light, exploring new performance and quality factors, and correcting issues with dimming and controls compatibility.

Table 5 shows the distribution of responses regarding the challenges affecting quality SSL product availability and adoption.

Table 5. Cited Primary Challenges Affecting Quality SSL Product Availability and Adoption

Challenges	Respondents (n=26)
Cost	69%
Consumers' awareness and trust	31%
Technical and performance characteristics	19%
Production capacity, supply, and demand	12%

Cost

The majority of respondents reported cost to be the primary challenge facing the availability and adoption of SSL products in the residential, commercial, and industrial markets. A respondent reported that high costs, combined with limited customer experience with LEDs, will lead consumers to consider LEDs an immature technology. Another respondent noted high costs prove prohibitive to implementing trials with commercial and residential customers. Another respondent stated that many customers prove reluctant to seriously consider LEDs, given that the product offers the same performance as other bulbs, but costs more. A few respondents raised concerns regarding how much customers should pay for SSL products while the technology continues to evolve and improve.

Three respondents said that pricing, having objective information, and being able to direct people to it is a major ongoing challenge. Another respondent remarked that pricing needs to adjust to a point where people can afford SSL and understand the value of the products. Another respondent suggested a cost payback calculation method that is readily available to consumers was needed as a way to encourage adoption of SSL technologies.

Consumers' awareness and trust

Most respondents cited consumers' awareness as a significant challenge facing the adoption of SSL products. Respondents, however, noted commercial customers generally knew of SSLs more frequently than residential customers did. Another respondent noted that the industrial and commercial markets primarily differ in that the industrial sector operates more conservatively than does the commercial sector.

Several respondents said that consumers had reservations about new lighting technologies as a result of early CFL performance. Combined with the lack of awareness about the technology and knowledge

about how SSL can be used in homes, these issues remain as key challenges that must be addressed to influence adoption of these technologies.

One respondent noted that many consumers continue to wait to identify products they can trust, and when this happens they will enter the market with more confidence. This respondent felt the wave of early adopters had passed, and a lag exists as others continue using CFLs (or even incandescent lamps) until LEDs enter the mainstream. Another respondent stated that some SSL products still do not have traditional shapes that are compatible with a consumer's existing sockets—a challenge for the residential sector. Another respondent echoed this view in citing challenges arising from the visual aesthetics and feel of the products.

A respondent found that residential consumers required further education regarding LEDs, despite the substantial educational efforts underway. Consumers especially require more tools to compare and understand products. Another respondent observed that the lighting industry has yet to determine how to differentiate fluorescent and SSL technologies for the end user, as evident in consumers' lack of understanding of the added value of SSL products and the benefits they provide in comparison to other technologies.

Several respondents raised issues addressing credibility and uncertainty among consumers regarding SSL products; remarks that were made on these issues include:

- Some consumers did not believe the bulbs' claimed long lifespans and this represents a substantial information gap that DOE must address.
- Although people knew of SSLs, the remained uncertain what products to trust.
- Consumers have exhibited a lack of understanding during the incandescent phase-out, and do not understand which new technologies to choose from.
- Commercial customers remained uncertain of SSL products.
- Helping consumers understand how to properly evaluate SSL products remained the biggest challenge.

When asked about future challenges, many responses echoed the current challenges:

- A respondent noted managing high consumers' expectations will be a challenge going into the future.
- Respondents cited maintaining product quality and efficiency as a continuing challenge for SSL adoption and suggested there needs to be a way to delineate between cheap price and poor quality to help keep customers from purchasing bad products.
- One respondent recommended that appropriate quality standards be set in place.

SSL products' technical and performance characteristics

The third most commonly mentioned type of factor limiting SSL adoption and availability was technical and performance characteristics. Respondents most often reported that SSL product performance and

technical qualities were challenges affecting the *availability* of quality products in the market. Some of the technical and performance limitations that were cited by respondents include:

- Some SSL products produce insufficient light output, reinforcing customers' impressions that the technology remains immature.
- Controllability—specifically regarding dimming—remains a major barrier as customers expect a perfect product and solution.
- Many commercial customers expect LEDs to match existing lighting in performance and color (which they cannot); the challenge proves even greater for the residential sector as customers make decisions on their own, while commercial customers have designers and specifiers to aid them.
- Manufacturers and suppliers of SSL products present large variations in advertised products' performance and specifications, which indicates a need to ensure the accuracy of advertised attributes.

One respondent said the quality of SSL products in terms of color consistency presents another challenge facing development of these technologies. Other respondents highlighted the following major challenges facing the wide availability of quality SSL products:

- Uncertainty regarding compatibility with control systems
- Appropriate application of SSL products
- Lack of standards for LED drivers

Production capacity, supply, and demand

The final category of challenges mentioned by respondents was related to the rate of technological development and lag times between the development of new technology and its availability to consumers. For example, a respondent said product availability becomes an issue when promoting a technology in advance of its availability. Promotion generates interest, but there is a time lag between when consumers receive the information about new products and when these products become available. Furthermore, retailers may be eager to stock the newest technologies, often before they are market-ready.

Respondents mentioned several specific issues related to incompatibilities between the timing and extent of product supply and market demand, including the following remarks:

- When technology changes rapidly, products may not be available long enough for consumers to learn about and adapt to them.
- Production capacity is the biggest issue currently encountered, as demand for SSL products increases and there is insufficient capacity to produce high-quality products.

A respondent noted that the classical split incentive problem was a challenge for the adoption of SSL technologies in leased commercial space since a tenant occupying a space for three to five years is likely

to care little about energy efficiency and the property owner may be reluctant to invest in energy efficiency because the tenant pays the utility bill.

Regarding future challenges, one respondent noted that one challenge will be verifying whether the tested or rated chips for SSL technologies are the same chips that end up being sold. The respondent clarified that from an industry perspective many of the current chip manufacturers are generally reputable, but this could be a challenging area in the future. Dimming issues and cost were also identified as ongoing challenges likely to become more significant in the future as demand grows. Multiple respondents specifically identified SSL design, appropriate application, and compatibility with a range of pre-existing dimmers as key future challenges.

Program Effectiveness

Interviewees were asked a battery of questions to identify how the program has addressed the market barriers and challenges, specifically in the following areas:

- Program effects on coordination among various market actors
- Program's information dissemination activities and effects of these activities
- Program effects on product performance and quality, cost, and applications

Interviewees also were asked to rate DOE's SSL program overall regarding its targeting of the appropriate market actors; staff responsiveness in providing feedback to market actors; dissemination of high quality and useful information; and facilitating market introduction of high-quality SSL products.

The responses were generally very positive regarding each of these measures of program effectiveness as shown in Table 6. In most cases, nearly all respondents agreed with the statement about the program. The only notable exception was one respondent who gave a low rating regarding the staff's responsiveness in addressing the feedback received from market actors. The area where the program received the lowest average rating was in successfully facilitating market introduction of high-quality SSL products, but 23 of 26 respondents agreed that it had been successful.

Table 6. Respondents' Ratings of DOE SSL Program Effectiveness

Program Effectiveness Measure	Agree	Neutral	Disagree
The SSL program provides unbiased, objective information.	96%	4%	0%
The information received from the SSL program has been valuable.	96%	4%	0%
The SSL program has been successful at facilitating the market introduction of high-quality SSL products.	88%	12%	0%
Program staff members are responsive to feedback from market actors.	96%	0%	4%
The SSL program is targeting the correct market actors (such as manufacturers, program sponsors, retailers etc.).	100%	0%	0%

We have grouped the market actor responses to the questions on program effects into the following topic areas:

- Changes in technical knowledge and awareness about SSL product performance and appropriate applications
- Changes in product quality and performance
- Effects on product costs
- Effects of specific program elements

Effects on Knowledge and Awareness

The interviews provided the most information on how the program had affected market actor knowledge and awareness about SSL products. Overall, the responses indicated the program has been successful in communicating useful information about product performance, quality, and appropriate applications.

Several respondents highlighted the program's role in increasing SSL awareness and knowledge through its effort directed at increasing collaboration among market actors and DOE:

- Several respondents indicated the major benefits of the SSL program included networking and collaboration. One respondent stated that DOE has done an excellent job facilitating collaboration and communication among market actors and the EPA.
- Most respondents concurred that DOE's and PNNL's efforts have increased collaboration, which facilitates sharing knowledge of and views regarding SSL technologies.
- Some respondents agreed that DOE's efforts to bring together stakeholders have increased communication and collaboration, thus benefitting the SSL market.
- Other respondents noted that DOE's SSL program elements were especially valuable in providing a medium for increased communication and collaboration between manufacturers and lighting designers.
- One respondent stated that DOE's model of uniting diverse stakeholders early in the technology's development history "got the ball rolling" and has been replicated successfully by other groups. Another respondent agreed, noting that the program created a clear path that brought the industry together to address issues from the beginning of the product life to its end use.
- One respondent noted the collaborative process has proved very influential in helping the SSL industry to grow at its current, rapid pace, especially through use of milestones and communications about progress toward those milestones.
- Another benefit noted by one respondent was that DOE's collaboration efforts changed an older perception of DOE's role as one of an adversary to one of a partner.

Outreach activities, especially those conducted through TINSSL, received high marks from most market actors in terms of enhancing awareness and knowledge:

- There is general consensus amongst most respondents that the TINSSL program elements, along with webinars and workshops, proved absolutely critical in advancing SSL products and in increasing communications and collaborations among stakeholders. One respondent noted that the information disseminated through workshops, webinars, and other means has had a significant impact in closing the gap between manufacturers and their customers.
- Another respondent stated that without DOE's program the information flow would not occur, and another highlighted the value of the timely information provided by the program.
- One respondent noted that DOE provided a positive platform for information flow, speeding the adoption of SSL technologies to consumers. They perceived DOE's main role to include a leadership position, and, without such leadership, SSL adoption would have taken longer (which relieved some of the burden on manufacturers).
- One respondent felt that workshops were more effective than webinars because participants became more engaged.

Interviewees were asked to comment on the content and type of information they received from the program and how useful that information was to their respective professions, organizations, or programs. The majority of respondents found the various types of information provided by the program to be very helpful and said they applied the information in various ways in their respective organizations:

- The majority of respondents concurred that the information they received helped them improve their understanding of quality SSL products, guide their technology selections, and develop minimum specifications for energy efficiency programs. One respondent noted that market studies had helped one of their energy efficiency programs determine the energy savings potential of SSL, and LED Lighting Facts was used as a component in their programs and as a reference for customers.
- Respondents from standards and testing labs indicated that they used the program SSL information in a variety of ways. One noted that they used it to understand what customers need and to develop testing procedures and services aligned with those needs.
- Another respondent stated that all of the program's venues and channels were very helpful because they all play different and complementary roles: for example, the GATEWAY demonstration information provided a practical application example to learn from, while information about performance issues and challenges gave market actors a benchmark from which to operate. The respondent commended DOE on providing the right type of targeted information through those venues.
- Another respondent stated that the information DOE provided was useful because it helped limit the introduction of cheap and low-quality products into the market.

Interviewees also were asked to discuss how DOE's SSL program has affected the market through the quality of information made available by the program to stakeholders such as designers, specifiers, program sponsors, and retailers. There was a general consensus that the program has had a large impact on the market through the information it provided. Two effects commonly noted by the respondents included:

- Easy access to quality information (from an unbiased, independent, and trusted source) that could be used by various market actors, for example to inform consumers and establish industry standards
- Availability of information to benchmark quality products, therefore decreasing the likelihood of poor products surviving the market.

Specific observations about the effects of the program information on market actors on the supply side of the market include:

- DOE's SSL program provided access to effective information that organizations can distribute to their customers, such as energy efficiency programs. One respondent stressed the importance of the information being from an unbiased source.
- The SSL program provided a useful avenue to obtain information and had increased the quality of information available, decreased confusion in the marketplace, and helped remove inferior products.
- The program has provided quality information to stakeholders. One respondent noted the importance of the independent voice that DOE brings and the fact that there is more information on SSL products than there had been with prior technologies.
- DOE SSL program has been effective in providing useful information to the supply-side of the market. One respondent noted the value to retailers of establishing communication on benchmarked SSL products.

There were a few comments, however, on areas for improvement in the program's delivery of information to the supply side of the market:

- Two respondents were unsure of the impact the information made with retailers, with one remarking that the method in which information was disseminated made it challenging to impact some market actors.
- Two other respondents noted the information needed to reach a wider range of audiences.

Cadmus also interviewed respondents about how the DOE SSL program has affected the market through the quality of information made available by the program to end-users and customers. There was a general consensus that the program had a smaller impact on the market in this particular area and that there were opportunities for the program to increase its educational and outreach activities to consumers and end-users. Some of the remarks made by respondents include:

- Although the program has had a positive effect in providing quality information to end users and customers, the program had not been as successful as it was in other areas.
- The SSL program has had a positive effect in this area, but there is more work to be done. One respondent stated that reaching big box customer is still a challenge because the average consumer lacks knowledge about traditional light sources, making it difficult to convey the benefits of SSL products. For retailers and specifiers, "the importance of these programs is huge" because they have more knowledge than the average consumer and they can take steps such as directing people to the SSL program website.
- One respondent stated that, aside from the LED Lighting Facts program and the LED Lighting Facts Label, there is little success in this area and there is room for improvement.
- One respondent pointed out that customers do not think to obtain information from DOE and generally seek information from lighting manufacturers' websites ; such sources of information could be less reliable than information from an independent and trustworthy source, like the DOE.

Effects on Product Quality and Performance

We asked Interviewees to describe how DOE's SSL program affected the SSL market through its efforts in addressing SSL quality and performance. We also asked interviewees their views on the program's effects in increasing the pace of development of quality SSL products. Overall, the respondents gave the program very high marks for enhancing product quality and performance:

- Most respondents indicated that the quality and performance of the SSL products had increased as a result of DOE's SSL program. One respondent remarked that they were able to get good information on where technologies were in the pipeline and this enabled them to determine the level of support they should provide.
- Another respondent indicated that the program directly led to manufacturers improving performance.
- Most respondents agreed that DOE's SSL Program had played a large role in improving product quality and performance. One respondent mentioned that increased product quality had increased adoption of these products. Another respondent stated that the program's focus on quality led to advancements in three years that could have taken 10 years otherwise—the combined efforts of the SSL program elements have "pushed people to understand what a quality product is and support that."

- A respondent stated that DOE's activities in this area helped establish minimum benchmarks for quality products and helped weed out low-end products.

Effects on SSL Product Cost

Cadmus asked interviewees to describe their views on how the DOE SSL program had affected the SSL market by addressing the cost of SSL products relative to competing technologies. There were mixed views and uncertainties expressed by the respondents regarding the effects of the program on the cost of SSL products.

- Insufficient information on costs limited the ability of several respondents to provide views on how the program had impacted product cost. However, there was a general consensus among most respondents that information disseminated through the SSL program had had a positive impact in decreasing the cost of quality products. One respondent suggested that DOE should provide more information on pricing, perhaps through a database.
- Several respondents pointed out that DOE's activities had accelerated the cost-competitiveness of SSL products particularly during the introductory phase of SSL technology.
- Other respondents noted SSL products are still costly and more work needs to be done to bring the cost down.
- Two respondents took the view that the program had led to higher costs for SSL products than would have occurred without the program. One respondent thought the program's efforts might have increased costs because it promoted higher quality products than what might be in the market without the program. Another respondent concurred that cheaper products probably would have been on the market without the program, but the cheaper products would have been of lower quality.

Effects of Specific Program Elements

When we interviewed market actors, we also asked about their views on the impacts of specific program elements, and their feedback is summarized below.

TINSSL

The majority of the respondents thought the information provided through TINSSL was very valuable in increasing awareness and understanding of the benefits of quality SSL products. One mentioned that the information was very useful in developing training and educational materials. Another respondent had a more neutral view, saying that it had been only somewhat valuable, noting that explaining the benefits of SSL products was not as important as it was in the past.

LED Lighting Facts, Market Studies, and Fact Sheets

Most respondents indicated that LED Lighting Facts has been very successful in increasing awareness and understanding of the benefits of quality SSL products. One respondent noted that the influence of LED Lighting Facts has improved over the last year, whereas it was not as influential during its first five years.

The majority of the interviewees concurred that information dissemination through LED Lighting Facts has led to increased awareness and understanding of the benefits of quality SSL products, which has impacted the pace of technology development. One respondent mentioned that LED Lighting Facts had a large influence on high quality SSL products and helped them educate their customers on product selection. However, one respondent stated that the information was not as valuable for consulting businesses.

Most respondents also thought that the LED Lighting Facts program was successful in increasing awareness and understanding of the benefits of quality SSL products.

However, few respondents were less positive about LED Lighting Fact's contribution to increasing awareness and understanding of SSL products. Some of the remarks made include:

- Two respondents said that consumers still do not know to look for the label.
- One respondent said that it had never been viewed as a way to promote the benefits of LEDs—"it's just a database."
- Notably, some of the respondents mentioned that the LED Lighting Facts program was not the basis of their incentive programs. Four respondents indicated that they used the DLC and not LED Lighting Facts.

NGL Design Competition

Most respondents indicated that the NGL competition program was somewhat influential in the pace of development of commercial SSL applications:

- One respondent indicated that NGL competition provide more benefits to participating manufacturers, such as increased promotion of winning manufacturers,
- Another respondent noted that the competition generates interest around the winning products and raises awareness of SSL products, but some manufacturers don't pay attention to the competition at all.

One respondent observed that the NGL competition has been somewhat influential in accelerating the pace of development of SSL products. However, the respondent noted that, while the competition showcases the top products, it does not generate the same technical information as other DOE SSL programs. One respondent reported that NGL was not too influential because the criteria used in the competition were not viewed as credible by market actors in the industry.

L Prize

Overall, there was consensus among the majority of respondents that the L Prize program was influential in influencing the pace of development of high quality SSL products, but respondents noted that high cost and limited availability of the winning product may have hindered customers' uptake.

Several respondents made observations regarding the perceived difficulties with implementing the competition, including:

- The rapid pace of development for SSL products was the most often mentioned difficulty perceived by respondents in implementing the competition.
- One respondent suggested that introducing criteria in future competitions that address improvements in efficacy and quality characteristics of SSL products may increase the likelihood that more manufacturers would participate in the program, therefore increasing the competition and the influence of the L Prize program on the pace of development of quality SSL products.
- One respondent noted that although customers were satisfied with the winning bulb's performance, the price was too high and sales were not as anticipated. One respondent mentioned that L Prize is somewhat influential with manufacturing companies because it provides manufacturers with a comparison point for new products that are available in the market.

CALiPER

There was a general consensus among most respondents that CALiPER has increased the accuracy of reporting by manufacturers on product performance and quality of products available, and has had impacts on sales and the resulting electric savings. One respondent remarked that CALiPER has been incredibly valuable, especially at the beginning of SSL development, and the benefit CALiPER provided was enhancing the performance of the technology in comparison to other technologies. This respondent added that it essentially brought about truth-in-advertising for SSL products, and also conveyed the importance of the need for testing. Respondents cited CALiPER testing results to be one of the most valuable program products.

A few respondents indicated that some of the effects from CALiPER were indirect or difficult to determine. Indirect effects that were cited by the respondents included the quality of products resulting from the program's reporting, product sales, and savings.

- One respondent commented that the impact on energy savings was likely fairly small so far due to the limited number of LEDs being used as compared to conventional products, noting that this has more to do with the cost of the product than with the impacts from the program.
- Another respondent noted that it is hard to accurately determine CALiPER's impacts on sales and savings related to quality SSL products due to limited information available on sales and savings. They mentioned that customers' experience was improved through good reporting of information, which consequently encouraged companies to provide accurate numbers on their packaging for customers.

GATEWAY Demonstrations and DOE Municipal Solid State Street Lighting Consortium

With a few exceptions, there was a general consensus among respondents familiar with GATEWAY that the program had increased awareness and visibility of SSL products and provided information about SSL product performance, as well as affected the level of sales, adoption rates, and savings pertaining to quality SSL products.

- A respondent noted that the level of sales can be attributed to the confidence consumers have in the quality of products as a result of GATEWAY demonstrations.
- A few respondents, however, believed there was no direct effect of GATEWAY on the sales of quality products. One respondent remarked that GATEWAY had not done a great job in targeting the correct market actors, such as lighting designers and potential end users. Another respondent noted that it is hard to understand reliability of some of the program's reports because the reports do not present lighting quality data or lighting results clearly.
- Some respondents noted that the information from GATEWAY demonstrations has been invaluable while a few respondents noted that they rely more on CALiPER data.

All respondents familiar with DOE's MSSSLC agreed on the positive impacts that the program has had on increasing awareness and visibility of SSL products. One respondent noted that this program was effective in providing objective information on SSL products and promoting information exchange. All respondents agreed that the Municipal SSL Consortium had had an impact on the quality of SSL products available in the market, sales of quality products, the adoption rate for quality SSL products, and electricity savings.

Standards and Test Procedures Support

The general consensus from respondents familiar with this aspect of DOE's program is that DOE's standards and test procedures development support has been very useful in influencing the development of effective and credible standards and test procedures, and has helped enhance the quality of SSL products available in the market and provide electricity savings.

- A respondent noted that the impact has been even bigger internationally, because the IES has taken the lead in the development of many standards. However, one respondent from the manufacturers and trade organizations group mentioned that there is a need to push IES and other standards-setting bodies to adopt standards more quickly.
- One respondent remarked that these mechanisms provide quality control and baselines, which are very important in this market.
- A respondent that DOE's involvement, while behind the scenes, has been instrumental in making sure standards are believable and achievable and helping to make the standards and test procedures committees "one big happy family" of representatives working together to develop complex procedures.
- Another respondent remarked on the important role that DOE played in helping market actors understand and use these standards and testing procedures.

Opportunities and Recommendations to Accelerate Market Adoption of SSL Products

Interviewees were asked to identify opportunities that were available to mitigate the current challenges and barriers facing the availability and adoption of quality SSL products. In addition, interviewees were asked to recommend specific steps and approaches the program could pursue to enhance the SSL market.

Opportunities

Most interviewees agreed that there were significant opportunities to accelerate adoption of SSL products. One of the manufacturers interviewed mentioned that it was basically a matter of time before SSL products were widely adopted as there are many great products on the market. The respondents identified the following opportunities to overcome the challenges facing the availability and adoption of quality SSL products:

- Enhancing market actors' engagement and coordination
- Educating the demand side of the market and increasing awareness
- Reducing initial cost and improving product performance.

Market actor engagement and coordination

Several respondents saw increased engagement with and coordination among market actors as an opportunity for accelerating SSL market adoption. A respondent said market actors in the supply chain determined what products were produced and available to end users, so focusing on this area offered a great opportunity. In particular, opportunities existed for working up the supply chain to manufacturers to ensure production of quality products and testing coordinated with standards and testing bodies, and then moving down the supply chain to educate and influence retailers, distributors, and sales representatives on the SSL products' benefits.

Other opportunities mentioned for engaging market actors and enhancing coordination included:

- Sharing information between architects and manufacturers, possibly through round table discussions, so manufacturers could be made more aware of challenges associated with specifying a product.
- Providing outreach and education about SSL products more proactively to architects who tend to prefer information about "look and feel" over technical specifications. Outreach could include materials such as best practice design templates.
- Working more with retailers, as suggested by a respondent from one big retailer, to ensure quality products are available because retailers provide education to all customers—residential and commercial. This influences utility support through incentives and ensures that manufacturers engage retailers properly, through targeted price points and a product launch strategy.

- Developing new specifications more rapidly and providing a road map for upgrading specifications by SSL product type and appropriate applications could engage manufacturers more in the process.
- Aligning all energy-efficiency programs with the same specifications also would drive manufacturers toward developing better-quality products and eliminate currently existing market confusion.

Demand-side education and awareness

Many respondents cited a wide range of opportunities for enhancing SSL market adoption through increased consumer and user education. Key opportunities noted included the following:

- Increasing awareness of LEDs' benefits as a way to offset some concerns about adoption risk and reduce the likelihood of choosing products based on lowest cost.
- Increasing the focus on the residential market, as suggested by one manufacturer respondent, because it is the fastest growing market, though the smallest market to date.
- Conducting webinars or other outreach efforts to commercial real estate professionals, facilities managers, and building operators on the energy savings potential and selling points of maintaining an efficient space, especially for renters.
- Using flyers, displays, and product packaging information (as suggested by respondents from trade organizations) to inform customers about the benefits of SSL products
- Communicating more to commercial specifiers and purchasers what testing numbers mean and using metrics such as ENERGY STAR to narrow the information gap for end users
- Providing enhanced training for designers, specifiers, and end users about controls and SSL compatibility and encouraging more involvement by designers
- Reaching consumers using mass market media, rather than a website or other tool, and informing consumers using brevity and digestible information

Reduction in cost and improvement in product performance

While SSL product cost was identified as one of the major barriers to wider adoption, the market actors interviewed identified many opportunities for reducing this barrier. Respondents also frequently mentioned that opportunities could be leveraged in enhancing product performance and bringing down the cost of SSL products.

Many respondents suggested continuing incentives and rebates to overcome the residential consumer cost barrier and one respondent noted that when consumers see the benefits from quality products, more rapid adoption will occur and prices will fall. This respondent cited the computer industry as an example of this phenomenon.

- A respondent addressing the commercial market recommended using rebates in different regions to reduce product costs.

- Similarly, other respondents recommended offering rebates to customers to reduce costs in all market sectors.

Although several respondents mentioned rebates and incentives, there were other mechanisms identified to reduce the product cost challenge:

- One of the respondents noted how helpful DOE's grants to manufacturers have been in driving down costs.
- A respondent noted that the biggest push to address the cost challenge has emerged from the chip side and he noted opportunities existed for improving phosphor efficiencies and chip efficiencies to reduce overall LED costs.
- A respondent said LEDs currently perform well, but the bar has been set too high for the technologies (such as for life span) and the respondent suggested that, if DOE imposed a lower life requirement and electrical requirements similar to CFLs, cost would fall and the adoption rate would increase.
- A respondent provided a similar view—that an opportunity to accelerate adoption for SSL products could be achieved by streamlining the ENERGY STAR review process for labeling SSL products, allowing for a very fast development cycle and reducing risks and costs. The respondent expressed a concern that the more time required for testing, the higher risk there was of becoming outdated or even obsolete. The respondent did note, though, that the process still needed to identify poor-quality products.

Many respondents pointed out the link between product cost, product benefits, and performance. Several noted the need to convince the market of the performance benefits of SSL products.

- One respondent cited the need with commercial and industrial markets to demonstrate that products will last as long as advertised to rebut skeptics.
- A respondent reported that LED Lighting Facts has greatly helped to address some issues, but the FTC should continue to enforce performance standards and keep bad products out of the market. Another respondent said the program's efforts towards maintaining minimum criteria for entry into the market serve as an effective start because they screen out very low-end players.
- One respondent recommended maintaining SSL products that reflect the ENERGY STAR standard, which will help avoid the backlash resulting from poor-quality CFLs.
- One respondent noted the residential sector is "about numbers;" if consumers become aware of quality SSL products at reasonable prices, adoption should increase substantially. In his view, product attributes such as long life, color quality, and dimmability position SSL lamps better in comparison to competing technologies.

Several respondents identified specific ways in which the performance characteristics of SSL products could be demonstrated to consumers and enhanced to lead to wider adoption. Several respondents pointed out the merits of coupling controls with SSL products:

- One respondent remarked that smart, integral controls offer an opportunity to accelerate SSL adoption as they do not require multiple systems. The ease and low cost of adopting wireless connectivity for controls makes them easier to adopt.
- A respondent stated the biggest opportunities for energy savings today remain in the commercial and industrial sector and include integration of commercial and industrial lighting with building lighting controls, as standards currently do not address this issue.
- One respondent noted that plenty of opportunities exist within the commercial sector, as these customers know more about the benefits and cost savings associated with lighting. Opportunities for increased adoption of SSL applications exist for down-lights, outdoor lighting, track lighting, spot lighting, directional lighting, and decorative luminaires. Opportunities exist for many SSL applications as SSL becomes increasingly viable at high-mounting positions.
- Respondents identified SSL applications—including high-bay lighting, indoor ambient lighting (troffers, pendants, and linear), and street lighting—as offering the greatest opportunities within the industrial sector to increase adoption of high-quality SSL products. The industrial sector differs from the residential and commercial sectors due a better understanding of and accounting for life cycle costs in lighting design.

Market Actor Recommendations to Improve DOE's SSL Program

When asked to provide their recommendations on how the program could be improved, the respondents provided a wide range of suggestions.

Recommendations on Current Program Elements and Activities

When asked for their recommendations about how to enhance the SSL program elements, many market actor respondents offered very positive feedback on the program's accomplishments in addition to specific recommendations. Some respondents provided contradictory recommendations, but there were a few common themes such as the need to continue and increase information flow and outreach, enhance collaboration with market actors, and minimize overlap and inconsistencies among various rating systems and data. The market actors provided diverse recommendations, summarized below, for how current program elements and activities could be improved:

TINSSL and information content and dissemination

- Multiple respondents indicated that the SSL program provides excellent and useful information through quarterly calls, but that TINSSL should include more information on GATEWAY and CALiPER.
- Several respondents suggested the audience reach should be expanded, especially because the information was considered to be new and useful. One respondent suggested broader dissemination. Another recommended the use of mainstream media, such as National Public

Radio and newspapers, to disseminate information to a wider audience. Another respondent noted the importance of doing more market surveillance to understand better consumer perceptions and needs and to guide information content and distribution.

- A respondent recommended that DOE collaborate more with the designer community, especially on issues regarding appropriate applications and implementation of SSL products.
- Regarding the LED Lighting Facts program, some respondents recommended that DOE/PNNL partner with retailers to focus on promoting the label in stores.
- Respondents recommended enhancements to LED Lighting Facts including: requiring submissions to include lifetime data on products; identification of whether products are ENERGY STAR certified or supported through DLC; and additional provisions of color information, such as reporting the R9 value (a measure of how well the light source renders deep red colors); the program currently provides information on color appearance and general color rendering.
- A few respondents pointed out the potential for market confusion due to the existence of two lighting labels, the FTC and DOE labels, and inconsistencies between the DOE and EPA databases.

NGL Design Competition

- Some respondents noted that there is a need to integrate the NGL with the DLC, EPA, and utility databases, to streamline program managers' ability to use the information.
- Other respondents suggested engaging more manufacturers and utility programs.
- A respondent suggested that more marketing around the NGL and its outputs would allow people to understand that the technology is evolving and improving constantly. A respondent recommended that winners from the NGL competition should be promoted more broadly beyond the lighting industry groups.
- One respondent recommended that NGL support commodity grade luminaires and SSL products, while a respondent from the manufacturers group suggested that there should be more objective criteria incorporated into the judging criteria, citing style and aesthetics as not being objective criteria.

L Prize

- Several comments centered on connecting the L Prize better to the market, but did not typically offer ways to remedy limitations. Some respondents noted their view that L Prize bulbs are not ready for the market when they receive the award. Another respondent said the cost of L Prize bulbs is too high and recommended that price competitiveness be embedded into the competition. Despite the changes DOE made in 2012, members of the energy efficiency and initiatives group recommended reducing the demands on the PAR38 competition and shortening the testing process, but manufacturers and distributors disagreed, saying they were satisfied with the changes DOE had made.

- Several respondents suggested ways the L Prize could have more immediate influence on the market, including placing winning products into the hands of utilities immediately after the competition, increasing promotion activities of the L Prize winners, and partnering with manufacturers to increase product availability in the market.
- Finally, a few respondents suggested enhancing the program by expanding the categories offered and incentivizing companies that demonstrate achievements above the established targets in L Prize.

CALiPER

- Several respondents said the troffer study produced through CALiPER was very useful and they would like to see more demonstration studies.
- A respondent said he would like to see a report on every product line each year so users would know how products are trending over time. One respondent recommended that CALiPER test products more frequently and another respondent recommended that the information be summarized in a consumer-friendly way.
- One respondent suggested that the CALiPER program lend its technical expertise to the ENERGY STAR program and work closely with the EPA to strengthen that program from a technical perspective.

GATEWAY

- Several respondents recommended that GATEWAY disseminate and advertise its results to a wider audience by expanding the program's outreach and marketing activities, for example, by focusing on high-bay lighting.
- Another respondent recommended that the program should increase its partnerships with local utilities.
- A respondent suggested that GATEWAY expand the number of demonstrations, and a respondent recommended that GATEWAY conduct and provide more post-installation analysis.

Municipal Solid State Street Lighting Consortium

- Two respondents recommended that GATEWAY increase its staffing levels to dissemination of the benefits of the technology as well as policy-related issues to municipalities, which have no background information on these subjects.

Standards and Test Procedures Support

- Several respondents had mostly positive comments about the program's standards and test procedure activities. Their recommendations focused on the program working more closely with ANSI and other standards organizations.
- One respondent stated that standards and test procedures should focus more on lighting quality, not just quantity factors.

Recommendations on Increasing the Impacts of DOE's SSL Program

Interviewees were asked to provide recommendations, based on lessons learned from the past introduction of new technologies, that could be applied to the SSL market and recommendations for new activities the program should pursue to speed the adoption of quality SSL products.

Lessons learned

Most of the recommendations reflecting lessons learned from the introduction of other technologies were based on experiences with CFLs. One respondent cited the document that DOE developed, *CFLs in America: Lessons Learned on the Way to Market*, as a valuable tool to guide SSL product introduction.

- A major, recurring recommendation based on lessons learned with CFLs was the need to ensure quality control of SSL products, particularly as they are promoted by utility programs.
- An associated recommendation was the importance of defining and applying appropriate quality metrics and thresholds, for example, color quality replicating that of incandescent bulbs, to ensure customer acceptance.
- Several respondents pointed out that little attention was given to designing with CFLs and recommended this be considered for SSLs.
- Three respondents were careful to point out that SSL technology is not the same as incumbent technologies and needs to be treated differently, by staying ahead of changes in technology and communicating those changes to all market actors well in advance. One respondent mentioned that the semiconductor and electronics industries should be studied to provide insights into how SSL technologies might evolve.

As with recommendations involving most of the current program elements and activities, many respondents reflected on the past benefits of collaboration and recommended continued and expanded collaboration:

- A respondent mentioned the importance of bringing all stakeholders together to discuss all facets of the program before setting a mission statement. A specific recommendation was to create a group of 12 to 15 industry leaders to enhance collaboration and to open the discussion to the larger community.

New program activities to accelerate SSL market adoption

Market actor respondents recommended that DOE/PNNL direct its future efforts primarily to three areas to accelerate the adoption of SSL products: (1) enhanced outreach and education targeted to consumers, (2) improvements in the performance and efficacy of SSL products, and (3) reduction of initial cost for consumers. Within these areas they presented a few recommendations for specific steps that the program could take, primarily involving increased outreach and education:

- Regarding outreach, one respondent stressed the need to overcome the very large gap between people engaged in the energy-efficiency world and typical consumers. Others echoed this, stressing the need to provide education to reduce confusion among consumers.

- Reiterating recommendations made related to other topics, some respondents recommended DOE/PNNL work closely with a range of standards bodies to ensure that standards are regularly updated and created to include quality standards for future products. A respondent added that collaboration should be enhanced to ensure consistency of standards and suggested that PNNL be involved in modifications to the ENERGY STAR program as it relates to SSL, for example, by helping guide the discussion about color consistency versus angle.
- Although there were few recommendations on how the program could best reduce costs or improve performance, one respondent suggested creating a higher tier in ENERGY STAR as a way to motivate performance improvements, and possibly cost reductions of more standard products.
- Finally, the theme of enhanced collaboration with market actors emerged, with several respondents recommending that DOE/PNNL work with a larger group of market actors, including retailers, lighting designers, and contractors. One aspect of this was a recommendation to direct more efforts toward applications rather than specific products, as a way to grow the technology and showcase its capabilities.

Program Effects on Market Adoption

This chapter presents the analysis used to estimate the effects of the SSL program on the market adoption of installed products.

Methodology

To estimate the effects of the DOE SSL program on market adoption of SSL products, Cadmus used a modified Delphi approach. The Delphi method is a structured, interactive technique for obtaining expert group inputs, usually to develop forecasts. The experts answer questionnaires, providing forecasts and the experts' rationale in two or more rounds. After each round, a facilitator provides the group an anonymous summary of the experts' forecasts and their supporting reasons. The experts are given an opportunity to revise their forecasts and again provide their reasoning. The process ends after a number of rounds with the intention of reaching consensus or stability. Cadmus' modified Delphi approach uses a convenient, flexible, web-based data collection application developed by Cadmus, which allows the experts to provide their input when convenient, view the anonymous responses of the other experts, and provide their revised inputs. The Cadmus Market Adoption Tool (MAT), as configured for this study, assumes that market adoption over time can be characterized with an exponential diffusion curve (the Bass S-shaped curve). This way of representing market diffusion of technologies and products has been used widely in prior market studies.

Because there are many SSL applications and products, we used aggregated product categories that would facilitate the analysis and increase the likelihood of panelist participation. We aggregated products into the same three SSL product groups described in the Navigant report *Adoption of Light-Emitting Diodes in Common Lighting Applications,*[11] published in April 2013 by DOE. Cadmus asked panelists to provide input on these three groups:

- Indoor Lamps – includes A-type, directional, MR-16, and decorative lamps
- Indoor Luminaires – includes downlights, troffers, and high-bay luminaires
- Outdoor Luminaires – includes streetlights and parking luminaires

To assess the program effects on the market, we asked panelists to use the MAT to provide their estimate of what the market adoption, in terms of installed lighting, would have been for each group of SSL products if DOE had not engaged in the program's SSL activities. The difference between the market adoption estimated with MAT and the actual market adoption provided an estimate of the program market effect.

Panel input consisted of two input rounds. In the initial round, each individual on the panel was asked to log into the web-based MAT and construct a diffusion curve for 2005 through 2025 that fit his or her

[11] Navigant. *Adoption of Light-Emitting Diodes in Common Lighting Applications*. U.S. Department of Energy. April 2013. Available online: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/led-adoption-report_2013.pdf

expectations for market adoption of a particular SSL product group assuming the program had not been in effect. The data collection application allows members to construct the diffusion models by either specifying the three underlying parameters of the exponential function, or by grabbing and dragging the existing Bass curve provided on the model graphic. Panel members were encouraged to provide comments and/or observations supporting their models. During the initial input round, panel members were not able to view the input of other panel members.

After all panel members had constructed their individual first round models, they were invited to participate in a second input round where they were permitted to view the models constructed by the rest of the panel,[12] along with any supporting information provided. Panel members then had the opportunity to comment on the models constructed by other members, as well as to adjust their own models in light of the input submitted by other panel members. This allowed members to pool their knowledge to develop a consensus forecast.

In this study, we limited the process to two rounds. After the second round, we developed an aggregated curve and compared it to the estimates of actual market adoptions of installed lighting for each SSL product group as estimated in the *Adoption of Light-Emitting Diodes in Common Lighting Applications*. The difference was the estimated market effect of DOE's SSL program for each SSL product group.

Panelist Input

Cadmus recruited panelists from the same market actor contact lists provided by PNNL as were used for the sampling frame for the market actor interviews. We attempted to obtain submission of full, round 2 inputs from 10 individuals with diverse perspectives in the lighting industry by using the same stratification structure we used in the market actor interviews. Table 7 provides the strata definitions, sampling frame, initial interest, recruitment targets, and the number of submitted Round 1 and Round 2 inputs for each stratum.

[12] Each panel member can view input including the market adoption curves and text comments from other panel members but anonymity is maintained throughout the process.

Table 7. Panelist Stratum Definitions and Targets

Stratum	Recruitment Target	Sampling Frame	Agreed to Participate	Submitted Round 1 Input	Submitted Round 2 Input
Manufacturers and trade organizations	2	5	5	3	3
Buyers, distributors, and retailers	2	2	2	0	0
Designers, specifiers, and energy-efficiency program managers	4	9	5	3	3
Individuals involved in development of standards and test procedures	2	3	3	1	0
Total	**10**	**19**	**15**	**7**	**6**

Cadmus recruited panelists at the close of the market actor interviews. Fifteen panelists initially agreed to participate; of these 15, only 7 ultimately logged into the web-based application and submitted round 1 input. After the close of round 1, six of the seven round 1 panelists continued with the analysis and provided round 2 input.

Special Considerations

The original purpose of applying this tool was to project the market impacts of DOE program on adoptions of the three categories of SSL technologies by generating forecasts of adoption with and without the DOE program. During study planning, however, PNNL indicated the primary focus of the market impact analysis should be on the impacts of the program to date.

Typical diffusion curve modeling, as well as the Cadmus MAT, is best suited to creating relatively long-term forecasts of market changes over time. Given the study's focus on the near-term program market impacts, however, Cadmus specifically tailored the data collection and analysis processes to satisfy the objective of providing an accurate portrayal of the market in the near term.

The background product information provided to respondents when they entered the MAT included information on the actual installed market adoptions of each product from 2009 through 2012. We provided this information so respondents would have a reference for what actually happened in the market given that the DOE program was in existence during that period. To reinforce the importance of this market information and the near-term focus, the information provided to respondents recruiting them to complete round 2 further highlighted the actual market adoptions. Each respondent received an invitation that compared the average first-round MAT market adoption estimate for 2012 with the actual market adoption. The invitation also explained that an actual market adoption greater than the estimate made assuming the program did not exist implied that the program had increased market adoption; while an actual market adoption less than if the program did not exist implied that the program had actually dampened sales of SSL products.

Based on the panelists' market adoption estimates and supporting comments, emphasizing this information did succeed in getting respondents to focus on trying to estimate market adoptions in the near-term under the counterfactual conditions. As a result, the findings presented here address the MAT estimates for this period. We believe this focus on the near term reduces the validity of the longer-term estimates (that is, 10 years and more into the future) and therefore we do not examine them. Nevertheless, this approach could be used to develop credible forecasts and comparisons of the market into the future under conditions with and without the program.

Market Adoption Estimates

Cadmus calculated estimates of actual market adoptions for SSL products using data provided in the report *Adoption of Light-Emitting Diodes in Common Lighting Applications.* The report provides installed lighting market share data sourced from the *2010 U.S. Lighting Market Characterization* study[13] and from LED sales and financial reports provided by manufacturers, retailers, and industry experts, as well as the shipment data from NEMA and ENERGY STAR for the nine SSL applications described above. The installed base units used to calculate the market adoptions are provided in Table 8.

Table 8. LED Installed Base Units (In Millions)

	2009	2010	2011	2012
Indoor Lamps				
A-type Lamps	0.4	1.6	5.5	19.9
Directional Lamps	0.1	0.5	7.2	11.4
MR16 Lamps	0.1	0.3	2.6	4.8
Decorative Lamps	0.2	1.2	2.6	4.7
Total - Indoor Lamps	**0.8**	**3.6**	**17.9**	**40.8**
Indoor Luminaire				
Downlights	*N/A*	0.5	1.8	5.5
*Troffers et al.**	*N/A*	0.04	0.1	0.7
High-Bay	*N/A*	0.06	0.1	0.3
Total - Indoor Luminaires	**0**	**0.6**	**2**	**6.5**
Outdoor Luminaire				
Streetlights	*N/A*	0.2	0.6	1
Parking Garage & Lot	0.02	0.06	0.2	0.6
Total - Outdoor Luminaires	**0.02**	**0.26**	**0.8**	**1.6**
TOTAL LED PRODUCTS	**0.82**	**4.46**	**20.7**	**48.9**

Table 9 provides the estimates of installed base units, sourced from the *Adoption of Light-Emitting Diodes in Common Lighting Applications.* Table 10 provides the estimates of market adoptions of SSL products calculated by dividing the values in Table 8 by those in Table 9.

[13] Navigant. "*2010 U.S. Lighting Market Characterization*." U.S. Department of Energy. January 2012. Available online: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/2010-lmc-final-jan-2012.pdf

Table 9. Installed base Units for All Lighting Products (In Millions)

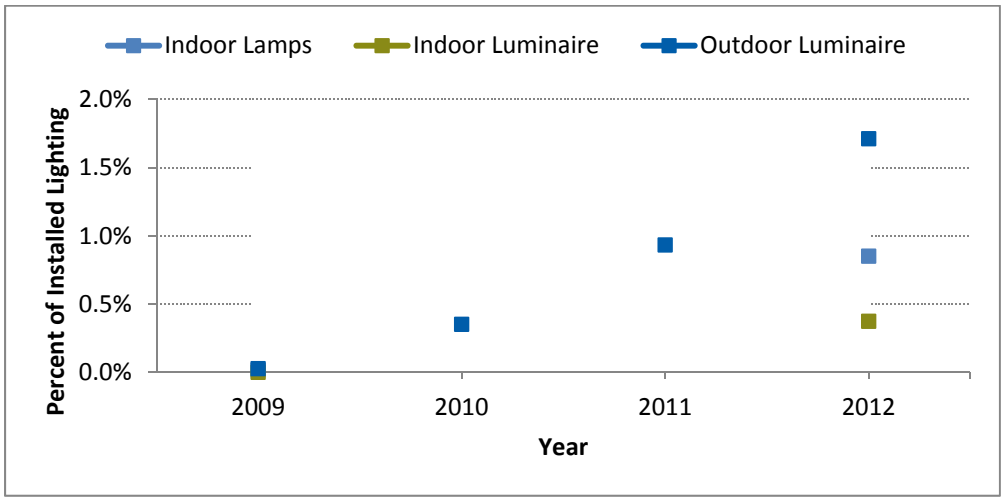
	2009	2010	2011	2012
Indoor Lamps				
A-type Lamps	3,300	3,300	3,300	3,300
Directional Lamps	248	248	248	248
MR16 Lamps	46	46	46	46
Decorative Lamps	1,200	1,200	1,200	1,200
Total - Indoor Lamps	4,794	4,794	4,794	4,794
Indoor Luminaire				
Downlights	*N/A*	703	706	708
*Troffers et al.**	*N/A*	957	961	964
High-Bay	*N/A*	66	67	67
Total - Indoor Luminaires	0	1,726	1,733	1,739
Outdoor Luminaire				
Streetlights	*N/A*	20	32	43
Parking Garage & Lot	0.02	54	54	50
Total - Outdoor Luminaires	74	74	86	93
TOTAL LED PRODUCTS	**4,794**	**6,594**	**6,612**	**6,626**

Table 10. Market Adoption Estimates for SSL Products

	2009	2010	2011	2012
Indoor Lamps				
A-type Lamps	0.0%	0.0%	0.2%	0.6%
Directional Lamps	0.0%	0.2%	2.9%	4.6%
MR16 Lamps	0.2%	0.7%	5.7%	10.4%
Decorative Lamps	0.0%	0.1%	0.2%	0.4%
Total - Indoor Lamps	0.0%	0.1%	0.4%	0.9%
Indoor Luminaire				
Downlights	*N/A*	0.1%	0.3%	0.8%
*Troffers et al.**	*N/A*	0.0%	0.0%	0.1%
High-Bay	*N/A*	0.1%	0.2%	0.4%
Total - Indoor Luminaires	0%	0.0%	0.1%	0.4%
Outdoor Luminaire				
Streetlights	*N/A*	1.0%	1.9%	2.3%
Parking Garage & Lot	100.0%	0.1%	0.4%	1.2%
Total - Outdoor Luminaires	0.0%	0.4%	0.9%	1.7%
TOTAL LED PRODUCTS	**0.0%**	**0.1%**	**0.3%**	**0.7%**

Figure 1 provides the market adoption summaries for SSL products derived from these data for the three SSL product groups.

Figure 1. Estimate of Actual Market Adoption of SSL Products



Program Effects on Market Adoptions of SSL Products

The following sections summarize panelist input for each SSL product group. While the web-based application allowed panelists to estimate the market adoption for the years 2005 to 2025, we targeted the analysis to the years for which we had estimates of actual market adoption, 2009 – 2012,[14] and asked panelists providing estimates in round 2 to focus on these years as they considered their input.

We interpreted the results as follows: An average panelist market adoption estimate less than the actual market adoption indicated panelists thought the program had a *fostering* effect on the market for SSL products; an average market adoption estimate greater than the actual market adoption indicated panelists thought the program had a *dampening* effect on the market.

Indoor Lamps

Taking the input of all panelists into account, the average market adoption estimate for indoor lamps provided by the panelists, shown in Figure 2, indicates they believed DOE program initially had a dampening effect on the market, but by 2012, the aggregate panelist estimates indicate SSL indoor lamps would have achieved approximately the same market adoption (0.97%) as the actual market adoption (0.91%), as shown in Table 11.

[14] Navigant. *Adoption of Light-Emitting Diodes in Common Lighting Applications.* U.S. Department of Energy. April 2013. Available online: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/led-adoption-report_2013.pdf

Figure 2. Indoor Lamps – Unadjusted Market Adoption Estimates

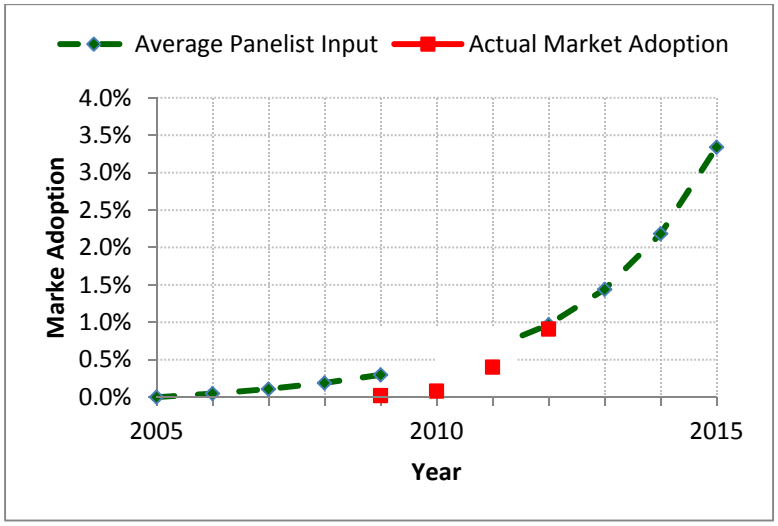


Table 11. Indoor Lamps – Unadjusted Market Adoption Estimates

Year	Average Panelist Input	Actual Market Adoption
2009	0.30%	0.02%
2010	0.45%	0.08%
2011	0.66%	0.40%
2012	0.97%	0.91%

One panelist predicted that, in the next two years, there will be rapid growth in the adoption of SSL screw-in lamp products, particularly for replacements for A-line bulbs in residential sockets. This will occur as incandescent bulbs phase out of the market at the same time as prices drop for LED bulbs.

The five panelists did not all agree, however, on the effect of DOE's SSL program on the market for indoor lamps. While four panelists provided estimates lower than the actual market adoption estimates, indicating the program increased market adoption, one panelist felt that the program had "a dampening effect on growth in market adoption in the short term due to its focus on quality and performance testing and verification," and provided a market adoption estimate substantially higher than the actual market adoption estimate. Although this view was in the minority, it was not totally unexpected given DOE's focus on quality products. To examine how the assessment would change if the input from this one panelist was excluded, we averaged the inputs of remaining experts, and the results are shown in Figure 3 and Table 12.

Figure 3. Indoor Lamps – Market Adoption Estimates without High Estimate

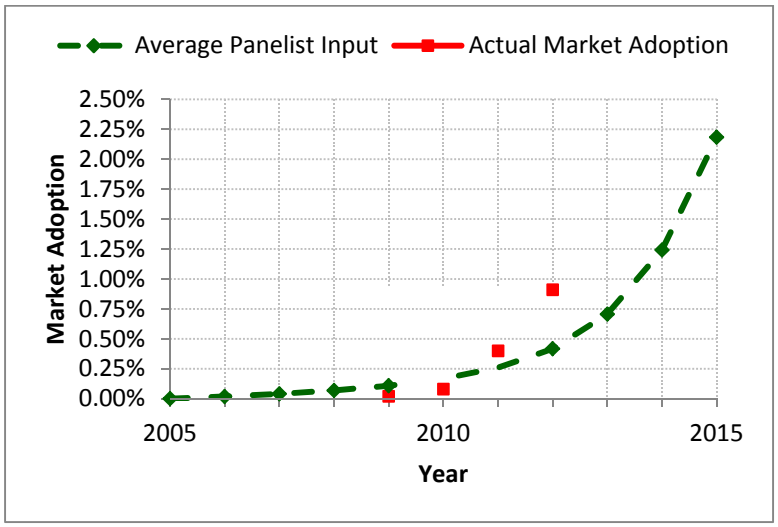


Table 12. Indoor Lamps – Market Adoption Estimates without High Estimate

Year	Average Panelist Input	Actual Market Adoption
2009	0.11%	0.02%
2010	0.17%	0.08%
2011	0.26%	0.40%
2012	0.42%	0.91%

Without the input from the one dissenting panelist, the average panelist market adoption indicates the program fostered the market for SSL indoor lighting products and increased it by nearly 0.5%. These four panelists noted that DOE programs "definitely had a positive effect on adoption" and that it was "unlikely that consumers would have been as well informed about LED technology" and therefore would have been less likely to purchase solid state indoor lighting products. Additionally, customers "are much less likely to adopt the technology if they can still read or hear stories of quality problems with a new technology." Another panelist noted that, "in another 12 years SSL will be widely accepted in indoor applications in any event," but that this would have occurred more slowly without the quality assurance elements of DOE SSL program. Additionally, the panelist attributing a dampening effect to the program concurred on the program's benefits, noting that, "in the absence of the DOE program we could have relived all of the problems experienced with market adoption of often poorly performing CFLs."

Indoor Luminaires

The average market adoption estimate for indoor luminaires provided by the panelists, shown in Figure 4 and Table 13, indicates they believed DOE program initially had a dampening effect on the market but later had a fostering effect.

Figure 4. Indoor Luminaires – Market Adoption Estimates

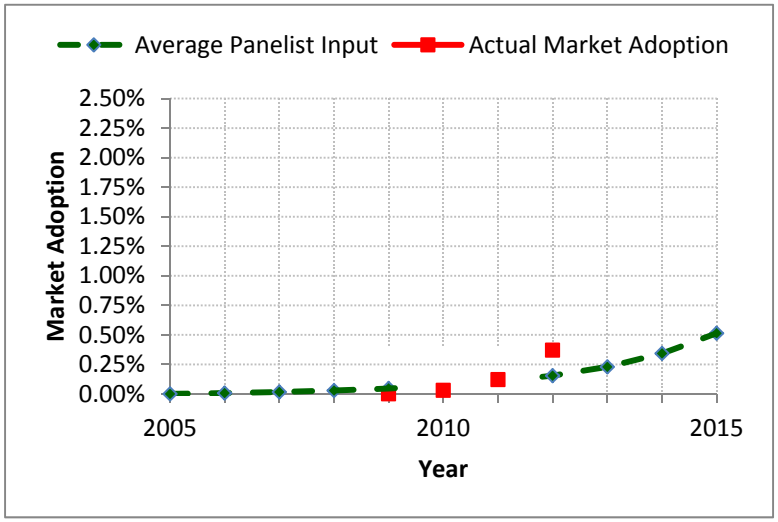


Table 13. Indoor Luminaires – Market Adoption Estimates

Year	Average Panelist Input	Actual Market Adoption
2009	0.05%	0.00%
2010	0.07%	0.03%
2011	0.10%	0.12%
2012	0.15%	0.37%

All panelists were in agreement on the fostering effect of DOE SSL programs on the market for indoor luminaires. Panelists attributed DOE SSL program with a 0.22% increase by 2012 in the installed market adoption for solid state indoor luminaires. Panelists commented that "DOE programs have a definite effect on the adoption," and stated that the "DOE published information very early on regarding performance of downlights and linear tubes for use in troffers." One panelist noted further that access to this information helped instill confidence in promoting solid state indoor luminaires, specifically, downlights. Another panelist noted that indoor luminaires appear to be on a "longer, slower path to adoption than screw-in lamp products."

Outdoor Luminaires

In the market for solid state outdoor luminaires, panelists attributed the DOE SSL program with the greatest effect in fostering the market. As shown in Figure 5 and Table 14, panelists indicated they believed DOE's program was responsible for increasing the market adoption of installed lighting approximately 1.14% by the end of 2012.

Figure 5. Outdoor Luminaires – Market Adoption Estimates

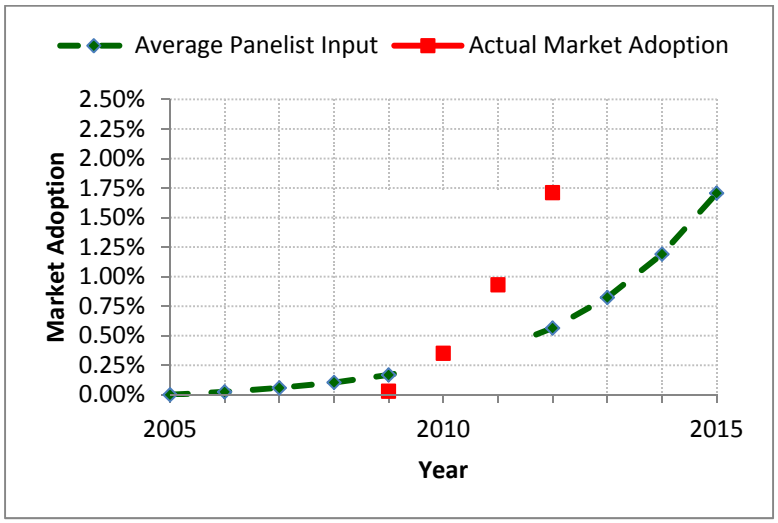


Table 14. Outdoor Luminaires – Market Adoption Estimates

Year	Average Panelist Input	Actual Market Adoption
2009	0.17%	0.03%
2010	0.26%	0.35%
2011	0.38%	0.93%
2012	0.57%	1.71%

One panelist noted that "GATEWAY reports and MSSLC have provided information that has assisted municipalities to specify LED roadway luminaires much more quickly than if they had to do individual demonstrations and write individual specifications," and "the promised long life of outdoor luminaires would likely be attractive to many municipalities and businesses even without DOE SSL program, but without DOE SSL, Municipal SSL Consortium adoption would be more haphazard and uncoordinated. In addition, without the GATEWAY program, larger numbers of poor-quality products would likely be installed in cities and towns, turning other local governments away from the technology." Additional panelists noted "some lower-cost products are now (2013) in the market and so the market adoption curve should grow more rapidly in the next few years," and "the announcement of outdoor LED roadway luminaires in the $200 range puts LEDs competitively in cost competition with HPS and MH luminaires. These factors suggest faster adoption over the next few years."

Summary

In general, panelists attributed a market fostering effect to DOE SSL program activities and contributed many positive comments. With one exception, the panelists' estimates indicated the program had increased adoption by a factor of about two to three times by 2012. The effect was especially large for outdoor luminaires where the estimated effect was about a three-fold increase. Estimates for indoor lamps and indoor luminaires showed the least degree of consensus given the input of one expert who

believed the program's quality and testing requirements had slowed market adoption slightly. Including this expert's estimate resulted in bringing down the average estimate of the program effect on adoption from a factor of two to no effect by 2012. While results for early program years suggest a dampening effect of the program, this was likely an artifact of two things: the extremely small size of the market for SSL in those years and the difficulty of applying a specific functional form to describe the market adoption.

Program Progress towards Quality and Efficiency Goals

Program Goals on SSL Quality

Cadmus conducted secondary research to collect market data on quality SSL products and estimates on energy savings. We analyzed and summarized the information available through the Design Lights Consortium (DLC) Quality Product List (QPL),[15] a project of NEEP, which provides a database that distinguishes high-quality, high efficiency LED products for the commercial sector. We then compared the data obtained from DLC's QPL to the goals that were set by DOE's SSL program. DOE's goals are set to induce the manufacture and purchase of highly efficient LED luminaires and efficient lamps, leading to the U.S market introduction of quality SSL products for FY 2012[16] and FY 2013[17]. Table 15 shows the FY 2012 and FY 2013 program's SSL quality targets to be attained by the market.

Table 15. DOE's SSL Program Goals on Characteristics of Quality SSL Products

Program Goals	FY 2012 Goals		FY 2013 Goals	
	Warm-White Products	Cool-White Products	Warm-White Products	Cool-White Products
Efficacy (lm/W)	68	88	92	129
CRI	85	70	85	70
k CCT	3,500	6,500	3,500	6,500

Program SSL Quality Goals for FY 2012 and FY 2013 and Market Status

To facilitate comparison of SSLs currently on the market with the DOE's SSL program goals for FY 2012 and FY 2013, we generated the average efficacy of SSL products from the DLC QPL, by applying constraints to the CRI and CCT values, in order to match those provided in the program goals, as follows:

- For warm white products: at least 85 CRI and 2580-3500 k CCT; and
- For cool white products: at least 70 CRI and 4746-6500 k CCT.

We then summarized the average efficacy of SSL products meeting the above criteria, for the top 10% and top 20% of all products, in terms of efficacy.

Table 16 shows the summary of the average efficacy values calculated for the top 10% and 20% SSL products in the DLC QPL in the years 2012, and 2013.

[15] http://www.designlights.org/QPL
[16] 5-year (FY 2008-FY 2012) Solid State Lighting Commercialization Support Plan, April 2007
[17] 5-year (FY 2009-FY 2013) Solid State Lighting Commercialization Support Plan, May 2009

Table 16. DLC's QPL Quality Characteristics of SSL Products (2012-2013)

DLC QPL Data	2012		2013	
	Warm-White Products	Cool-White Products	Warm-White Products	Cool-White Products
Average Efficacy (lm/W) in the top 10th percentile	109	101	128	107
Average Efficacy (lm/W) in the top 20th percentile	104	97	118	101

When comparing the average efficacy levels of these most efficacious SSL products[18] in the DLC's QPL in 2012 to those in the program goals for FY 2012, it is evident that the warm-white products exceeded the program targets by at least 53%. The data also indicate that the average efficacy levels for cool-white products in the QPL are higher than the FY 2012 program targets by at least 10%.

For the year 2013, when comparing the average efficacy levels of the most efficacious SSL products[19] in the DLC's QPL to those in the program goals for FY 2013, warm-white products average efficacy levels are shown to have exceeded the program targets by at least 28%. However, cool-white products did not achieve the FY 2013 program targets; average efficacy values were at least 17% lower than the targets.

Table 17 summarizes the average efficacy values of the top 10% and top 20% of products in the DLC QPL, for years 2012 and 2013, compared to the DOE's SSL efficacy goals for FY 2012 and FY 2013, respectively.

Table 17. Comparison of DLC QPL in 2012 and 2013 to FY 2012 and FY 2013 Program Quality Goals*

	2012		2013	
	Warm-White Products	Cool-White Products	Warm-White Products	Cool-White Products
Average Efficacy (% of Goals) in the top 10 percentile	60%	15%	39%	-17%
Average Efficacy (% of Goals) in the top 20 percentile	53%	10%	28%	-22%

* Positive values indicate higher efficacy of SSL products than goals and negative values indicate lower efficacy.

From the DLC QPL, we also summarized the number of types of SSL products that were available in 2012 and 2013 (with the applied constraints discussed above). There was about a 48% decrease in the total

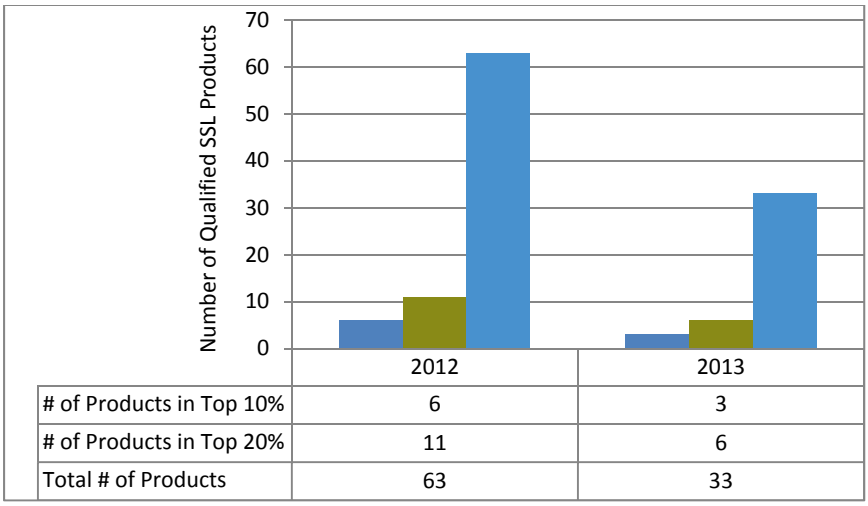
[18] For warm white products with at least 85 CRI and 2580-3500 k CCT; and for cool white products with at least 70 CRI and 4746-6500 k CCT.

[19] For warm white products with at least 85 CRI and 2580-3500 k CCT; and for cool white products with at least 70 CRI and 4746-6500 k CCT.

number of warm-white products in the QPL, from 2012 to 2013. This is could be due to the fact that the QPL contains data only through the end of May 2013 (Figure 6).

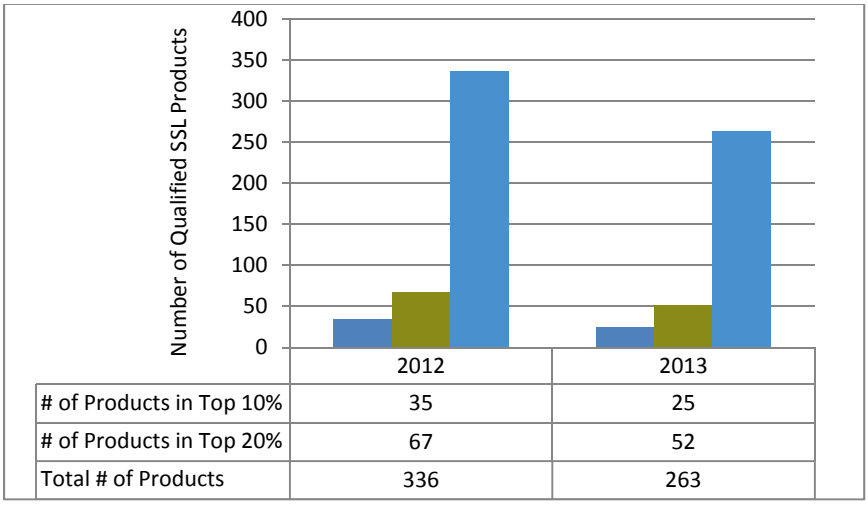
For cool-white products, the total number of types of SSL products was considerably higher than that of warm-white products, in both 2012 and 2013. Likewise, the total number of high efficacy cool-white products in the top 10th percentile and 20th percentile was much higher than for warm-white products. There was about a 22% decrease in the total number of SSL products meeting the color constrained defined above from 2012 to 2013 (Figure 7).

Figure 6. Number of Warm-White Products in DLC QPL in 2012 and 2013 that Match FY 2012 and FY 2013 Program Quality Targets



	2012	2013
# of Products in Top 10%	6	3
# of Products in Top 20%	11	6
Total # of Products	63	33

Figure 7. Number of Cool-White Products in DLC QPL in 2012 and 2013 that Match FY 2012 and FY 2013 Program Quality Targets



	2012	2013
# of Products in Top 10%	35	25
# of Products in Top 20%	67	52
Total # of Products	336	263

Program Progress towards FY 2016 Goals on SSL Quality

To assess whether the program is progressing towards meeting its FY 2016 SSL[20] quality targets, we generated the average efficacy of SSL products from the DLC QPL by applying constraints to the CRI and CCT values to match those provided in the FY 2016 program goals, as follows:

- For warm white products: at least 85 CRI and 2580 – 3710 k CCT; and
- For cool white products: at least 75 CRI and 4746 - 7040 k CCT.

Table 18 shows the average efficacy of SSL products that are available in 2013 in the DLC QPL, and that meet the color characteristics listed above, to those in the FY 2016 program's goals. The table also indicates the FY 2016 program efficacy goals.

When comparing the average efficacy levels of SSL products in the DLC's QPL in 2013 to the program goals for FY 2016, warm-white products are exceeding the FY 2016 program targets by 15% and 4%, in the top 10th and 20th percentiles, respectively. However, the average efficacy values for cool-white products are much lower than the FY 2016 targets (by 19 % and 23%, for products in the top 10th and 20th percentiles, respectively).

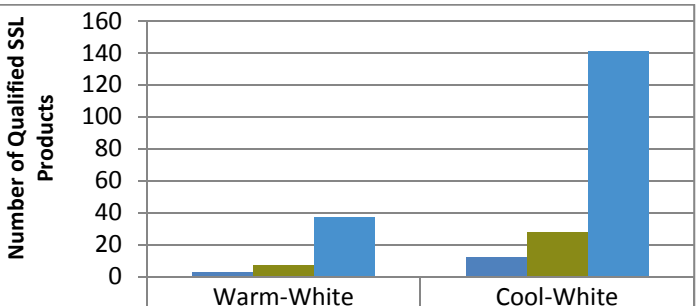
Table 18. Comparison of Market SSL Qualities to FY 2016 Goals

	DLC QPL Data 2013		FY 2016 Goals (lm/W)
	Average Efficacy (lm/W) in the top 10th percentile	Average Efficacy (lm/W) in the top 20th percentile	
Warm-White Products	129	117	112
Cool-White Products	106	101	131

Figure 8 shows the number of SSL products in the DLC QPL in 2013 with quality characteristics matching the characteristics of the DOE SSL FY 2016 program quality targets. The total number of warm-white products is much lower than cool-white products; however, the proportion of high efficacy SSL products of the total number of products remains consistent for both warm- and cool-white products.

[20] Solid State Lighting Multi-Year Market Development Support Plan (FY 2012-FY 2016), May 2012

Figure 8. Number of SSL Products in DLC QPL in 2013 that Match FY 2016 Program Quality Targets



	Warm-White	Cool-White
# of Products in Top 10%	3	12
# of Products in Top 20%	7	28
Total # of Products	37	141

Summary on Quality of SSL Products

The results indicate that high-efficacy warm-white products available in the market[21], although in much lower quantities than cool-white products, have exceeded the DOE's SSL FY 2012 and FY 2013 program efficacy goals by at least 53% in 2012, and by at least 28% in 2013, respectively. In 2012, the average efficacy values for cool-white products exceeded the DOE's SSL FY 2012 targets by at least 10%, but were lower than FY 2013 program goals by at least 17%, in 2013.

DOE's SSL program efficacy goals increased by 35% for warm-white and by 47% for cool-white products, in FY 2013 compared to FY 2012 goals. In contrast, the pace of efficacy improvement for SSL products in the market (with similar quality specifications as those in the program's goals) was much lower. As indicated by the average efficacy values for the top products in the DLC QPL, the values have only increased by at about 17% for warm-white and about 6% for cool-white products, from 2012 to 2013.

On the other hand, when comparing DOE's SSL program efficacy targets for FY 2016 to FY 2013, the targets increased by 22% for warm-white and by 2% for cool-white products. If the pace of improvement in efficacy for SSL products in the market continues at the same rate as that between the years 2012 and 2013 (i.e., an annual increase of about 17% for warm-white and 6% cool-white products), there is a high likelihood that warm-white products in the market will meet or exceed the FY 2016 efficacy targets; however, there is less likelihood that cool-white products will reach the FY 2016 efficacy targets.

Although the DLC QPL does not represent the quality of all SSL products that are currently available in the market, it provides a reasonable estimate of the proportion of higher quality commercial SSL products. We, therefore, can only derive findings regarding the evaluated products in the DLC's QPL, but we are cautious not to generalize these findings regarding the type and level of qualities of all SSL products that are available in the market.

[21] Note that there is no information available on the market share of the products in the DLC QPL, but the results indicate the *quality* of products that are available in the market.

Given that currently there are low quantities of SSL products (especially warm-white products) with characteristics that match those of DOE's SSL FY 2016 quality goals; there is a market need for an increase in the volume of production of these high efficacy products. While pushing the market to produce high-quality products is important, there is also a need for market pull strategies to increase the demand for affordable quality SSL products.

Program Goals on SSL Energy Savings and Market Status

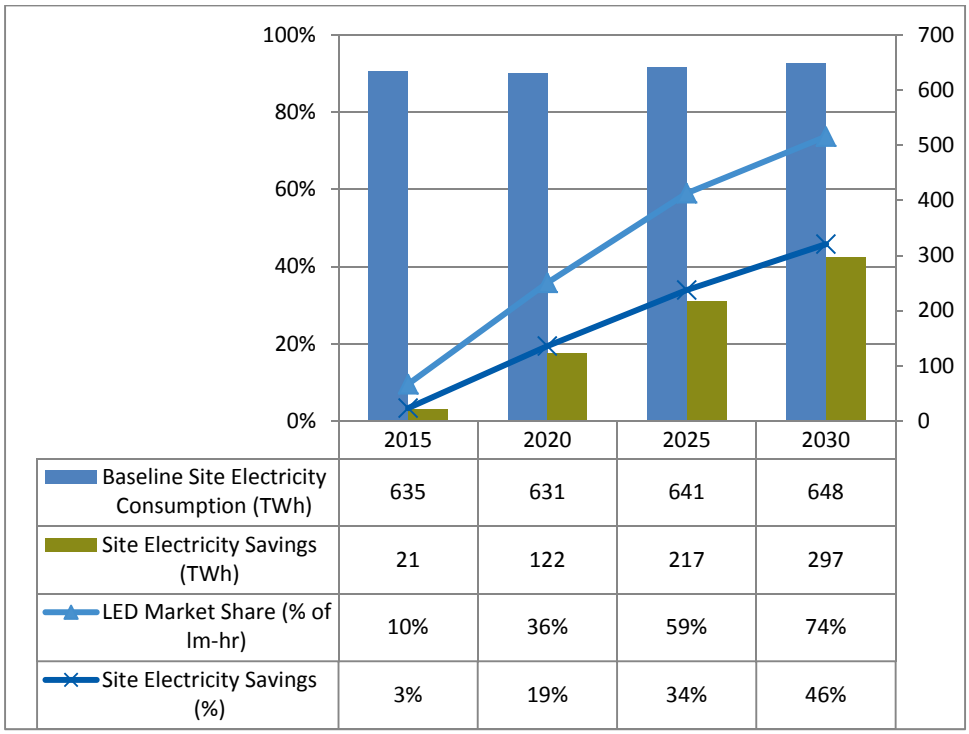
One of the most recent reports published on energy savings associated with SSL products was commissioned by DOE's SSL program, *Energy Savings Potential of Solid-State Lighting in General Illumination Applications, 2012.*[22] The report includes findings on potential energy savings, based on 2010 baseline site electricity consumption, from nine major lighting applications in which LEDs are competing with traditional light sources. However, the savings values are not differentiated by quality characteristics of the LED products, such as efficacy levels, CRI, and CCT values.

Figure 9 shows the forecasts (2015-2030) for LED baseline site electricity consumption, site electricity energy consumption, LED market share, and site electricity savings. In 2015, it is projected that electricity savings for LEDs will reach a total of 21 TWh, based on LED market share of 10% of lumen-hours (lm-hr), a measure of actual lighting use. By 2020 and 2030, these savings are projected to reach 122 TWh and 297 TWh, based on LED market shares of 36% and 74% of lm-hr, respectively.

By 2030, the majority of LED electricity savings are projected to originate from residential and commercial applications (34% and 37%, respectively); whereas, about 25% of the savings are projected to come from outdoor application, and only 4% from industrial applications.

[22] Navigant Consulting, Inc., Energy Savings Potential of Solid-State Lighting in General Illumination Applications, January 2012. http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/led-adoption-report_2013.pdf

Figure 9. *Energy Savings Projections based on Energy Savings Potential of SSL in General Illumination Applications*, 2012.



	2015	2020	2025	2030
Baseline Site Electricity Consumption (TWh)	635	631	641	648
Site Electricity Savings (TWh)	21	122	217	297
LED Market Share (% of lm-hr)	10%	36%	59%	74%
Site Electricity Savings (%)	3%	19%	34%	46%

In addition, according to a recent report on adoption of LED, (*Adoption of Light-Emitting Diodes in Common Lighting Application,* published in 2013[23]), in 2012, 6.8 TWh of LED energy savings was estimated to result from LED installation across three major categories: indoor lamps, indoor luminaires, and outdoor luminaires. These energy savings were based on varying degrees of LED penetration (see Table 19). If the full potential energy savings was realized, the savings could have reached up to 373 TWh, in 2012; however, the realized savings in 2012 constituted only about 2% of the total energy savings potential.

[23] Navigant. *Adoption of Light-Emitting Diodes in Common Lighting Applications.* U.S. Department of Energy. April 2013. Available online: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/led-adoption-report_2013.pdf

Table 19. LED Installation, Consumption and Energy Savings in 2012 (*Adoption of Light-Emitting Diodes in Common Lighting Applications, 2013)*

LED TYPE	Units Installation (millions)	LED Penetration (%)	Total Application Energy Use (TWh)	2012 LED Energy Savings (TWh)	Potential LED Energy Savings (TWH)	Energy Savings Realized of Total Potential (%)
Indoor Lamps						
A-type Lamps	19.9	<1%	101.8	2.1	79.1	3%
Directional Lamps	11.4	4.6%	18.7	2.3	16.7	14%
MR16 Lamps	4.8	10.0%	6.7	0.4	6.2	6%
Decorative Lamps	4.7	<1%	35.4	0.1	28.7	0%
Total - Indoor Lamps	**40.8**		**162.6**	**4.9**	**130.7**	**4%**
Indoor Luminaire						
Downlights	5.5	<1%	36.8	0.9	26.8	3%
*Troffers et al.**	0.7	<0.1%	228.6	0.1	110.4	0%
High-Bay	0.3	<1%	105.6	0.2	46.5	0%
Total - Indoor Luminaires	**6.5**		**371**	**1.2**	**183.7**	**1%**
Outdoor Luminaire						
Streetlights	1	2.3%	43.5	0.3	22.9	1%
Parking Garage & Lot	0.6	1.2%	60	0.5	35.7	1%
Total - Outdoor Luminaires	**1.6**		**103.5**	**0.8**	**58.6**	**1%**
Total (all categories)	**48.9**		**637.1**	**6.9**	**373**	**2%**

Summary on Energy Savings from SSL Products

We compared the forecasted electricity savings from LED to the DOE's SSL program goals. In 2012, (based on Navigant report, 2013), the energy savings realized from LED (in three categories) were about 36% of DOE's SSL FY 2012 energy savings targets. If the full potential of energy savings from these products were realized, the energy savings in 2012 would have exceeded the program's targets. There were no published data on energy savings estimates for 2013.

Due to the limited information available, it is hard to estimate whether the magnitude of energy savings that could be realized by 2016; however, there is large potential of energy savings from SSL products that could be gained if market penetration increased.

Table 20 shows DOE's SSL program goals for FY 2012 and FY 2016, and estimates of energy savings from LED products, based on current market data.

Table 20. DOE's SSL Energy Savings Goals (FY 2012 and FY 2016) and Market Estimates of Energy Savings

DOE's SSL Energy Savings Goals (TWh/Year)	Market LED Energy Savings Estimates (TWh/Year)
19 (FY 2012)[24]	6.8 (2012)*
21 (FY 2016)[25]	21 (2015)**
* Navigant. *Adoption of Light-Emitting Diodes in Common Lighting Applications.* U.S. Department of Energy. April 2013. ** Navigant Consulting, Inc., Energy Savings Potential of Solid-State Lighting in General Illumination Applications, January 2012.	

[24] 5-year (FY 2008-FY 2012) Solid State Lighting Commercialization Support Plan, published April 2007
[25] Solid State Lighting Multi-Year Market Development Support Plan (FY 2012-FY 2016), May 2012

Program Theory and Logic Model

Cadmus revised the program theory and logic model (PTLM) to reflect the program's activities; outputs; short-term, mid-term, and long-term outcomes. The revised PTLM is based on feedback received from PNNL program leads and staff, as well as evidence collected through secondary research regarding program activities and outputs. In addition, Cadmus used the analysis of responses from the market actors' interviews to verify the expected outcomes from the program.

DOE's SSL Program Activities and Outputs

DOE's SSL market introduction support program engages in numerous activities through its various program elements. The program outputs are informational materials regarding SSL performance and specifications, as well as appropriate applications of quality SSL products. The major program activities include:

- Engaging key market actors and providing feedback on technical information, including product specifications and performance, to targeted market actors;
- Performing product verification and lab testing;
- Demonstrating products in field applications, and conducting measurements and evaluation;
- Developing reports on results from product evaluation, testing, and demonstrations; and
- Disseminating information on quality SSL products and performance.

DOE SSL Program Outcomes

Short-Term Outcomes

Short-term program outcomes refer to the expected effects that are directly linked to the program's activities and outputs. Based on the findings from the study, the main expected short-term outcomes from DOE's SSL market introduction support program are:

- Increased coordination, collaboration, and communication among market actors on (up- and mid-stream) the supply side;
- Increased technical knowledge and awareness about quality product performance and appropriate applications among market actors on the supply side;
- Reduction in performance uncertainty and risk associated with manufacturing of quality SSL products;
- Increase in the pace of development of quality SSL products; and
- Increase in the pace of development of new and updated industry standards and testing procedures.

Mid-Term Outcomes

Mid-term outcomes refer to the expected effects that are indirectly linked to the program activities and outputs. These effects could result from secondary actions taken by the entities that have direct

engagement with and/or participation in the program. Based on the findings from this study, the main expected mid-term outcomes from DOE's SSL market introduction support program are:

- Increased manufacturing capacity of quality SSL products and reduction in manufacturing cost;
- Increased visibility of quality SSL products, and increased awareness and acceptance of quality SSL products and appropriate applications among consumers and end-users;
- Increased market availability of quality SSL products and decreased incremental cost;
- Increased annual sales of quality products; and
- Increased annual energy savings from the implementation of SSL products.

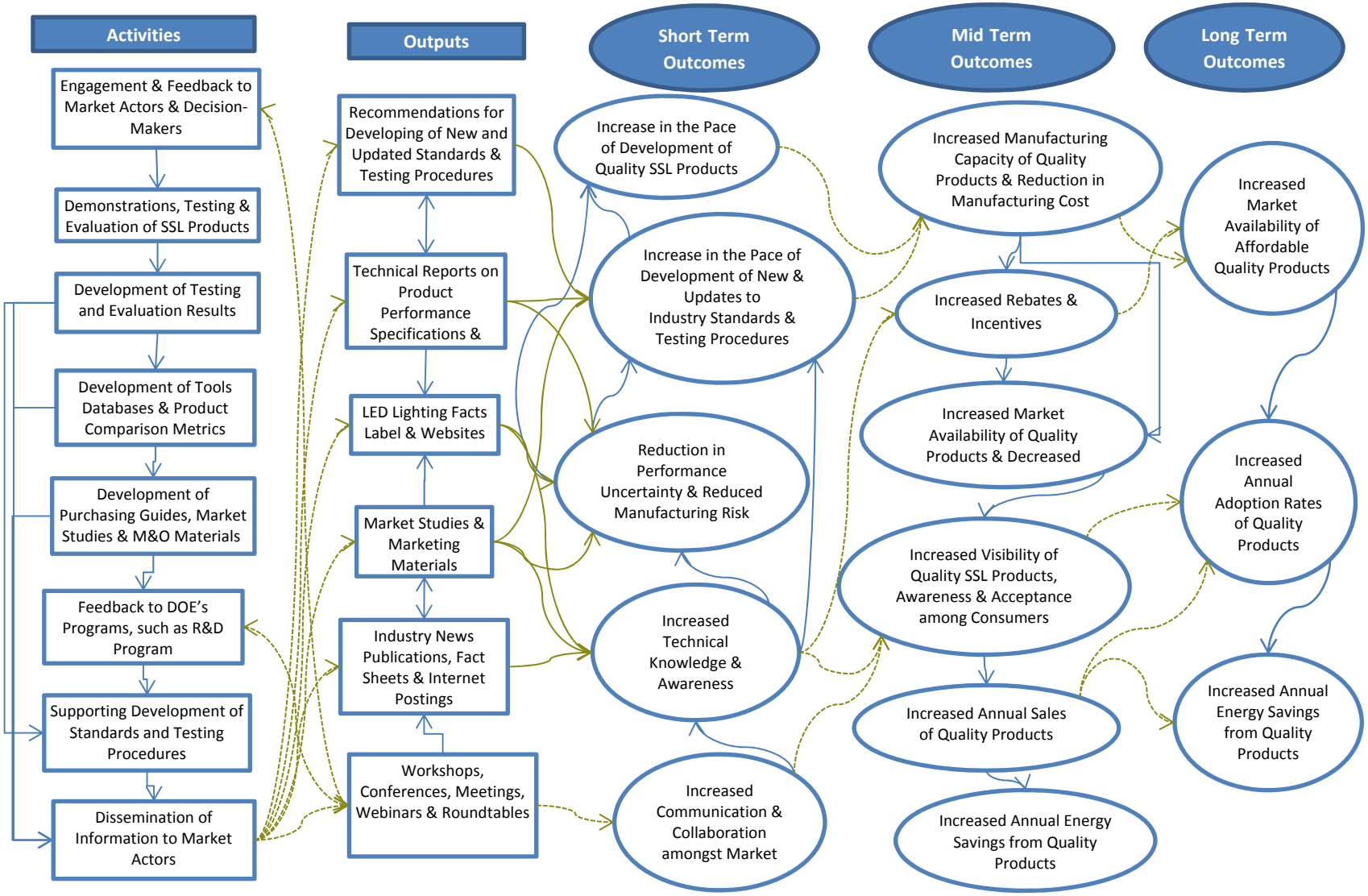
Long-Term Outcomes

Long-term outcomes refer to the expected cumulative results that are directly and indirectly linked to the program. These outcomes could be the direct effects from the program's activities and outputs, in addition to effects from activities and efforts from other programs and market factors. Findings from this study indicate that the main expected long-term outcomes are:

- Increased market availability of affordable quality SSL products;
- Increased annual adoption rates of quality products among consumers and end-users; and
- Increased annual energy savings from the implementation of SSL products.

Figure 10 shows the PTLM of DOE's SSL market introduction program.

Figure 10. DOE's SSL Program PTLM



Conclusion and Recommendations

This chapter summarizes the findings from the study, including assessing the program impacts the SSL program has had on the development of SSL market; and determining the program effectiveness and progress toward achieving the SSL program objectives and goals. In addition, this chapter includes overarching recommendations based on findings from this study.

Program Impacts

The primary product of DOE's SSL market introduction support program is in the form of information regarding SSL product qualities, performance, and specifications, as well as details on demonstrations, case studies, testing and evaluation results, and market studies. Hence, the magnitude of the program impacts highly depends on the quality and usefulness of the information provided, the way that information is communicated and disseminated, and the targeted market actors who would benefit from and use that information.

Based on the findings from this study, DOE's SSL market introduction support program has four key impacts on the SSL market. These impacts are:

1. Impacts on knowledge and awareness regarding quality SSL products and performance characteristics;
2. Impacts on availability of quality SSL products;
3. Impacts on cost of quality SSL products ; and
4. Impacts on adoption of quality SSL products and resultant energy savings.

Program Impacts on Knowledge and Awareness

Strong Evidence

Based on analysis of the results from the market actors' interviews, as well as the amount of information developed and disseminated by the program, there is strong evidence that DOE's SSL market introduction support program has had a direct impact on *technical knowledge and awareness*. Specifically, the program impacts result from emphasizing the attributes of quality SSL products, specifications, and performance characteristics, and understanding of the benefits of quality products among key market actors in the up- and mid-stream supply side. The market actors targeted by the program included manufacturers, distributors, big-box and large retailers, and large buyers, as well as energy-efficiency programs and initiatives. Results based on responses from the majority of interviewees indicate that the program has had a large impact on knowledge and awareness resulting from:

(a) The program efforts in leading the collaboration and communication among key market actors through partnerships, alliances, and consortiums such as Municipal Street Lighting Consortium, Technical Information Network for SSL, stakeholders' workshops and roundtables, webinars, and meetings.

(b) Dissemination of quality information through various program elements and activities, including the TINSSL information network and website, postings, fact sheets, market and evaluation studies, Gateway demonstration findings, CALiPER testing results, and LED Lighting Facts.

Moderate Evidence

Based on the analysis of the results from the market actors' interviews, there is moderate evidence that DOE's SSL market introduction support program has had a direct impact in increasing knowledge and awareness of the *benefits of quality SSL products* among market actors on the demand side, including consumers and end-users. Results based on responses from the majority of interviewees indicate that these effects were directly linked to the program information dissemination activities listed above, including technical specifications targeting large-facility managers and federal entities. The effects on consumers and end-users are indirectly linked to the program through information dissemination efforts of market actors on the supply side.

Program Impacts on Availability of Quality SSL Products

Strong Evidence

Based on the analysis of the results from the market actors' interviews, there is strong evidence that DOE's SSL market introduction support program has had a direct impact on increasing the *pace of development of quality and performance of SSL products*. Results based on responses from the majority of interviewees indicate that these effects result from:

- CALiPER: has had a large influence on product labeling and accuracy of reporting by manufacturers on product performance and quality attributes.
- GATEWAY Demonstrations and Municipal Solid State Street Lighting Program: have led to an increase in knowledge, awareness, and visibility of quality product performance and appropriate applications through objective and unbiased reporting on results.
- L Prize: has contributed to an increase in quality and performance of products by providing a benchmark for comparison.
- Standards and testing procedures support: has had a large influence on the pace of development and adoption of credible industry standards and testing procedures, which influence the type and quality of SSL products available in the market.

Moderate Evidence

Based on the analysis of the results from the market actors' interviews, there is moderate evidence that DOE's SSL market introduction support program has had a direct impact the *availability of quality products* in the market. In addition, based on the increased counts of products available in the DLC qualified product list from an average of two products in 2009 to an average of 21,462 products in 2013, there is evidence that the availability of quality products has tremendously increased in the market. Results based on responses from the majority of interviewees indicate that the program effects could be attributed to:

- L Prize: has had a moderate influence on the availability of the winning product due to difficulty in getting the product to the market because of limited production and high cost.
- NGL Design Competition: has had a moderate influence on the availability of winning products due to limited awareness among non-participating manufacturers, stakeholders' doubts on the credibility of the judging criteria, and limited information produced by this program element as compared to other programs.

Program Impacts on Cost of Quality SSL Products

Weak Evidence

Based on the analysis of the results from the market actors' interviews, there is weak evidence that DOE's SSL market introduction support program has had a direct impact on *decreasing the cost of quality SSL products*. Results based on responses from the majority of interviewees indicate that these effects could be attributed to:

- Information dissemination activities: there has been limited information on SSL product prices, leading to little knowledge among market actors about the variability in cost of quality products.
- L Prize: high cost of winning products affects the competition in the market, as there are no criteria addressing cost in the competition.

Program Impacts on Adoption of Quality Products and Energy Savings

Mixed Evidence

The *adoption rates of SSL products* have increased significantly since 2006, but they still represent a very small share of the installed lighting market (less than 1% in 2012). Our analysis suggested that the program led to a two- to three-fold increase in adoption of indoor luminaires and outdoor SSL lighting products by 2012.

Based on analysis of the results from the market actors' interviews, there is weak evidence that DOE's SSL market introduction support program has had a direct impact on *increasing the magnitude of sales and adoption of quality SSL products* among end-users, and consequently had low effects on the resultant energy savings. These results are confirmed by the low market adoption and penetration rates of SSL products established in current studies and discussed in this report. Results based on responses from the majority of interviewees indicate that these effects could be attributed to:

- Information dissemination activities: limited outreach and marketing to consumers and end-users resulted in less wider adoption of quality SSL products.
- GATEWAY Demonstrations: there has been limited engagement of key market actors, such as lighting designers and end-users, who can influence the adoption of quality products.
- There has been limited information disseminated through the program on sales and savings associated with quality SSL products.

- L Prize: the limited availability and high cost of the winning product could result in low sales, adoption rates, and savings.

Program Progress towards Goals

There is evidence that DOE's SSL market introduction program has been very effective in accelerating development and production of quality SSL products in the following ways:

- Providing objective, reliable, and unbiased information regarding quality characteristics, performance, and appropriate applications of SSL products
- Lowering transaction cost among buyers and specifiers is important for these market actors to access valuable information on the specifications and appropriate applications of quality products
- Pushing the market towards developing and manufacturing quality SSL products
- Increasing the visibility and credibility of product performance claims
- Supporting the development of new and updated standards and testing procedures

While the program has made great strides on the supply-side of the market, there is ample opportunity remaining for the program to increase adoption of SSL products by consumers and end-users. The current market data show that there are high quantities and types of quality SSL products available in the market but that adoption rates are very low. This could be the result of lack of information and awareness among consumers as well as the high cost of SSL products relative to the competing technologies. The savings associated with quality SSL products can only be realized if there is wider adoption of these technologies.

Progress towards Quality Goals for SSL Products

Market data[26] on SSL efficacy indicate that high-efficacy warm-white products available in the market, although in much lower quantities than cool-white products, have exceeded the DOE's SSL FY 2012 and FY 2013 program efficacy goals by at least 53% in 2012, and by at least 28% in 2013. In 2012, the average efficacy values for cool-white products exceeded the DOE's SSL FY 2012 targets by at least 10%, but were lower than FY 2013 program goals by at least 17%, in 2013.

DOE's SSL program efficacy goals were increased by 35% for warm-white and by 47% for cool-white products, in FY 2013 compared to FY 2012 goals; whereas, the targets were increased by 22% for warm-white and by 2% for cool-white products, in FY 2016 compared to FY 2013 goals. In contrast, the pace of efficacy improvement for SSL products in the market (with similar quality specifications as those in the program's goals) was much lower. The average efficacy values for the most efficacious (top 10th percentile) products in the DLC QPL have increased by at about 17% and 6% for warm-white and cool-white products, respectively, in the year 2013 (as of May 2013) compared to 2012.

[26] Data is based on DLC QPL, which only provides quality information on SSL products in the commercial sectors; there is no information available on the market share of these products.

If the pace of improvement in efficacy for SSL products in the market continues at the same rate as that between the years 2012 and 2013, there is a high likelihood that warm-white products in the market will meet or exceed the FY 2016 efficacy targets; however, there is less likelihood that cool-white products will reach the FY 2016 efficacy targets.

Given that currently there are low quantities of SSL products (especially warm-white products), with characteristics that match those of DOE's SSL FY 2016 quality goals; there is a market need for an increase in the volume of production of these high efficacy products. While pushing the market to produce high-quality products is important, there is also a need for market pull strategies to increase the demand for affordable quality SSL products.

Progress towards Energy Savings Goals for SSL Products

When comparing the market forecasted data on electricity savings from LED to the DOE's SSL program goals, in 2012, the energy savings realized from LED (in three categories) were about 36% of DOE's SSL FY 2012 energy savings targets. If the full potential of energy savings from these products were realized, the energy savings in 2012 would have exceeded the program's targets. There were no published data on energy savings estimates for 2013. Due to the limited information available, it is hard to estimate the magnitude of energy savings that could be realized by 2016; however, there is large remaining potential of energy savings from SSL products that could be gained if market penetration increased.

Recommendations

Recommendations on Program SSL Quality and Savings Goals

Cadmus recommends that DOE's SSL program revise its FY 2016 efficacy goals for cool-white products, to reflect the current status of SSL quality characteristics in the market. Given the lack of information on market adoption and energy savings of the targeted quality SSL products, we recommend that DOE conduct longitudinal national studies to assess the market adoption, in-terms of installed units, and determine the actual efficacy levels and quality metrics, as well as energy savings of the adopted products. These studies could be commissioned every three to five years to assess the progress in adoption rates and the type/quality of products adopted and their energy savings. The results from these studies can inform setting future realistic and achievable goals regarding market sales and energy savings targets.

Measurement of Program Achievements

We recommend that the program establish program performance metrics and market indicators to track and report program achievements annually. The program performance metrics should measure the direct outputs from the program, for example, the number of tests, the number of demonstration projects, the number of publications and technical reports, and workshops. The market indicators should measure the outcomes of the program, for example, the quantity of quality products available on the market, market sales of quality products, adoption rates, energy savings, the increase in technical knowledge among market actors, and the increase in awareness and acceptance among consumers. By

developing a tracking and reporting system to keep a record of these metrics and indicators, DOE will more easily be able to conduct future evaluations of the program's success and measurement of program achievements.

Recommendations on Program Impacts on Market Adoption

For the program to accelerate market adoption of quality SSL products by consumers and end-users, we recommend that the program expand its outreach activities to end-users, including residential consumers. This could either be directly implemented by the program or indirectly by influencing market actors, including utility program implementers, to address this issue. One possibility is for the program to sponsor a national campaign utilizing mainstream media to assure that the information reaches a wider-audience. Another possibility is that the program could produce user-friendly marketing materials and guides, which could be used by energy efficiency programs and retailers to distribute to their customers. Increasing the number of demonstrations through scaled-field placements at targeted consumers' sites, such as chain stores, restaurants, universities and colleges, is another opportunity that the program could pursue to enhance the visibility of these products among wider audiences.

The program should maintain its successful efforts in coordination and collaboration with various market actors and decision makers. Those efforts will ensure continuous feedback from industry professional and implementers on the status of the technology. There is a possibility that the program could increase its impacts on the adoption of quality products by incentivizing manufacturers to reduce the initial cost of the products. That could be achieved through efforts to increase the competition between manufacturers and by providing grants to support the research and development of these technologies. In addition, through DOE's leadership, nationally coordinated efforts among utilities and energy efficiency program sponsors could be pursued to provide more incentives on quality SSL products.

Appendix A: Market Actors Interview Guide

INTRODUCTION

Thank you for taking the time to talk with Cadmus today about your experience with the US DOE's Solid State Lighting program - specifically the market introduction support efforts for LED products. **Your feedback is important for improving the program and your individual responses will be kept anonymous**. We are conducting this study on behalf of Pacific Northwest National Laboratory (PNNL) on the market impacts of the U.S. DOE's SSL program.

We expect this interview to take about 45 minutes to an hour. Do you have any questions before we begin?

Part 1: Status of SSL Products & Market Adoption

I would like to start by asking a few questions about your perspective on the SSL products and market development.

1. First, please tell me briefly about your work or your organization's work on the solid state lighting technologies.
2. What type of SSL products do you work with the most?
3. From your perspective, who are the key market actors and/or decision makers who can affect or influence the type and "quality" of SSL products available in the U.S. market?

    3.1 What do you think are the primary challenges facing the availability of these quality products to consumers? Can you comment on whether the challenges are: technical or performance related, informational/awareness, and/or related to limited production and cost?

    3.2 What recommendations do you have regarding what would be the best strategy to engage these market actors (reference responses on market actors above) to ensure that the products that are brought to market achieve high levels of quality and performance?

4. What market sectors do you focus on, such as residential, commercial or industrial?

    4.1 Based on your knowledge of SSL market**,** what opportunities are available to accelerate the adoption of high quality SSL products in this sector? (Probe for factors contributing to opportunities by sector see table below)

    4.2 Regarding the current status of the SSL market, what do you think are the main challenges facing the "adoption" of these products, in terms of customers' acceptance? (Probe for specifics, why)

    4.3 What strategies do you recommend for addressing these challenges?

Part 2: INVOLVEMENT WITH SSL PROGRAM

Now, I would like ask some questions about the level of your involvement with DOE's Solid State Lighting program.

5. How did you first learn about the SSL program?
6. When did you first get involved?
7. I am going to read you the names of some of DOE's SSL program elements that are designed to speed the market introduction and adoption of SSL products through a variety of program efforts, and I am going to ask you if you have heard of them or have participated in them.

Program Element/Activities	**Heard about them**	**When?**	**Participated in them**	**When?**	**If yes go to Part:**
Information disseminated by the DOE's SSL Program, such as: • Technical Information Network for Solid-State Lighting (TINSSL) • Municipal Consortium Fact Sheets and Market Studies, Postings and SSL Updates • Workshops, webinars					Part 3
LED Lighting Facts					Part 4
Next Generation Luminaires					Part 5
L Prize					Part 6
CALiPER					Part 7
GATEWAY Technology Demonstrations					Part 8
Standards & Test Procedures Support					Part 9

[Continue with the Parts 3-9 based on the responses to Q7]

Part 3: Technical Information Network for Solid-State Lighting (TINSSL) Program & Other Information Dissemination Activities

TINSSL increases awareness of SSL technology, performance, and appropriate applications. TINSSL members include representatives from regional energy efficiency organizations and program sponsors, utilities, state and local energy offices, lighting trade groups, and other stakeholders.

8. Are you familiar with the Technical Information Network for Solid-State Lighting (TINSSL)?
   - 8.1 [If Yes] How helpful is the information you receive through TINSSL?
   - 8.2 [If Yes] Of the following, which venues or channels are most helpful and which are least helpful:
     1. Access to technical information on quality SSL products
     2. Market studies & Fact Sheets
     3. GATEWAY demonstration information
     4. CALiPER testing results
     5. Specifications for effective SSL lighting design and installation
     6. Learn what others are doing with SSL products
     7. Information about performance issues and challenges
     8. Performance information on specific SSL applications
     9. Other _____ [RECORD VERBATIM]

   - 8.3 [If No] What type of information do you typically receive from DOE's SSL Program? [RECORD VERBATIM]
9. Have you participated in any DOE SSL Workshops, Webinars, Meetings, and/or Conferences?
   - 9.1 [If Yes] How helpful is the information you receive through these venues
   - 9.2 No
10. How do you use the information that you obtain through DOE's SSL program? [READ AND RECORD ALL THAT **APPLY**]
    1. Improve understanding of quality SSL products
    2. Guide selection of SSL products for inclusion in programs/design
    3. Develop minimum specifications for SSL products for programs/design
    4. Other _____
11. How valuable was information provided by DOE in increasing awareness and understanding of the benefits of quality SSL products?
    1. Not at all valuable
    2. Not too valuable
    3. Somewhat valuable
    4. Very valuable
    5. Don't know [DO NOT READ RESPONSE]

    [If 1 or 2] Why do you say that? _____ [RECORD VERBATIM]

For EE Program Sponsors/Utilities only [*Skip to next question if not***]**

12. How useful was the information conveyed from DOE in developing SSL programs and associated trainings?
    1. Not at all useful
    2. Not too useful
    3. Somewhat useful
    4. Very useful
    5. Don't know [DO NOT READ RESPONSE]

[If 1 or 2] Why do you say that? _____ [RECORD VERBATIM]

13. What recommendations do you have regarding enhancements that could be made to improve the effectiveness of information provided by the DOE SSL Program?

Part 4: LED Lighting Facts

The LED Lighting Facts® is a program that showcases LED products for general illumination from manufacturers who commit to testing products and reporting performance results according to industry standards. For lighting buyers, designers, and energy efficiency programs, the LED Lighting Facts label provides information essential to evaluating products and identifying the best options.

14. Are you a LED Lighting Facts partner?
    1. Yes
    2. No

    14.1 [If YES] What are the benefits you found from being a partner? [RECORD VERBATIM]

    14.2 [If NO] Why did you choose to not to become a partner? [RECORD VERBATIM]

    14.3 [If NO] What benefits has the program brought to you or to your organization? [RECORD VERBATIM]

15. Can you explain what effect of the LED Lighting Facts program has on the type and quality of SSL products that are brought to the market? [RECORD VERBATIM]
16. How successful is the LED Lighting Facts program in increasing awareness and understanding of the benefits of quality SSL products?
    1. Not at all successful
    2. Not too successful
    3. Somewhat successful
    4. Very successful
    5. Don't know [DO NOT READ RESPONSE]

    16.1 Why do you say that? _____ [RECORD VERBATIM]

For Manufacturers ONLY [Skip to next question if not]

17. Did you notice a difference in sales for your SSL products after you started using the LED Lighting Facts label?
    1. Yes
    2. No

17.1 [If YES] How much? _____ [RECORD PERCENTAGE]

For EE Program Sponsors/Utilities ONLY [*Skip to next question if not***]**

18. Did you provide any incentives specifically for SSL products using the LED Lighting Facts Label?

18.1 [If Yes] What types of SSL products are most successful in your programs using the LED Lighting Facts Label?

18.2 [If Yes] Did you notice a difference in customers' adoption for your SSL products after you started using the LED Lighting Facts label?
    1. Yes
    2. No

18.3 [If YES] Can you provide an estimate? _____ [RECORD PERCENTAGE]

19. Did you conduct any marketing or training to educate your customers on the LED Lighting Facts Program? [RECORD VERBATIM]
    1. Yes: What did you do specifically?
    2. No: Why not?

For All Interviewees

20. **What recommendations do you have regarding enhancements that could be made to the LED Lighting Facts program to improve its effectiveness?**

_____ [RECORD VERBATIM]

Part 5: Next Generation Luminaires Competition

The Next Generation Luminaires™ (NGL) Solid-State Lighting (SSL) Design Competition seeks to encourage technical innovation and recognize and promote excellence in the design of energy-efficient LED luminaires for commercial, industrial and institutional applications.

21. How do you normally interact with this program?
22. What benefits has the NGL program brought to you or to your organization?
23. How influential has this program been in the pace of development for commercial SSL applications?
    1. Not at all influential
    2. Not too influential
    3. Somewhat influential
    4. Very influential
    5. Don't know [DO NOT READ RESPONSE]

23.1 [If 1 or 2] Why do you say that? [RECORD VERBATIM]

For Manufactures ONLY [Skip to next question if not]

24. Did you participate in the NGL competition?
    1. Yes
    2. No

24.1 [If YES] Why did you participate? [Probe for the following]
    1. Build awareness of new commercial SSL products to wide audience
    2. Opportunity to gain feedback from influential buyers, specifiers, and designers
    3. Potential to include information in marketing and outreach materials
    4. Other _____ [RECORD VERBATIM]

24.2 [If YES] How easy was it to participate in the competition?
    1. Not at all easy
    2. Not too easy
    3. Somewhat easy
    4. Very easy
    5. Don't know [DO NOT READ RESPONSE]

[If 1 or 2], Why do you say that? _____ [RECORD VERBATIM]

25. What effect did the competition have on sales of your SSL products?

Record % _____ [RECORD VERBATIM]

For Designers/Specifiers ONLY [*Skip to next question if not***]**

26. How did you support the winning products?
27. How satisfied were your customers with the performance and quality of the NGL winning products?
    1. Not at all satisfied
    2. Not too satisfied
    3. Somewhat satisfied
    4. Very satisfied
    5. Don't know [DO NOT READ RESPONSE]

27.1 [If 1 or 2] Why do you say that? _____ [RECORD VERBATIM]

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28. **What recommendations do you have to enhance the effectiveness of NGL program?**

Part 6: L Prize Competition

The L Prize is the first government-sponsored technology competition designed to spur lighting manufacturers to develop high-quality, high-efficiency solid-state lighting products that set leading-edge performance benchmarks for industry. The L Prize competition was implemented to substantially accelerate America's shift from inefficient, dated lighting products to innovative, high-performance products.

29. How have you interacted with this program?

30. How influential has was the L Prize program in the pace of development for LED replacement bulbs?
    1. Not at all influential
    2. Not too influential
    3. Somewhat influential
    4. Very influential
    5. Don't know [DO NOT READ RESPONSE]

30.1 Why do you say that? [RECORD VERBATIM] _____

For Manufacturers ONLY [Skip to next question if not]

31. How likely is it that you will participate in the current PAR 38 L Prize competition?
    1. Not at all likely
    2. Not too likely
    3. Somewhat likely
    4. Very likely
    5. Don't know [DO NOT READ RESPONSE]

For EE Program Sponsors/Utilities ONLY [*Skip to next question if not***]**

32. Have you offered any incentives on the L Prize bulbs in your programs?
    1. Yes
    2. No

32.1 [If YES] How successful are the programs offering L Prize bulbs?
    1. Not at all successful
    2. Not too successful
    3. Somewhat successful
    4. Very successful
    5. Don't know [DO NOT READ RESPONSE]

32.1.1 [If 1 or 2] Why do you say that? _____ [RECORD VERBATIM]

32.2 [If YES] Did you have any issues with customers' satisfaction regarding those products (L Prize bulbs)?

33. **What recommendations would you make to enhance the effectiveness of L Prize program?**

Part 7: Commercially Available LED Product Evaluation and Reporting (CALiPER) program

The DOE CALiPER program supports testing of a wide array of SSL products available for general illumination, using industry-approved test procedures. CALiPER test results guide DOE planning for SSL R&D and market introduction activities, including ENERGY STAR® program planning; support DOE GATEWAY demonstrations and technology procurement activities; provide objective product performance information to the public in the early years, helping buyers and specifiers have confidence that new SSL products will perform as claimed; and guide the development, refinement, and adoption of credible, standardized test procedures and measurements for SSL products.

34. How do you normally interact with this program?
35. What benefits has the programs brought to you or to your organization?
36. What effect has CALiPER had on the following: (DO NOT READ RESPONSES)
    - 36.1 The accuracy of reported SSL products' performance by manufactures
        1. Increased
        2. No effect
        3. Other _____
    - 36.2 The quality of SSL products available in the market.
        1. Increased
        2. No effect
        3. Other _____
    - 36.3 The number of sales of quality SSL products.
        1. Increased
        2. No effect
        3. Other_____
    - 36.4 Electric savings resulting from the application of SSL products.
        1. Increased
        2. No effect
        3. Other_____
37. What recommendations would you make to enhance the effectiveness of CALiPER program?

Part 8: GATEWAY Technology Demonstrations

GATEWAY demonstrations showcase high-performance LED products for general illumination in a variety of commercial and residential applications. Demonstration results provide real-world experience and data on state-of-the-art solid-state lighting (SSL) product performance and cost effectiveness. These results connect DOE technology procurement efforts with large-volume purchasers and provide buyers with reliable data on product performance.

38. How do you normally interact with these aspects of the program?
39. What benefits has these program activities brought to you or to your organization?
40. How successful do you think GATEWAY demonstrations are at increasing awareness and visibility of SSL products in real world applications by end-users?

1. Not at all successful
2. Not too successful
3. Somewhat successful
4. Very successful
5. Don't know [DO NOT READ RESPONSE]

40.1 Why do you say that [response]? _____

41. How successful do you feel GATEWAY demonstrations are in providing information regarding SSL performance?
    1. Not at all successful
    2. Not too successful
    3. Somewhat successful
    4. Very successful
    5. Don't know [DO NOT READ RESPONSE]

    41.1 Why do you say that [response]? _____

42. What effect have the GATEWAY demonstrations had on the following: (DO NOT READ RESPONSES)

    42.1 The quality of SSL products available in the market.
    1. Increased
    2. No effect
    3. Other _____

    42.2 The number of sales of quality SSL products.
    1. Increased
    2. No effect
    3. Other_____

    42.3 The adoption rate of quality SSL products.
    1. Increased
    2. No effect
    3. Other_____

    42.4 Electric savings resulting from the application of SSL products.
    1. Increased
    2. No effect
    3. Other_____

The DOE Municipal Solid-State Street Lighting Consortium shares technical information and experiences related to LED street and area lighting demonstrations and serves as an objective resource for evaluating new products on the market intended for those applications. Cities, power providers, and others who invest in street and area lighting are invited to join the Consortium and share their experiences. The goal is to build a repository of valuable field experience and data that will significantly accelerate the learning curve for buying and implementing high-quality, energy-efficient LED lighting.

43. Have you interacted with the DOE Municipal SSL Street Lighting Consortium?

44. What benefits has the SSL Street Lighting Consortium brought to you or to your organization?
45. How successful do you think Consortium is at increasing awareness and visibility of SSL products in real world applications by end-users?
    1. Not at all successful
    2. Not too successful
    3. Somewhat successful
    4. Very successful
    5. Don't know [DO NOT READ RESPONSE]

    45.1 Why do you say that [response]? _____

46. How successful do you feel the Consortium has been in serving as an objective resource on SSL technology and promoting information exchange with its members?
    1. Not at all successful
    2. Not too successful
    3. Somewhat successful
    4. Very successful
    5. Don't know [DO NOT READ RESPONSE]

    46.1 Why do you say that [response]? _____

47. What effect have the Consortium had on the following: (DO NOT READ RESPONSES)
    47.1 The quality of SSL products available in the market.
    1. Increased
    2. No effect
    3. Other _____

    47.2 The number of sales of quality SSL products.
    1. Increased
    2. No effect
    3. Other_____

    47.3 The adoption rate of quality SSL products.
    1. Increased
    2. No effect
    3. Other_____

    47.4 Electric savings resulting from the application of SSL products.
    1. Increased
    2. No effect
    3. Other_____

48. What recommendations would you make to enhance the effectiveness of GATEWAY program in general, and the Municipal SSL Street Lighting Consortium in particular?

Part 9: Standards & Test Procedures development support

49. How do you normally interact with these aspects of the program?
50. What benefits has these program activities brought to you or to your organization?
51. How useful has the SSL program's support been in influencing the development of effective standards and testing procedures for SSL products?
    1. Not at all useful
    2. Not too useful
    3. Somewhat useful
    4. Very useful
    5. Don't know [DO NOT READ RESPONSE]

    51.1 Why do you say [response]? _____
52. What effects have the standards and test procedures pertaining to SSL technologies on the following: (DO NOT READ RESPONSES)

    52.1 The quality of SSL products available in the market.
    1. Increased
    2. No effect
    3. Other _____

    52.2 Electric savings resulting from the application of SSL products.
    1. Increased
    2. No effect
    3. Other_____
53. What recommendations would you make regarding improving the effectiveness of the Standards & Test Procedures development support aspects of the SSL program?

Part 10: Closing

54. Based on your knowledge, how much have the DOE's SSL program-elements we just discussed, as well as, other activities, such as webinars and workshops, facilitated increased communication or collaboration between stakeholders to advance SSL?
55. Based on what you know about the SSL Program, how has it affected the SSL technology and market in the following areas: [RECORD VERBATIM]

    55.1 Product quality and performance

    55.2 Quality of information available to lighting designers, specifiers, program sponsors, and retailers

    55.3 Quality of information available to end-users and customers

    55.4 Availability and credibility of industry standards and test procedures

    55.5 Cost of SSL products relative to competing technologies

56. I'm going to read to you a series of statements. Please indicate how much you agree with the statement using a scale from 1 to 5 where 1 means you strongly disagree and 5 means you strongly agree) [For interviewers: code "0" if they don't know]
    1. The Solid State Lighting program provides unbiased, objective information.

Response: [If 2 or less, why do you say that?]

2. Overall, the information you have received from the Solid State Lighting program has been valuable to you.

Response: [If 2 or less, why do you say that?]

3. The Solid State Lighting program has been successful at facilitating the market introduction of high quality SSL products.

Response: [If 2 or less, why do you say that?]

4. Program staff members are responsive to feedback from market actors, such as you.

Response: [If 2 or less, why do you say that?]

5. The Solid State Lighting program is targeting the correct market actors (e.g., manufacturers, program sponsors, retailers).

Response: [If 2 or less, why do you say that?]

57. Are there new activities you would like to recommend for PNNL and DOE staff to speed the adoption of quality SSL products? Please explain your answer.
58. In your opinion, what lessons have been learned from introduction of new technologies/products that could be applied in the market introduction of SSL products?
59. What do you believe will be the greatest challenge(s) in the years to come to successfully expand the market for quality SSL products?

[NOT ON MAT LIST]

Those are all the questions I have today. Thank you so much for your time and for the information you have provided.

[ON MAT LIST]

Thank you so much for the information you have provided. At this point, I would like to invite you to participate in an online panel of experts, using a Web-based interactive tool to provide estimates of market adoption rates for solid state lighting products. This component of the study will be used to assess what the market adoption for these SSL products would have been without the effects of DOE's Solid State Lighting Program activities. Most people find using this tool interesting and it should take no longer than 15 minutes of your time.

Your participation will help the DOE to better understand the impacts of their program on the solid state lighting market.

Are you interested in participating in this component of the study?

1. **YES [My colleague will email you with the details on how to access the online tool and will provide you with further information regarding this application]**
2. **NO [THANK AND TERMINATE]**