SSL Pricing and Efficacy Trend Analysis for Utility Program Planning

Jason Tuenge
Pacific Northwest National Laboratory

TINSSL Webinar
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Background

• April 2012 TINSSL Utility Planning Roundtable
  ▪ Roadmap needed to forecast when important SSL product applications will become cost-effective, looking 2-3 years out
  ▪ Price and performance projections
    ➢ Provide time for planning
    ➢ Enable prioritization by application or product category
    ➢ Inform delivery and education approaches
    ➢ Allow estimation of energy savings potential and appropriate incentive levels to overcome price barriers
  ▪ DOE viewed as a credible source of such data for regulatory review
Background

• October 2013 report
  ▪ Informed by additional input from Advisory Task Force
    ➢ Appropriate type/timing/magnitude of energy efficiency activities will vary from organization to organization
    ➢ Price is a primary barrier
  ▪ Focused on category-specific projections of pricing and efficacy
    ➢ Cost-effectiveness beyond scope
  ▪ Historical data from
    ➢ CALiPER
    ➢ LED Lighting Facts (LF)
    ➢ ENERGY STAR (ES)
    ➢ DesignLights Consortium (DLC)
  ▪ To serve as a starting point...
### LED market penetration and savings potential in key categories

<table>
<thead>
<tr>
<th>Category</th>
<th>Savings potential in 2012 (TWh)</th>
<th>Penetration in 2012 (%)</th>
<th>Installed base in 2012 (million units)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Troffers et al.</td>
<td>110.4</td>
<td>&lt; 0.1</td>
<td>0.7</td>
</tr>
<tr>
<td>A lamps</td>
<td>79.1</td>
<td>&lt; 1</td>
<td>19.9</td>
</tr>
<tr>
<td>High-bay luminaires</td>
<td>46.5</td>
<td>&lt; 1</td>
<td>0.3</td>
</tr>
<tr>
<td>Decorative lamps</td>
<td>28.7</td>
<td>&lt; 1</td>
<td>4.7</td>
</tr>
<tr>
<td>Downlights</td>
<td>26.8</td>
<td>&lt; 1</td>
<td>5.5</td>
</tr>
<tr>
<td>Parking lot luminaires</td>
<td>20.4</td>
<td>1</td>
<td>0.2</td>
</tr>
<tr>
<td>Parking garage luminaires</td>
<td>15.3</td>
<td>1</td>
<td>0.4</td>
</tr>
<tr>
<td>Streetlight luminaires</td>
<td>22.9</td>
<td>2</td>
<td>1.0</td>
</tr>
<tr>
<td>Directional lamps (PAR, BR, R)</td>
<td>16.7</td>
<td>4.6</td>
<td>11.4</td>
</tr>
<tr>
<td>MR16 lamps</td>
<td>6.2</td>
<td>10</td>
<td>4.8</td>
</tr>
</tbody>
</table>

*Adoption of Light-Emitting Diodes in Common Lighting Applications (April 2013)*

[www.ssl.energy.gov/tech_reports.html](http://www.ssl.energy.gov/tech_reports.html)
Current performance (sample: omnidirectional lamps)
Current performance (sample: decorative lamps)

- LF listed LED decorative lamps (as of 2013-10-10)
- ES listed LED decorative lamps (as of 2013-09-26)
- CALiPER measured benchmarks (upper/lower bounds)
- ES target for 60 W inc. deco. lamp replacement
ENERGY STAR omnidirectional and decorative lamps

A  BT  P  PS  S  T  B  C  CA  F  G
LED efficacy trends

• Projections using least-squares regression fits to logarithmic mathematical models based on historical product data
  ▪ LF and ES or DLC
  ▪ CALiPER for categories with adequate data
• Low $R^2$ values reflect diversity of population
  ▪ Some due in part to low/zero/negative slope
• Upper and lower 95% confidence bands also shown
LED efficacy trends: Omnidirectional lamps

![Graph showing LED efficacy trends for different types of lamps, with logarithmic scale for efficacy and linear scale for year. The graph includes markers for LF A lamp, Modeled avg. LF A lamp, CALiPER A lamp, Modeled avg. CALiPER A lamp, ES A lamp, Modeled avg. ES A lamp, current criterion and date effective for ES omni. lamps < 10 W, and new criterion and date effective for ES omni. lamps < 15 W. The equations for the trend lines are provided: y = 72.82ln(x) - 116.30 with R² = 0.21, y = 46.36ln(x) - 60.05 with R² = 0.29, and y = 14.63ln(x) + 28.27 with R² = 0.00. The graph displays data points and trend lines for the year range of 2000-2021.]
LED efficacy trends: Decorative lamps

- LF decorative lamp
- Modeled avg. LF decorative lamp
- ES decorative lamp
- Modeled avg. ES decorative lamp
- Current criterion and date effective for ES deco. lamps
- New criterion and date effective for ES deco. lamps < 15 W

Equations:

- $y = 108.47 \ln(x) - 220.65$
  $R^2 = 0.39$

- $y = 41.91 \ln(x) - 50.77$
  $R^2 = 0.05$
LED efficacy trends: Directional lamps (PAR-BR-R)

- LF PAR-R lamp
- Modeled avg. LF PAR-R lamp
- CALiPER PAR-BR-R lamp
- Modeled avg. CALiPER PAR-BR-R lamp
- ES PAR-BR-R lamp
- Modeled avg. ES PAR-BR-R lamp
- Current criterion and date effective for ES directional lamps ≤ 20/8 inch
- New criterion and date effective for ES directional lamps < 20 W

Mathematical equations:

\[ y = 65.69 \ln(x) - 106.18 \]
\[ R^2 = 0.30 \]

\[ y = 62.91 \ln(x) - 101.65 \]
\[ R^2 = 0.15 \]

\[ y = 57.27 \ln(x) - 87.91 \]
\[ R^2 = 0.32 \]
LED efficacy trends: Directional lamps (MR16)

![Graph showing LED efficacy trends for MR16 lamps with data points and trend lines. The graph includes symbols for different lamp types and criteria.]

- **LF MR16 lamp**
- **Modeled avg. LF MR16 lamp**
- **CALiPER MR16 lamp**
- **Modeled avg. CALiPER MR16 lamp**
- **ES MR16 lamp**
- **Modeled avg. ES MR16 lamp**

- Current criterion and date effective for ES directional lamps ≤ 20/8 inch
- New criterion and date effective for ES directional lamps < 20 W

**Equations and R² values:**

1. $y = 65.87 \ln(x) - 110.03$
   - $R^2 = 0.31$
2. $y = 72.71 \ln(x) - 129.47$
   - $R^2 = 0.26$
3. $y = 53.89 \ln(x) - 79.95$
   - $R^2 = 0.22$

**Legend:**
- Blue solid line: LF MR16 lamp
- Blue dashed line: Modeled avg. LF MR16 lamp
- Orange line: CALiPER MR16 lamp
- Orange dashed line: Modeled avg. CALiPER MR16 lamp
- Green line: ES MR16 lamp
- Green dashed line: Modeled avg. ES MR16 lamp

**X-axis:** Year (-2000)

**Y-axis:** Initial luminous efficacy (lm/W)
LED efficacy trends: Downlights

![Graph showing LED efficacy trends for Downlights with various data points and lines for different categories.]

- LF downlight
- Modeled avg. LF downlight
- CALiPER downlight
- Modeled avg. CALiPER downlight
- ES downlight luminaire
- Modeled avg. ES downlight luminaire
- ES downlight retrofit
- Modeled avg. ES downlight retrofit
- Current criterion and date effective for ES downlights
- MYPP luminaire target for 2017

Equations:

1. $y = 67.38 \ln(x) - 116.00$
   - $R^2 = 0.21$
2. $y = 60.19 \ln(x) - 97.05$
   - $R^2 = 0.29$
3. $y = 40.55 \ln(x) - 43.45$
   - $R^2 = 0.03$
4. $y = 3.29 \ln(x) + 45.85$
   - $R^2 = 0.00$
LED efficacy trends: Troffer luminaires

- LF troffer luminaire
- Modeled avg. LF troffer luminaire
- CALiPER troffer luminaire
- Modeled avg. CALiPER troffer luminaire
- DLC troffer luminaire
- Modeled avg. DLC troffer luminaire
- Old criterion and date effective for DLC 2x2 troffers
- Current criterion and date effective for DLC 2x2 troffers
- MYPP luminaire target for 2017

Equations:

\[ y = 108.16 \ln(x) - 187.19 \]

\[ R^2 = 0.57 \]

\[ y = 112.13 \ln(x) - 201.01 \]

\[ R^2 = 0.15 \]

\[ R^2 = 0.01 \]
LED efficacy trends: High-bay & low-bay luminaires

- $y = 84.83\ln(x) - 128.87$
- $R^2 = 0.06$
- $y = 75.00\ln(x) - 105.13$
- $R^2 = 0.13$

- LF highbay/lowbay luminaire
- Modeled avg. LF highbay/lowbay luminaire
- DLC highbay/lowbay luminaire
- Modeled avg. DLC highbay/lowbay luminaire
- Old criterion and date effective for DLC high-bays
- Current criterion and date effective for DLC high-bays
- MYPP luminaire target for 2017
LED efficacy trends: Garage luminaires

![Graph showing LED efficacy trends for garage luminaires. The graph plots initial luminous efficacy (lm/W) against year (-2000). Two models are shown: one with a slope of $y = 65.40\ln(x) - 86.34$, $R^2 = 0.13$, and another with a slope of $y = 63.46\ln(x) - 82.24$, $R^2 = 0.10$. The graph includes various data points and markers representing different types of garage luminaires and criteria.]
LED efficacy trends

- Excerpt from table

<table>
<thead>
<tr>
<th>Product category</th>
<th>Dataset</th>
<th>Curve</th>
<th>Projected efficacy at start of year (lm/W)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>2014</td>
</tr>
<tr>
<td>LED omnidirectional lamps</td>
<td>LF</td>
<td>Upper 95% confidence band</td>
<td>78</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Modeled average</td>
<td>76</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lower 95% confidence band</td>
<td>74</td>
</tr>
<tr>
<td></td>
<td>ES</td>
<td>Upper 95% confidence band</td>
<td>71</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Modeled average</td>
<td>67</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lower 95% confidence band</td>
<td>63</td>
</tr>
<tr>
<td>LED decorative lamps</td>
<td>LF</td>
<td>Upper 95% confidence band</td>
<td>68</td>
</tr>
<tr>
<td></td>
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<td>66</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lower 95% confidence band</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>ES</td>
<td>Upper 95% confidence band</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Modeled average</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lower 95% confidence band</td>
<td>57</td>
</tr>
</tbody>
</table>
LED efficacy trends

• Possible explanations for differences between LF and ES or DLC
  ▪ ES and DLC have minimum performance requirements, whereas LF only requires accurate performance claims
  ▪ LF dataset for a given product category may include some products above ES or DLC dataset, and some products below
  ▪ Category-specific benchmark pressures (efficacy, pricing, life, etc.)

• Differences between LF and CALiPER likely attributable to smaller CALiPER sample size (i.e., sampling error)
LED pricing trends

• Scoured CALiPER data for product categories meeting criteria
  ▪ Substantial number of models for which purchase date, purchase price, and measured lumens could be determined
    ➢ Rated life was not considered in this analysis
  ▪ Purchases dispersed fairly well over time
  ▪ Substantial span between oldest and most recent
• CALiPER datasets meeting criteria
  ▪ Omnidirectional lamps
  ▪ Decorative lamps
  ▪ Directional lamps (PAR-BR-R and MR16)
  ▪ Troffer luminaires
• Supplemented by Seattle City Light (SCL) streetlight luminaires
• Projections using least-squares regression fits to power mathematical models based on historical product data
LED pricing trends: Omnidirectional lamps

- MYPP luminaire target for 2017
- CALiPER LED A lamps
- CALiPER LED A lamps (power model)
- 95% confidence band for predicted avg.

$R^2 = 0.43$
LED pricing trends: Decorative lamps

- MYPP luminaire target for 2017
- CALiPER LED decorative lamps
- CALiPER LED decorative lamps (power model)
- 95% confidence band for predicted avg.

Price per kilolumen ($/klm)

Year (-2000)

R² = 0.38
LED pricing trends: Directional lamps (PAR-BR-R)
LED pricing trends: Directional lamps (MR16)

Graph showing the price per kilolumen ($/klm) over the years from 2007 to 2019. The graph includes data points for MYPP luminaire target for 2017 and CALiPER LED MR16 lamps. The trend line indicates a decrease in price per kilolumen over time, with an $R^2$ value of 0.49.
LED pricing trends: Troffer luminaires

- MYPP luminaire target for 2017
- CALiPER LED troffer luminaires
- CALiPER LED troffer luminaires (power model)
- 95% confidence band for predicted avg.

R² = 0.28
LED pricing trends: Streetlight luminaires

![Graph showing LED pricing trends for streetlight luminaires with key metrics and data points]

- MYPP luminaire target for 2017
- SCL LED cobrahead luminaires
- SCL LED cobrahead luminaires (power model)
- 95% confidence band for predicted avg.

R² = 0.62
LED pricing trends

- Modeled averages were initially normalized for equal value at start of 2008 to explore potential for merging (i.e., commonality)
  - Confidence band overlap indicated lamps could be merged together and luminaires could be merged together
    - Made possible in part by width of confidence bands
  - Agrees with A lamp curve previously published in 2013 DOE SSL MYPP
  - Curves roughly bound downlight retrofit curve from Adoption report

- Modeled averages were then normalized for equal value at start of fourth quarter of 2013 and merged
  - Efficacy data did not support grouping so cleanly
LED pricing trends
LED pricing trends

![Graph showing LED pricing trends](image)

- **avg. LED luminaire (power model)**
- **95% confidence band for predicted avg.**
- **avg. LED lamp (power model)**
- **95% confidence band for predicted avg.**

Mathematical equations:

- \( y = 82.311x^{-1.683} \)
- \( y = 29497x^{3.927} \)
LED pricing trends: Example projection

- September 2013 LED directional lamp pricing from major retailers
  - Ace Hardware, Best Buy, The Home Depot, Lowe’s, Sears, True Value
    - No adjustment for possible upstream incentives
  - Cree, EcoSmart, Feit, GE, Insignia, LSGC, Philips, Samsung, Sylvania, Utilitech, and TCP
  - CCT of 2700-3000 K
  - CRI and ENERGY STAR certification not consistently indicated
  - Strong relationship between price and output—and diameter
    - Similar relationship observed for omnidirectional and decorative
LED pricing trends: Example projection

• Estimation of current “average” pricing is difficult...
  ▪ Unknown relative sales volume
  ▪ Differing number of models offered by each brand
  ▪ Differing proportion of older and newer models on each website
  ▪ Variability between brands due to real or perceived quality
  ▪ Variability for smaller lamps

• ...so we took an alternative approach
  1. Restrict product search to approximately 5-10 major retailers
  2. Obtain pricing for all models meeting criteria from approximately 10 leading brands
  3. For each brand, find the lowest $/klm model across retailers
  4. Average pricing for lowest $/klm models across included brands
LED pricing trends: Example projection

<table>
<thead>
<tr>
<th>Brand</th>
<th>&lt; 3” diameter</th>
<th>&gt; 3” diameter</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lowest pricing ($/klm)</td>
<td>Efficacy (lm/W)</td>
</tr>
<tr>
<td>A</td>
<td>28</td>
<td>56</td>
</tr>
<tr>
<td>B</td>
<td>44</td>
<td>56</td>
</tr>
<tr>
<td>C</td>
<td>69</td>
<td>57</td>
</tr>
<tr>
<td>D</td>
<td>30</td>
<td>50</td>
</tr>
<tr>
<td>E</td>
<td>49</td>
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</tr>
<tr>
<td>Mean</td>
<td>50</td>
<td>56</td>
</tr>
</tbody>
</table>

* No model available for this brand at these retailers.
LED pricing trends: Example projection

- Applied current values to normalized lamp curve for projections

<table>
<thead>
<tr>
<th>Lamp diameter</th>
<th>$/klm pricing at beginning of year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2014</td>
</tr>
<tr>
<td>&lt; 3 inch</td>
<td>47</td>
</tr>
<tr>
<td>&gt; 3 inch</td>
<td>28</td>
</tr>
</tbody>
</table>
Key findings

- Average efficacy for LED lamps and LED luminaires is projected to remain well below L Prize and DOE SSL R&D Multi-Year Program Plan (MYPP) thresholds through 2017, but given the high variability among products and the performance potential of new color mixing technologies, these goals might soon be met by leading products.
Key findings

- In several key LED product categories (omnidirectional lamps, decorative lamps, downlight luminaires, and troffer luminaires) projected efficacies based on LED Lighting Facts listings are substantially higher than projections based on the corresponding ENERGY STAR or DesignLights Consortium (DLC) listings.
Key findings

- Comparison of historical data compiled by CALiPER and Seattle City Light indicates two distinct normalized curves—one for LED lamps, and one for LED luminaires—can be used to make projections from current $/klm pricing for a given product category.
Key findings

• LED lamp $/klm pricing is expected to decrease roughly 55% by 2017, relative to current pricing—a more modest decrease of 30% is projected for LED luminaires over this same period.
DOE SSL resources

• Direct link to report presented today:

• More DOE SSL market studies and technical reports:
  http://www1.eere.energy.gov/buildings/ssl/tech_reports.html

• DOE SSL programs (e.g., TINSSL, CALiPER, LED Lighting Facts, L Prize) are all linked from:
  www.ssl.energy.gov

• More info from the BBA and FEMP:
  http://www4.eere.energy.gov/alliance/activities/technology-solutions-teams
  https://www1.eere.energy.gov/femp/technologies/technologies.html
Thank you for participating!

Any questions?