QUANTIFYING POTENTIAL ENERGY SAVINGS OF NEXT GENERATION LED LIGHTING TECHNOLOGIES

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THE LIGHTING MARKET MODEL
1. Calculate national lighting inventory and service

**MODEL APPROACH**

- **Lighting Performance**
- **Lighting Price**
- **Hours of Use**
- **Efficiency Standards**

**Logit Potential**

- Bass Diffusion
- Acceptance Factor
- Sales and Shipment Data
- Efficiency Standards

**Bass Diffusion**

- Lighting & Control Stock Forecast
  - Renovations & Growth
  - Lighting Failures
- Energy Use - Baseline
- Energy Use - Efficient
- Per Control Savings
- Energy Savings Forecast
- Lighting Market Characterization, Residential Lighting End-Use Consumption Study, LED Adoption Report, etc.
- Control Use
- Baseline Load Profile
- Energy Effect
### LIGHTING COMPETITION AREAS

#### 2. Develop arenas for competition

<table>
<thead>
<tr>
<th>Sectors</th>
<th>Residential</th>
<th>Commercial</th>
<th>Industrial</th>
<th>Outdoor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Submarkets</td>
<td>A-Type</td>
<td>Decorative</td>
<td>Linear Fixture</td>
<td>Low / High Bay</td>
</tr>
</tbody>
</table>

**4 Sectors**

**8 Submarkets**

**15 Lighting Technologies**

<table>
<thead>
<tr>
<th>Lighting</th>
<th>Incandescent</th>
<th>Incandescent Reflector</th>
<th>Halogen</th>
<th>Halogen Reflector</th>
<th>CFL</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFL Reflector</td>
<td>CFL Pin</td>
<td>T5</td>
<td>T8</td>
<td>T12</td>
<td></td>
</tr>
<tr>
<td>Metal Halide</td>
<td>High Pressure Sodium</td>
<td>Mercury Vapor</td>
<td>LED Lamp</td>
<td>LED Luminaire</td>
<td></td>
</tr>
</tbody>
</table>
3. Project annual lighting demand forecast and calculate available market

**MODEL APPROACH**

- **Lighting Performance**
- **Lighting Price**
- **Hours of Use**
- **Efficiency Standards**

**Bass Diffusion**
- Sales and Shipment Data
- Acceptance Factor

**Logit Potential**

**Renovations & Growth**

**Lighting Failures**

- Energy Use - Baseline
- Energy Use - Efficient

**Initial Stock**
- Energy Savings Forecast
- Per Control Savings
- Control Use
- Baseline Load Profile
- Energy Effect

**EIA AEO data**

**Lighting & Control Stock Forecast**
4. Project conventional and LED technology improvement

MODEL APPROACH

- Lighting Performance
- Lighting Price
- Hours of Use
- Efficiency Standards

ENERGY STAR, LED Lighting Facts, DesignLights Consortium, DOE Lighting Standards, etc.

Renovations & Growth
Lighting Failures

Energy Use - Baseline
Energy Use - Efficient

Per Control Savings

Initial Stock

Control Use
Baseline Load Profile
Energy Effect

Energy Savings Forecast

Lighting & Control Stock Forecast

Bass Diffusion
Logit Potential

Sales and Shipment Data
Acceptance Factor

Logit Potential

Bass Diffusion

Renovations & Growth
Lighting Failures

Initial Stock

Energy Savings Forecast

Energy Use - Baseline
Energy Use - Efficient

Per Control Savings

Control Use
Baseline Load Profile
Energy Effect

4. Project conventional and LED technology improvement
5. Model the market share of all lighting technologies

- Bass Diffusion
- Logit Potential
- Lighting & Control Stock Forecast
- Renovations & Growth
- Lighting Failures
- Energy Use - Baseline
- Energy Use - Efficient
- Per Control Savings
- Initial Stock
- Energy Savings Forecast
- Control Use
- Baseline Load Profile
- Energy Effect

Factors:
- Lighting Performance
- Lighting Price
- Hours of Use
- Efficiency Standards
- Sales and Shipment Data
- Acceptance Factor
MARKET SHARE METHODOLOGY

1. The lighting market model uses a **conditional logit model** to award available market to multiple competing lighting technologies.

2. To simulate this lag effect on newer technologies, the lighting market model applies a **Bass technology diffusion model** to the logit model market share predictions.

3. Calibrate the modeled data to actual recent data.

**Step 1.** Develop initial market share through an econometric logit model that considers first and annual O&M costs of a technology.

**Step 2.** Limit market shares using Bass diffusion that predicts maximum adoption potential due to market barriers of a technology.

**Step 3.** Calibrate LED market share projections by minimizing delta between actual and modelled market share.
6. Forecast market shares and lighting stock

- Lighting Performance
- Lighting Price
- Hours of Use
- Efficiency Standards

- Bass Diffusion
- Logit Potential
- Sales and Shipment Data
- Acceptance Factor

- Renovations & Growth
- Lighting Failures

- Energy Use - Baseline
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- Energy Savings Forecast
- Per Control Savings
  - Control Use
  - Baseline Load Profile
  - Energy Effect

- Initial Stock

Efficiency Standards

- Logit Potential
- Sales and Shipment Data
- Acceptance Factor

- Lighting Performance
- Lighting Price
- Hours of Use

- Bass Diffusion
- Logit Potential
- Sales and Shipment Data
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- Initial Stock
MODEL APPROACH

7. Model market share and energy savings of lighting controls.
8. Calculate overall lighting market energy savings
A new scenario was created in the model with advanced LED technologies entering the market in 2022.

New data inputs were used to define advanced LED lighting technologies in 3 representative market segments.

Results from these segments were scaled to all other segments in the sector.

**Advanced LED Scenario**

<table>
<thead>
<tr>
<th>New Data Inputs</th>
<th>New Lighting Technologies</th>
<th>Market Segments</th>
<th>Scaled Sectors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price</td>
<td>Advanced LED Lamps</td>
<td>Residential General Service</td>
<td>Residential</td>
</tr>
<tr>
<td>Efficacy</td>
<td></td>
<td>Commercial Linear 4ft</td>
<td>Commercial &amp; Industrial</td>
</tr>
<tr>
<td>Cost Adjustment</td>
<td>Advanced LED Luminaires</td>
<td>Outdoor Street/Roadway</td>
<td>Outdoor</td>
</tr>
<tr>
<td>Lifetime</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating Hours</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lumen Output</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
PNNL is conducting advanced LED lighting research focused on glare reduction, flicker reduction, non-visual effects (lighting intensity and color temperature adjustment), color rendering, and dark sky and environmental impacts.

<table>
<thead>
<tr>
<th>Research Features</th>
<th>Submarket</th>
<th>Long Term Result (2030-2035)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glare Reduction</td>
<td>Commercial</td>
<td>Updated glare metrics combined with new findings on optical materials and optical control eliminate visual discomfort.</td>
</tr>
<tr>
<td>Flicker Reduction</td>
<td>Commercial</td>
<td>Updated flicker metrics and application guidelines combined with new developments in driver, dimming, and control technologies eliminate noticeable flicker.</td>
</tr>
<tr>
<td></td>
<td>Residential</td>
<td></td>
</tr>
<tr>
<td>Non-Visual Effects</td>
<td>Commercial</td>
<td>Wide range of adjustment possible for both light levels and various light colors. Addresses the desire to have bluer light during portions of the day, with higher light levels, and redder light at night, with lower light levels.</td>
</tr>
<tr>
<td></td>
<td>Residential</td>
<td></td>
</tr>
<tr>
<td>Color Rendering</td>
<td>Commercial</td>
<td>The light makes colors look vibrant and pleasing. Whites are crisp and clean. The light is an untinted neutral white.</td>
</tr>
<tr>
<td></td>
<td>Residential</td>
<td></td>
</tr>
<tr>
<td>Dark Sky/Environmental Effects</td>
<td>Outdoor</td>
<td>Advanced understanding of interactions between light, wildlife, and dark skies lead to better metrics and user guidance, allowing light that minimizes impact on dark skies and wildlife, while allowing improved human visibility.</td>
</tr>
</tbody>
</table>
PNNL MODEL INPUTS

- PNNL provided estimates of the price and efficacy effects in the near term and the long term that are expected from their research conducted on each lighting feature.
- Values for each feature were combined to obtain a single price and efficacy value for advanced LEDs in each submarket.
- The labor costs, operating hours, and lifetime projections are assumed to be the same as the non-advanced LEDs. Lumen output was the same except decreased for outdoor.
- Market entry year is assumed to be 2022.

![Advanced LED Price/Efficacy Difference from Baseline](chart.png)
• Additional adjustments were needed to account for the added value of the advanced technology features relative to the baseline.
• The values estimated from SERA’s analysis were used to adjust the first cost of advanced LED technologies to simulate increased favorability in the market.
DIFFUSION AND CALIBRATION

• There are three primary coefficient factors that affect bass diffusion curve:
  1. **Word of mouth factor:**
  2. **Marketing factor:**
  3. **Initial acceptance factors**
• Assumed default ‘moderate’ coefficients for Advanced LEDs
Energy savings for the Advanced LED Path Scenario were estimated relative to a Current SSL Path Scenario.

These are defined as:

- **Current SSL Path**: the expected future path for LED lamps and luminaires given continuation of current levels of SSL investment AND NO investment in the advanced LED technologies that are the focus of this study.

- **Advanced LED Path**: the expected future path for LED lamps and luminaires given continuation of current levels of SSL investment AND additional investment in advanced LED lighting features (glare reduction, flicker reduction, flicker reduction, non-visual effects, color rendering, dark sky/environmental effect) which result in commercialized technologies in 2022.
• In 2035, advanced LED technologies are projected to represent the **third most** installed lighting technology in the residential general service submarket, representing **17%** of the market.
In 2035, advanced LED technologies are projected to represent the **third most** installed lighting technology in the commercial linear 4ft submarket, representing **20%** of the market.
In 2035, advanced LED technologies are projected to represent the **second most** installed lighting technology in the outdoor street/roadway submarket, representing **32%** of the market.
SCALING METHODOLOGY

• Advanced LED technologies were modeled for three market segments:
  1) Commercial linear 4ft   2) Residential general service   3) Outdoor street/roadway
• The energy savings were scaled to the other submarkets within the sectors using the ratio of energy use for each submarket to the total energy use in the sector
• This was used to reduce number of model runs due to time/budget constraints

Note: Some smaller market segments are combined into the ‘other’ category in these graphics for simplification purposes.
ENERGY SAVINGS RESULTS

- Results showed the greatest cumulative energy savings in the residential sector, then outdoor, and finally the commercial/industrial sector.
- In 2035, source energy savings were **334 TBtu** representing **10%** of lighting energy use.
- Cumulative energy savings (2023-2035) were estimated to be **1,987 TBtu**

### Advanced LED Technology Source Energy Savings

<table>
<thead>
<tr>
<th>Sector</th>
<th>Energy Savings (TBtu)</th>
<th>Energy Savings (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commercial/Industrial</td>
<td>102 TBtu</td>
<td>6%</td>
</tr>
<tr>
<td>Residential</td>
<td>148 TBtu</td>
<td>18%</td>
</tr>
<tr>
<td>Outdoor</td>
<td>85 TBtu</td>
<td>12%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>334 TBtu</strong></td>
<td><strong>10%</strong></td>
</tr>
</tbody>
</table>

![Advanced LED Technology Energy Savings Graph](chart.png)