From the Laboratory to the California Marketplace: A New Generation of LED Lighting Systems

Key Research Outcomes
Today’s Agenda

• 10:00 am – Introduction (Cori Jackson, CLTC)
  • Project team
  • Project goals & objectives

• 10:10 am – Key Research Outcomes (CLTC Team)
  • Consumer Preference Study Results
  • Product Evaluation Results
  • Technology Transfer Activities
  • Industry Engagement

• 11:40 am – Questions & Answers (All)
Project Goals & Objectives
Today’s lighting products should be designed to:

• Meet consumer expectations
• Provide value
• While saving energy

We don’t know what consumers expect or value!
Today's Agenda

1. Determine consumer preferences for major lighting performance features in common applications
2. Apply outcomes in development of lighting system specifications & prototypes
3. Increase LED lighting system adoption across California through engagement with industry
4. Decrease energy use and carbon emissions

The Solution

- Vanity mock-up
- Home office mock up
- Color sorting task
Consumer Preference Studies

- Color
- Control
- Packaging
- Longevity

Targeted Products

- Sources
- Retrofit kits
- Luminaires
Key Research Outcomes
Key Research Outcomes

1. Consumer Preference Study Results
2. Product Evaluation Results
3. Technology Transfer Activities
4. Industry Engagement
Key Research Outcomes

1. Consumer Preference Study Results
   • Melanopic Threshold Study
   • Lighting Service Delivered & Color Fidelity
2. Product Evaluation Results
3. Technology Transfer Activities
4. Industry Engagement

The data in this presentation are considered confidential and are not intended for publication or distribution beyond the company or institution to which they have been provided by the CLTC. They are for development and verification only and not intended as a substitute for data generated by an Independent Testing Lab. Distribution or publication of these data is forbidden without the express written consent of the CLTC. CLTC makes no claim as to the accuracy of these data beyond the specific test conditions and parameters under which the data were obtained.
Melanopic Threshold Study
Melanopic Threshold Study

The data in this presentation are considered confidential and are not intended for publication or distribution beyond the company or institution to which they have been provided by the CLTC. They are for development and verification only and not intended as a substitute for data generated by an Independent Testing Lab. Distribution or publication of these data is forbidden without the express written consent of the CLTC. CLTC makes no claim as to the accuracy of these data beyond the specific test conditions and parameters under which the data were obtained.
The data in this presentation are considered confidential and are not intended for publication or distribution beyond the company or institution to which they have been provided by the CLTC. They are for development and verification only and not intended as a substitute for data generated by an Independent Testing Lab. Distribution or publication of these data is forbidden without the express written consent of the CLTC. CLTC makes no claim as to the accuracy of these data beyond the specific test conditions and parameters under which the data were obtained.
Color Sorting Results

Farnsworth-Munsell D-15 Test

Average (Mean) & Standard Deviation for Total Error Score

The data in this presentation are considered confidential and are not intended for publication or distribution beyond the company or institution to which they have been provided by the CLTC. They are for development and verification only and not intended as a substitute for data generated by an Independent Testing Lab. Distribution or publication of these data is forbidden without the express written consent of the CLTC. CLTC makes no claim as to the accuracy of these data beyond the specific test conditions and parameters under which the data were obtained.
Visual Acuity Results

The data in this presentation are considered confidential and are not intended for publication or distribution beyond the company or institution to which they have been provided by the CLTC. They are for development and verification only and not intended as a substitute for data generated by an Independent Testing Lab. Distribution or publication of these data is forbidden without the express written consent of the CLTC. CLTC makes no claim as to the accuracy of these data beyond the specific test conditions and parameters under which the data were obtained.
Transitioning Research to Residential Applications
Field Study in Residential Corridor

The data in this presentation are considered confidential and are not intended for publication or distribution beyond the company or institution to which they have been provided by the CLTC. They are for development and verification only and not intended as a substitute for data generated by an Independent Testing Lab. Distribution or publication of these data is forbidden without the express written consent of the CLTC. CLTC makes no claim as to the accuracy of these data beyond the specific test conditions and parameters under which the data were obtained.
Lighting Service Delivered & Color Fidelity
Lighting Service Delivered & Color Fidelity

<table>
<thead>
<tr>
<th></th>
<th>Color Fidelity (CRI - Ra)</th>
<th>R9</th>
<th>CCT (K)</th>
<th>Duv</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Color Fidelity</td>
<td>95</td>
<td>76</td>
<td>2679</td>
<td>0.0004</td>
</tr>
<tr>
<td>Low Color Fidelity</td>
<td>82</td>
<td>9</td>
<td>2666</td>
<td>0.0005</td>
</tr>
</tbody>
</table>
Lighting Service Delivered & Color Fidelity

Percent Difference in Light Chosen From Low to High CRI

Boxplot

Mean with C.I.
Transitioning Research to Healthcare Applications
Background

• Analysis of face and hands photos indicate color quality improvements between 82, 97 and 95 Red CRI lights sources

• Self examination tests at CLTC using mirror setup indicated that high CRI is more effective for skin evaluation than 82 CRI light
Project Partners

• UC Irvine Dermatology Department
  • Christopher B. Zachary, MD – *Chair of Dermatology at UCI*
  • Natasha Atanaskova Mesinkovska, MD PhD – *Chief Scientific Officer*
  • Margit Juhasz, MD – *Dermatology Clinical Research Fellow*

• California Lighting Technology Center (CLTC)

• California Energy Commission
Study Objectives

1. Improve assessment of skin disorders in dermatology clinics

2. Improve patient comfort
• CLTC and industry partners developed a variable CRI LED luminaire with three normalized channels:
  • 82 CRI
  • 97 CRI
  • 95 + (red enhanced) CRI
    • Red enhanced channel has a higher red-light spectral content than 97 CRI channel

• Luminaire power and switching is controlled through a PoE system with custom control software
Field Study at UC Irvine

- Adjustable color quality LED light fixtures in 15 rooms for clinical use

- For each setting, clinicians evaluate the following:
  - Different skin conditions
  - Naturalness of the patient's skin
  - Effectiveness of the lighting for skin evaluation
  - Room comfort
  - Preference for use in their dermatology practice
Key Research Outcomes

1. Consumer Preference Study Results
2. Product Evaluation Results
   • Product Life Testing
   • Linear LED Lamps – Interoperability Testing
3. Technology Transfer Activities
4. Industry Engagement
LED Product Life Testing
Product Evaluations – Life Testing

• Third-party verification of 138 LED lamp performance for 12,000 hours of runtime
  • Medium Screw Base LED Lamps (14 Products)
    • 7 omni-directional (2 are filament-style)
    • 7 directional
  • Linear LED Lamps (7 products)
    • UL Type A (3)
    • UL Type B (2)
    • UL Type A/B (1)
    • UL Type C (1)
  • Candelabra Lamps (2 Products)

• Three early failures (within 1,000 hours of run time)
  • 2 samples of one filament-style LED medium screw base product
  • 1 linear LED lamp sample
Product Evaluations – Life Testing

• Projected Rated Life vs. Manufacturer Claimed Rated Life
  • Used industry standard measurement and calculation methods
    • Lifetime standard, IES LM-84-14 & TM-28-14
    • Photometric Measurements, IES LM-79-08
  • 26% of tested products failed to meet manufacturer claimed rated life (6 of 23)

• Product Safety and Reliability
  • No safety concerns encountered over the course of the evaluation
  • All samples of two ‘filament-style’ products failed
Linear LED Lamp Product Evaluations

• 3 of the 7 linear LED lamp products experienced failures due to three main modes:
  • Connections between lamp and driver (6 of 6)
  • Driver (1 of 6)
  • Resistor (4 of 6)

<table>
<thead>
<tr>
<th>Manufacturer Claimed Rated Life (hours)</th>
<th>Projected Rated Life ($L_{70}$) Based on In-Situ Performance (hours)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TLED-1</td>
<td>50,000</td>
</tr>
<tr>
<td></td>
<td>N/A (6 failures)</td>
</tr>
<tr>
<td>TLED-2</td>
<td>50,000</td>
</tr>
<tr>
<td></td>
<td>&gt;60,000</td>
</tr>
<tr>
<td>TLED-3</td>
<td>50,000</td>
</tr>
<tr>
<td></td>
<td>&gt;60,000</td>
</tr>
<tr>
<td>TLED-4</td>
<td>50,000</td>
</tr>
<tr>
<td></td>
<td>&gt;60,000</td>
</tr>
<tr>
<td>TLED-5</td>
<td>50,000</td>
</tr>
<tr>
<td></td>
<td>&gt;60,000 (1 failure)</td>
</tr>
<tr>
<td>TLED-6</td>
<td>50,000</td>
</tr>
<tr>
<td></td>
<td>&gt;60,000</td>
</tr>
<tr>
<td>TLED-7</td>
<td>50,000</td>
</tr>
<tr>
<td></td>
<td>N/A (4 failures)</td>
</tr>
</tbody>
</table>
Linear LED Lamp – Interoperability Testing
Linear LED Lamp – Electrical Architectures

- **UL Type A:** Internal driver that is designed to operate on a linear fluorescent lamp ballast.

- **UL Type B:** Internal driver that must be connected directly to line voltage for power.

- **UL Type C:** External driver that is designed to replace both the linear fluorescent lamp and fluorescent lamp ballast.

- **Hybrids:** Linear LED lamps with two Type A, B or C options in one product. Also referred to as ‘dual-mode’ by select manufacturers.

The data in this presentation are considered confidential and are not intended for publication or distribution beyond the company or institution to which they have been provided by the CLTC. They are for development and verification only and not intended as a substitute for data generated by an Independent Testing Lab. Distribution or publication of these data is forbidden without the express written consent of the CLTC. CLTC makes no claim as to the accuracy of these data beyond the specific test conditions and parameters under which the data were obtained.
CLTC conducted interoperability testing to evaluate placing lamps currently found on the market into incorrect fixture types, i.e. Type A lamps in Type B wiring harness.

<table>
<thead>
<tr>
<th>Product ID</th>
<th>UL Type</th>
<th>Ballast 1</th>
<th>Ballast 2</th>
<th>Ballast 3</th>
<th>Ballast 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product A</td>
<td>Type A</td>
<td>-1.96% @ 83°F</td>
<td>2.04% @ 90°F</td>
<td>-8.64 @ 83°F</td>
<td>Baseline</td>
</tr>
<tr>
<td>Product B</td>
<td>Type A</td>
<td>Baseline</td>
<td>DNF</td>
<td>9.06% @ 82°F</td>
<td>16.37% @ 92°F</td>
</tr>
<tr>
<td>Product C</td>
<td>Type B</td>
<td>DNF</td>
<td>DNF</td>
<td>DNF</td>
<td>DNF</td>
</tr>
<tr>
<td>Product D</td>
<td>Type B</td>
<td>DNF</td>
<td>DNF</td>
<td>DNF</td>
<td>DNF</td>
</tr>
<tr>
<td>Product E</td>
<td>Type C</td>
<td>-53.42% @ 81°F</td>
<td>DNF</td>
<td>-57.62% @ 86°F</td>
<td>-52.77% @ 88°F</td>
</tr>
<tr>
<td>Product F</td>
<td>Type C</td>
<td>DNF</td>
<td>DNF</td>
<td>DNF</td>
<td>DNF</td>
</tr>
<tr>
<td>Product G</td>
<td>Type AC</td>
<td>7.4% @ 83°F</td>
<td>Baseline</td>
<td>12.18% @ 82°F</td>
<td>18.07% @ 94°F</td>
</tr>
<tr>
<td>Product H</td>
<td>Type AC</td>
<td>-7.58% @ 82°F</td>
<td>DNF</td>
<td>-3.56% @ 84°F</td>
<td>Baseline</td>
</tr>
<tr>
<td>Product I</td>
<td>Type AB</td>
<td>-18.49 @ 81°F</td>
<td>DNF</td>
<td>Baseline</td>
<td>15.18% @ 87°F</td>
</tr>
<tr>
<td>Product J</td>
<td>Type AB</td>
<td>-28.8% @ 81°F</td>
<td>DNF</td>
<td>Baseline</td>
<td>DNF</td>
</tr>
<tr>
<td>Product K</td>
<td>Type B</td>
<td>DNF</td>
<td>DNF</td>
<td>DNF</td>
<td>DNF</td>
</tr>
<tr>
<td>Product L</td>
<td>Type B</td>
<td>DNF</td>
<td>DNF</td>
<td>DNF</td>
<td>DNF</td>
</tr>
</tbody>
</table>
The data in this presentation are considered confidential and are not intended for publication or distribution beyond the company or institution to which they have been provided by the CLTC. They are for development and verification only and not intended as a substitute for data generated by an Independent Testing Lab. Distribution or publication of these data is forbidden without the express written consent of the CLTC. CLTC makes no claim as to the accuracy of these data beyond the specific test conditions and parameters under which the data were obtained.

# Linear LED Lamp with Drivers

<table>
<thead>
<tr>
<th>Product ID</th>
<th>UL Type</th>
<th>Driver 1</th>
<th>Driver 2</th>
<th>Driver 3</th>
<th>Driver 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product A</td>
<td>Type A</td>
<td>DNF</td>
<td>-19.06% @ 83°F</td>
<td>0.34% @ 82°F</td>
<td>DNF</td>
</tr>
<tr>
<td>Product B</td>
<td>Type A</td>
<td>DNF</td>
<td>-6.53 @ 82°F</td>
<td>22.09% @ 87°F</td>
<td>DNF</td>
</tr>
<tr>
<td>Product C</td>
<td>Type B</td>
<td>DNF</td>
<td>DNF</td>
<td>DNF</td>
<td>DNF</td>
</tr>
<tr>
<td>Product D</td>
<td>Type B</td>
<td>DNF</td>
<td>DNF</td>
<td>DNF</td>
<td>DNF</td>
</tr>
<tr>
<td>Product E</td>
<td>Type C</td>
<td>Baseline</td>
<td>-64.93% @ 81°F</td>
<td>-97.69% @ 81°F</td>
<td>-12.28% @ 79°F</td>
</tr>
<tr>
<td>Product F</td>
<td>Type C</td>
<td>DNF</td>
<td>DNF</td>
<td>DNF</td>
<td>Baseline</td>
</tr>
<tr>
<td>Product G</td>
<td>Type AC</td>
<td>DNF</td>
<td>Baseline</td>
<td>27.03% @ 87°F</td>
<td>DNF</td>
</tr>
<tr>
<td>Product H</td>
<td>Type AC</td>
<td>DNF</td>
<td>-13.18% @ 81°F</td>
<td>Baseline</td>
<td>DNF</td>
</tr>
<tr>
<td>Product I</td>
<td>Type AB</td>
<td>DNF</td>
<td>-16.15% @ 81°F</td>
<td>-31.16% @ 87°F</td>
<td>DNF</td>
</tr>
<tr>
<td>Product J</td>
<td>Type AB</td>
<td>DNF</td>
<td>1.69% @ 81°F</td>
<td>-0.39% @ 84°F</td>
<td>DNF</td>
</tr>
<tr>
<td>Product K</td>
<td>Type B</td>
<td>DNF</td>
<td>DNF</td>
<td>DNF</td>
<td>DNF</td>
</tr>
<tr>
<td>Product L</td>
<td>Type B</td>
<td>DNF</td>
<td>DNF</td>
<td>DNF</td>
<td>DNF</td>
</tr>
</tbody>
</table>
## Linear LED Lamp – Interoperability Testing

<table>
<thead>
<tr>
<th>Product ID</th>
<th>UL Type</th>
<th>Line Voltage</th>
<th>Single-Ended</th>
<th>Double-Ended</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product A</td>
<td>Type A</td>
<td>DNF</td>
<td>DNF</td>
<td>DNF</td>
</tr>
<tr>
<td>Product B</td>
<td>Type A</td>
<td>DNF</td>
<td>DNF</td>
<td>DNF</td>
</tr>
<tr>
<td>Product C</td>
<td>Type B</td>
<td>Baseline</td>
<td>DNF</td>
<td></td>
</tr>
<tr>
<td>Product D</td>
<td>Type B</td>
<td>DNF</td>
<td>Baseline</td>
<td></td>
</tr>
<tr>
<td>Product E</td>
<td>Type C</td>
<td>DNF</td>
<td>Sparks</td>
<td>DNF</td>
</tr>
<tr>
<td>Product F</td>
<td>Type C</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Product G</td>
<td>Type AC</td>
<td>DNF</td>
<td>DNF</td>
<td></td>
</tr>
<tr>
<td>Product H</td>
<td>Type AC</td>
<td>DNF @ 158°F</td>
<td>DNF</td>
<td></td>
</tr>
<tr>
<td>Product I</td>
<td>Type AB</td>
<td>Baseline</td>
<td>DNF</td>
<td></td>
</tr>
<tr>
<td>Product J</td>
<td>Type AB</td>
<td>Baseline</td>
<td>DNF</td>
<td></td>
</tr>
<tr>
<td>Product K</td>
<td>Type B</td>
<td>Baseline</td>
<td>DNF</td>
<td></td>
</tr>
<tr>
<td>Product L</td>
<td>Type B</td>
<td>Baseline</td>
<td>DNF</td>
<td></td>
</tr>
</tbody>
</table>

The data in this presentation are considered confidential and are not intended for publication or distribution beyond the company or institution to which they have been provided by the CLTC. They are for development and verification only and not intended as a substitute for data generated by an Independent Testing Lab. Distribution or publication of these data is forbidden without the express written consent of the CLTC. CLTC makes no claim as to the accuracy of these data beyond the specific test conditions and parameters under which the data were obtained.
Linear LED Lamp Performance Specification

- **Electrical Architecture**, UL Type C
- **Color fidelity**, Rf value greater than 92 +/- 2 measured by TM-30-18
- **Light Output**, single lamp output of 2,250 lumens
- **System Efficacy**, at least 120 lm/W
- **Controllability**, minimum dimming level of at least 10% full power
- **Distribution**, beam angle of at least 220 degrees with no less than 20% of total flux emitted in the 100-180 degree zone
- **Rated life**, 50,000 hours or greater (aligned with DLC)
Key Research Outcomes

1. Consumer Preference Study Results
2. Product Evaluation Results
3. Technology Transfer Activities
   - Transitioning Linear LED Lamp Specification into the Million LED Challenge
   - Investigating Areas Currently Governed by Standards
4. Industry Engagement

The data in this presentation are considered confidential and are not intended for publication or distribution beyond the company or institution to which they have been provided by the CLTC. They are for development and verification only and not intended as a substitute for data generated by an Independent Testing Lab. Distribution or publication of these data is forbidden without the express written consent of the CLTC. CLTC makes no claim as to the accuracy of these data beyond the specific test conditions and parameters under which the data were obtained.
Technology Transfer Activities
Transitioning Linear LED Lamp Specification into the Million LED Challenge
Million LED Challenge

- **Two-phase approach**
  - Phase 1: Screw base lamps and downlights (Available Now)
  - Phase 2: Retrofit solutions for recessed troffers, i.e. linear fluorescent replacements (Coming Soon)

- **Develop performance specification**
  - CLTC lighting quality & consumer preference research
  - California Energy Commission Voluntary Specification for MLC Phase 1

- **Establish MLC program**
  - UC Office of the President partners with California State University, California Community Colleges and the California Department of General Services
  - Establishes purchasing process
    - Assured product quality (RFP process)
    - Reduced price (collective purchasing)
    - Ease of purchase
Linear LED Lamps (TLEDs)
- Electrical architecture, UL Type C
- Light output, bare single lamp light output of 2,250 lumens
- Efficacy, at least 120 lumens per Watt
- Dimming, minimum dimming level to at least 10 percent of full light output
- Controllability, be able to pair with lighting control devices (control-ready)
- Color, R value greater than 90 measured by IES TM-30-18
- Distribution, beam angle of at least 220 degrees with no less than 20 percent of total flux emitted in the 100–180 degree zone
- All else, meet DLC minimum criteria

LED Retrofit Kits & Fixtures
- Efficacy, at least 120 lumens per Watt
- Dimming, minimum dimming level to at least 10 percent of full light output
- Controllability, be able to pair with lighting control devices (control-ready)
- Color, R value greater than 90 measured by IES TM-30-18
- Distribution, provide photometric distribution file in IES LM-63 format
- All else, meet DLC minimum criteria

What is control-ready?
All LED retrofit solutions should be pairable with lighting controls that will allow for control strategies including personal tuning, occupancy sensing, daylight harvesting and automated demand response, where appropriate.
Light Source Color Binning
Consumer preference testing conducted for two directions to plot quadrangles to determine ‘just noticeable difference’.
## Light Source Binning Results

<table>
<thead>
<tr>
<th></th>
<th>2700 K Bins</th>
<th></th>
<th>4000 K Bins</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Size</strong></td>
<td><strong>Edge</strong></td>
<td><strong>% Perceived</strong></td>
<td><strong>Edge</strong></td>
<td><strong>% Perceived</strong></td>
</tr>
<tr>
<td>1 Step</td>
<td>+CCT</td>
<td>4%</td>
<td>+CCT</td>
<td>22%</td>
</tr>
<tr>
<td></td>
<td>-CCT</td>
<td>13%</td>
<td>-CCT</td>
<td>2%</td>
</tr>
<tr>
<td></td>
<td>+duv</td>
<td>31%</td>
<td>+duv</td>
<td>22%</td>
</tr>
<tr>
<td></td>
<td>-duv</td>
<td>53%</td>
<td>-duv</td>
<td>28%</td>
</tr>
<tr>
<td>2 Step</td>
<td>+CCT</td>
<td>17%</td>
<td>+CCT</td>
<td>9%</td>
</tr>
<tr>
<td></td>
<td>-CCT</td>
<td>9%</td>
<td>-CCT</td>
<td>4%</td>
</tr>
<tr>
<td></td>
<td>+duv</td>
<td>93%</td>
<td>+duv</td>
<td>72%</td>
</tr>
<tr>
<td></td>
<td>-duv</td>
<td>84%</td>
<td>-duv</td>
<td>63%</td>
</tr>
<tr>
<td>4 Step</td>
<td>+CCT</td>
<td>65%</td>
<td>+CCT</td>
<td>63%</td>
</tr>
<tr>
<td></td>
<td>-CCT</td>
<td>72%</td>
<td>-CCT</td>
<td>70%</td>
</tr>
<tr>
<td></td>
<td>+duv</td>
<td>98%</td>
<td>+duv</td>
<td>91%</td>
</tr>
<tr>
<td></td>
<td>-duv</td>
<td>100%</td>
<td>-duv</td>
<td>93%</td>
</tr>
<tr>
<td>7 Step</td>
<td>+CCT</td>
<td>98%</td>
<td>+CCT</td>
<td>91%</td>
</tr>
<tr>
<td></td>
<td>-CCT</td>
<td>98%</td>
<td>-CCT</td>
<td>93%</td>
</tr>
<tr>
<td></td>
<td>+duv</td>
<td>100%</td>
<td>+duv</td>
<td>98%</td>
</tr>
<tr>
<td></td>
<td>-duv</td>
<td>98%</td>
<td>-duv</td>
<td>98%</td>
</tr>
</tbody>
</table>

Bins are plotted in u', v' chromaticity diagram using the CIE 2006 standard 10-degree observer.

---

The data in this presentation are considered confidential and are not intended for publication or distribution beyond the company or institution to which they have been provided by the CLTC. They are for development and verification only and not intended as a substitute for data generated by an Independent Testing Lab. Distribution or publication of these data is forbidden without the express written consent of the CLTC. CLTC makes no claim as to the accuracy of these data beyond the specific test conditions and parameters under which the data were obtained.
Just Noticeable Flicker
Flicker Study Results

Have you ever noticed or experienced flickering lights?

If you answered yes to the previous question: Did the flickering happen when the lights were being dimmed with a dimmer switch?

The data in this presentation are considered confidential and are not intended for publication or distribution beyond the company or institution to which they have been provided by the CLTC. They are for development and verification only and not intended as a substitute for data generated by an Independent Testing Lab. Distribution or publication of these data is forbidden without the express written consent of the CLTC. CLTC makes no claim as to the accuracy of these data beyond the specific test conditions and parameters under which the data were obtained.
Flicker Study Background

**Study Goal**
- Determine if study participants can detect visible flicker as compared to industry standards

**Setup**
- Phosphor converted white lights uniformly illuminated 0.5-meter sphere
- Lights programmed to flicker with 54 combinations:
  - 3 different waveforms
  - 3 different percent modulations
  - 6 different frequencies

**Procedure**
- Study participant shown 54 combinations in random and asked if they saw flicker:
  - If yes, they were instructed to press a button that logged their response
  - If no, the next combination was shown
The data in this presentation are considered confidential and are not intended for publication or distribution beyond the company or institution to which they have been provided by the CLTC. They are for development and verification only and not intended as a substitute for data generated by an Independent Testing Lab. Distribution or publication of these data is forbidden without the express written consent of the CLTC. CLTC makes no claim as to the accuracy of these data beyond the specific test conditions and parameters under which the data were obtained.

Flicker Study Results
Key Research Outcomes

1. Consumer Preference Study Results
2. Product Evaluation Results
3. Technology Transfer Activities
4. Industry Engagement
Field Study at UC Irvine
Field Study at UC Irvine
Amber/White Corridor Lighting
Amber/White Corridor Lighting
Million LED Challenge

Providing high-quality LED lights to students, staff, faculty, alumni and retirees with informed product
From the Laboratory to the California Marketplace: A New Generation of LED Lighting Systems

Questions?