Illuminating the Lighting Landscape

CHARLIE GRIST, JACK CURRAN, AND BRIAN CHEMEL
Connected Lighting and the Future of Intelligent Buildings
Brian Chemel
Founder and CTO

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Connected Lighting and the Future of Intelligent Buildings

• What exactly is Connected Lighting?

• A Brief Survey of Applications

• Why Should the Energy Industry Care?

• Issues to Keep an Eye On
What Exactly *Is* Connected Lighting?
The LED Revolution is Over

• Device price/performance curves are flattening

• Fixtures are becoming commoditized

• LED products represent well over 50% of sales for all major lighting companies
And Yet...

- Vast majority of the installed base still runs on legacy lighting
- Slowest adopters are some of the largest electricity users
- Tremendous opportunity remains as the installed base converts

Source: Department of Energy Solid-State Lighting R&D Plan, June 2016

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“SSL is creating an opportunity for a whole new lighting system paradigm...The convergence of SSL, low-cost sensors, smartphones and apps, and the Internet of Things (IoT) is expected to facilitate new lighting functionality and an unprecedented exchange of data among lighting and other building systems, the Internet and other devices (e.g., mobile phones).”

-U.S. Department of Energy
A Taxonomy of Connected Lighting

Type 1
• Digitally dimmable LED light sources
• Networked fixture-by-fixture control

Type 2
• Distributed sensing integrated into fixtures
• Software-adjustable rules with humans “in the loop”

Type 3
• Closed-loop autonomous control
• Flexible, data driven behaviors

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Why Now?

Key enabling technologies have improved at a rapid pace:

- LEDs and phosphors
- Microprocessors
- Sensors
- Networking chips
- Cloud computing and data storage
A Brief Survey of Applications
If every light over your head were intelligent - carrying its own processor, sensors and a network connection - what could we build?
Connected Lighting Application Categories

- Lighting Control
- Energy Management
- Environmental Monitoring
- Security
- Space Utilization
- Asset Tracking
- Location Services
Connected Industrial Lighting

Energy Management
Leverage facility-wide lighting networks to meter every electrical circuit

Asset Tracking
Determine the position of critical equipment and products in real time across hundreds of thousands of square feet
Connected Retail Lighting

Location Services
Provide shoppers with directions, product information and special offers while collecting info

Space Utilization
Map out high-traffic areas and place merchandise accordingly
Connected Office Lighting

💡 Lighting Control
Give employees the ability to adjust lighting to meet their needs

💻 Space Utilization
Identify underutilized real estate
Connected Health Care Lighting

💡 Lighting Control
Make patients more comfortable to improve outcomes

📍 Asset Tracking
Track the location of life-critical and costly equipment

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Connected School Lighting

💡 Lighting Control
Adapt spectrum to children’s unique circadian rhythms

🔒 Security
Monitor locations of students, teachers, staff and visitors in real time

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Connected Agricultural Lighting

Environmental Monitoring
Track temperature and humidity throughout large indoor farming facilities

Lighting Control
Tailor red-blue spectral mix to specific crops and growing cycles

Source: http://aerofarms.com/media/

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Connected Outdoor Lighting

Environmental Monitoring
Measure critical variables across large urban landscapes

Security
Monitor traffic, disturbances, and large gatherings

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Why Should the Energy Industry Care?
First, the Bad News

- **395 TWh**
  - The 2030 Projected Electricity Savings from Solid-State Lighting equals...

- **1.8X**
  - 2030 Projected Wind Power Electricity Generation
  - OR

- **20X**
  - 2030 Projected Solar Power Electricity Generation
  - OR

- **36 Million**
  - Annual Electricity Consumption of U.S. Homes
  - OR

- **$40 Billion (US)**
  - In Electricity Costs

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Source: Department of Energy Solid-State Lighting R&D Plan, June 2016

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Massive Opportunity Ahead

- Every light fixture and lamp socket across the globe is in play
- Energy savings provide hard dollar payback
- Connected lighting features provide additional recurring revenue streams

Global Lighting Market Share Projection

Source: Goldman Sachs Investment Research

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Three Ways To Make Money

- **Projects** ($) - Design and implement lighting retrofits
- **Financing** ($$) - Provide upfront capital against ongoing energy savings
- **Services** ($$$) - Monetize data via compelling applications

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A Few Names To Keep an Eye On

Lighting

PHILIPS
AcuityBrands
enlighted
CREE
GE

Building Systems

Schneider Electric
Honeywell
EATON
Johnson Controls
SIEMENS

Technology

CISCO
SAMSUNG
QUALCOMM
ECHelon
Intel

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We Have Issues
Privacy and Data Security

• What personal information do these systems collect?

• How is it anonymized?

• Who owns the data?

• How are the systems and their data secured?

Target Investigates Breach Involving Credit Card Data

SAN FRANCISCO — Target is investigating a security breach involving stolen credit card and debit card information for millions of its customers, according to one person involved in the investigation.

The breach, which was first reported Wednesday by Brian Krebs, a security blogger, began the day after Thanksgiving, and may be continuing, according to the person involved in the investigation, who spoke only on condition of anonymity.

Heat System Called Door to Target for Hackers

SAN FRANCISCO — Investigators say they believe they have identified the entry point through which hackers got into Target’s systems, zeroing in on the remote access granted through the retailer’s computerized heating and cooling software, according to two people briefed on the inquiry.

The latest revelation highlights the reality that a large company is actually a sprawling network of interconnected vendors, and that weak security at any one vendor can lead to a breach that costs hundreds of millions of dollars.

Source: New York Times

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Scalability

• What works for a conference room doesn’t work for an entire building
• What works for a single building doesn’t work for a campus
• What works for a campus doesn’t work for a global real estate portfolio
Interoperability

• Customers want things to “just work”, and don’t care how it gets done

• Lighting companies have a history of not playing well together

• Will this time be different?

• What will be the role of standards bodies?

• Will de facto standards carry the day?
Emerging Standards

Table 1 provides a summary of "Required" and "Reported" System Capabilities.

<table>
<thead>
<tr>
<th>'Required' System Capabilities</th>
<th>'Reported' System Capabilities</th>
<th>'Required' Interior System Capabilities</th>
<th>'Reported' Interior System Capabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Networking of Luminaires and Devices</td>
<td>Type of User Interface</td>
<td>Networking of Luminaires and Devices</td>
<td>Type of User Interface</td>
</tr>
<tr>
<td>Occupancy Sensing</td>
<td>Luminaire-Level Control (non-integrated)</td>
<td>Occupancy Sensing</td>
<td>Luminaire-Level Control (non-integrated)</td>
</tr>
<tr>
<td>Daylight Harvesting</td>
<td>Luminaire Level Control (Integrated)</td>
<td>Daylight Harvesting / Photocell Control</td>
<td>Luminaire Level Control (Integrated)</td>
</tr>
<tr>
<td>High End Trim</td>
<td>Localized Processing / Distributed Intelligence</td>
<td>Task Tuning / High End Trim</td>
<td>Personal Control</td>
</tr>
<tr>
<td>Zoning</td>
<td>Scheduling</td>
<td>Zoning</td>
<td>Load Shedding (DR)</td>
</tr>
<tr>
<td>Luminaire and Device Addressability</td>
<td>Personal Control</td>
<td>Luminaire and Device Addressability</td>
<td>Plug Load Control</td>
</tr>
<tr>
<td>Continuous Dimming</td>
<td>Load Shedding (DR)</td>
<td>Continuous Dimming</td>
<td>BMS/EMS/ HVAC Integration</td>
</tr>
<tr>
<td></td>
<td>Plug Load Control</td>
<td>Localized Processing / Distributed Intelligence</td>
<td>Device Monitoring / Remote Diagnostics</td>
</tr>
<tr>
<td></td>
<td>BMS/EMS/ HVAC Integration</td>
<td>Scheduling</td>
<td>Operational and Standby-Power</td>
</tr>
<tr>
<td></td>
<td>Energy Monitoring</td>
<td>Energy Monitoring</td>
<td>Emergency Lighting</td>
</tr>
<tr>
<td></td>
<td>Device Monitoring / Remote Diagnostics</td>
<td>[DC &amp; PoE only] Wiring &amp; Power Supplies</td>
<td>Inrush Current</td>
</tr>
<tr>
<td></td>
<td>Operational and Standby-Power</td>
<td></td>
<td>Security</td>
</tr>
</tbody>
</table>

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Obsolescence

Building systems
Average life span: 10 to 20 years

Tech hardware
Average life span: 21 months
Apps vs. Platforms

• Likely not to be a single killer application that fits every building type
• Platforms, not applications, may end up being the big winners
• Who owns the platform?
Thank you!
Brian Chemel
bchemel@digitallumens.com
Solid-State Lighting:
Where We Are and Where We're Going

Dr. John W. Curran,
President, LED Transformations, LLC
On behalf of the U.S. Department of Energy and the National Energy Technology Laboratory
This presentation will provide a view of the current state of solid-state lighting: where it is currently; where it is headed in the future and some of the obstacles to be overcome in order to achieve the energy and economic advantages promised including the often overlooked economics of people.

1) Understand the current performance levels of solid-state lighting
2) Examine how minimizing complexities will improve the chances of successful field applications
3) Evaluate the full impact of LED product selection when calculating overall project savings, including effect on building occupants
4) Determine what can be learned from LED standards
Output of the LEDs is only the starting point

Output Trend

- Red Output (in lumens/device)
- White Output (in lumens/device)
- Red Cost (in $/lumen)
- White Cost (in $/lumen)

Cost Trend

- Output Trend
- Cost Trend

Luminaire Efficacy – Where the losses come from

LED efficacy (@ 25°C & 350 mA) = 200 lumens/watt
Temperature Loss (@85°C) 87.9% = 175.8 lumens/watt
Drive Current Loss (1050 mA) 87.6% = 154.0 lumens/watt
Driver Loss 87.5% = 138.6 lumens/watt
Secondary Optics Loss 90% = 127.5 lumens/watt
Fixture Loss 95% = 121.1 lumens/watt

A fixture using 200 lm/W LEDs yields a luminaire efficacy of about 121 lm/W

LED Devices
Other approaches besides the traditional yellow phosphor provide additional improvements in LED device efficacy.

SSL Efficacy Roadmap – Where are we and where are we going

### Projected LED Improvements

<table>
<thead>
<tr>
<th></th>
<th>2015</th>
<th>2018</th>
<th>2020</th>
<th>2025</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver Efficiency</td>
<td>88%</td>
<td>91%</td>
<td>93%</td>
<td>95%</td>
<td>7%</td>
</tr>
<tr>
<td>Package Efficacy (lum/W)</td>
<td>137</td>
<td>175</td>
<td>208</td>
<td>237</td>
<td>255</td>
</tr>
<tr>
<td>Thermal Efficiency Droop</td>
<td>88%</td>
<td>91%</td>
<td>93%</td>
<td>95%</td>
<td>7%</td>
</tr>
<tr>
<td>Fixture/Optical Efficiency</td>
<td>90%</td>
<td>92%</td>
<td>94%</td>
<td>95%</td>
<td>5%</td>
</tr>
<tr>
<td>Overall Luminaire Efficacy (lum/W)</td>
<td>95</td>
<td>133</td>
<td>169</td>
<td>203</td>
<td>218</td>
</tr>
</tbody>
</table>

### Projected OLED Improvements

<table>
<thead>
<tr>
<th></th>
<th>2015</th>
<th>2017</th>
<th>2020</th>
<th>2025</th>
<th>Goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver Efficiency</td>
<td>85%</td>
<td>85%</td>
<td>85%</td>
<td>90%</td>
<td>95%</td>
</tr>
<tr>
<td>Panel Efficacy1 (lum/W)</td>
<td>60</td>
<td>100</td>
<td>125</td>
<td>160</td>
<td>190</td>
</tr>
<tr>
<td>Device to Luminaire Efficiency</td>
<td>85%</td>
<td>85%</td>
<td>85%</td>
<td>85%</td>
<td>86%</td>
</tr>
<tr>
<td>Optical Efficiency</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>90%</td>
<td>90%</td>
</tr>
<tr>
<td>Overall Luminaire Efficacy1 (lum/W)</td>
<td>51</td>
<td>85</td>
<td>106</td>
<td>130</td>
<td>162</td>
</tr>
</tbody>
</table>

*Possible use of beam shaping optics

Source: DOE Solid-State Lighting R&D Plan, 2016
An Experiment – What color is the ball?

Without light objects have **NO Color**

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**Color Consistency** – Can be extremely important over lifetime

Color changes occur due to binning which occurs during LED production as well as color shift due to phosphor/die changes over time

- Variation unit to unit
- Purchase to purchase
- Shift during lifetime

Source: LED Transformations
**Field Issue — Color shifts can change in many directions**

Results of DOE CALiPER testing from 2008 thru 2010 shows color shifts after 6000 hours of operation (black) and 12,000 hours (brown)

Source: Michael Royer, PNNL

**Standards — Rules for LED lighting**

- **LM-79-08** Approved Method: Electrical and Photometric Measurements of Solid-State Lighting Products
- **LM-80-15** Approved Method for Measuring Luminous Flux and Color Maintenance of LED Packages, Arrays and Modules
- **TM-21-11** Projecting Long Term Lumen Maintenance of LED Light Sources
- **TM-30-15** IES Method for Evaluating Light Source Color Rendition
- **ANSI C78.377-2015** Specifications for the Chromaticity of Solid-State Lighting (SSL) Products
- **LM-84-14** Measuring Luminous Flux and Color Maintenance of LED Lamps, Light Engines and Luminaires
- **TM-28-14** Projecting Long-Term Luminous Flux Maintenance of LED Lamps and Luminaires
- **LM-85-14** Electrical and Photometric Measurements of High-Power LEDs
### Color

**Color Shift** — No testable standard to date

- TM-31 — There is a standard in the works which according to members of the committee will provide guidance on color shift similar to that provided by TM30 regarding lumen depreciation.
  - Status: still in committee
  - Expect to see it in 2018
  - Remains to be seen how well it handles color shift
- OLEDs — There are presently **no standards** for OLED devices although some work is going on in committees.

### Field Issues

**Electronics/Driver** — Reliability depends on the driver as well

In one study it was found that 90% of the luminaire failures were due to something other than the LEDs!

![Failure Distribution](image)

*Source: Appalachian Lighting Systems*

Total number of failures = 29 out of 5,400 units installed (0.54%)
Field Issues

Electronics/Driver – Reliability depends on the driver as well

Two examples of failures caused by the driver

Stop & Shop, Raritan, NJ – 6 weeks
City Center, Las Vegas – 5 months

Not quite 50,000 hours!

Field Issues

Glare Issues – Pushing the limits

• Poor luminaire design
  • No optics; poor optics; no shielding
• Luminous intensity within solid angle
  • LEDs typically concentrate the light within narrow beams causing discomfort glare
• High contrast between fixture and background luminance
• Inappropriate output for height or direction of use
• Human eye response
  • As color temperature increases, the higher blue wavelength content of LEDs is perceived as "brighter" due to increased scotopic response in lower light environment

Conventional
LED

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LED Performance — Be careful what you ask for; you might get it

- There is much discussion on light trespass, light pollution, etc.
- The typical view is that light cut-off is desirable for many applications
- LEDs allow cut-offs that are not possible with other light sources
- Sometimes, that exact cut-off is not what people really want

Lumen Depreciation — Applied to LED sources

Five different light sources: 2 LED; 2 fluorescent; L Prize and their associated lumen depreciation rates

Source: M. Royer, Lumen Maintenance and Light Loss Factors: Consequences of Current Design Practices for LEDs, LEUKOS, 12/13
Lighting Controls & Sensors

**Controls – End user training**

- Intuitive
- Not intuitive
- Not much better
- Getting Better

**Installation Instructions – Wall dimmer**

**5a - Single-Pole Wiring**

- Black
- Green
- Ground

Source: Lutron
Energy savings will be a function of:

- **Time delay until turn-off**
  - Longer time delays decrease energy savings
  - Shorter time delays can increase the annoyance factor for facility occupants

- **Low illumination setting**
  - Decreasing the low level setting increases the potential energy savings

- **Exogenous factors such as amount of vehicular and pedestrian traffic the sensor detects**
  - Heavy traffic can negate the overall usefulness of an occupancy or motion sensor (e.g. it is on all the time)
The Ideal Lighting Control System - Simple

• Any complexity is hidden from user
• Ability to use right out of the box
• Intuitive and easy to use
  • Design and layout
  • Installation
  • End user
• Flexible and adapts to user
  • Self commissioning
  • Self optimizing
  • Easy to configure/reconfigure
  • Easy to maintain and repair, as necessary

Economics of People

Human Physiology – Circadian Cycle and its effect on the human body

"To every thing there is a season, and a time to every purpose under the heaven"
Sources: The Bible and The Byrds
**Economics of People**

**Human Physiology – Circadian Cycle and its effect on the human body**

- Without light, the human body's circadian cycle runs slightly longer than 24 hours.
- In order to stay in synchronization with the earth's 24 hour cycle, requires exposure to sunlight.
- Alternatively, circadian rhythms can be synced to a natural 24 hour cycle by the use of light with a CCT of 6500°K or greater at an intensity of 600 lux during the "daylight" period and 2700°K at an intensity of 50 - 80 lux during "evening" hours.
- Therefore the most healthy lighting system is one that mimics the natural daylight cycle.
- This implies a lighting system that controls intensity and CCT of the light.

Source: Light for Better Sleep, Mariana G. Figueiro, LRC, November 2013

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**Lifecycle Operating Costs – For a typical office building**

An often overlooked element - people

- **Salary/Benefits**: 88%  
- **Operating**: 7%  
- **Construction**: 5%

*Data source: Graham Ive*

A 50% reduction in energy usage due to lighting changes represents a 0.6% decrease in lifecycle operating costs, while a 1% decrease in office worker performance represents a 0.9% increase in lifecycle operating costs.  
**Do the math!**

Data source: E Source
Lifecycle Operating Costs – An example

Reno Nevada Main Post Office

A $300,000 renovation in the facility’s lighting system, produced a little over $50,000 annual savings ($22,400 in direct energy savings and 30,000 in reduced cost of maintenance)

That same renovation resulted in major reductions in operator errors (to 0.1%) as well as a 6% improvement in employee productivity which was worth an additional $400,000 annual savings

Economics of People

Electronics Assembly – Worker response to dynamic lighting levels

Dynamic change in lighting levels at a Flextronics assembly facility resulted in 4% improvement in performance

The study attributed the improvement to the reduced level of stress during work brought about by the dynamic lighting.

Source: Effect of changing room light on the productivity of permanent morning shift workers at industrial workstations, Markus Canazei and Dehoff, Zumtobel Lighting, 3/13
Economics of People Plants

Specialty Lighting — A horticulture example

Using specific lighting spectral recopies, a nursery found improved plant stands, reduced crop time, and increased overall plant health.

Photosynthesis is a process where plants use light to strip a hydrogen atom from water and combine it with carbon from CO₂ to produce glucose. Chlorophyll is the most efficient pigment at performing this function.


The Lighting World Is Changing — A revolution like never before

• LED technology has overtaken every other light source in terms of efficacy and longevity – that battle is over
• Now it is time to get back to designing quality lighting that takes issues such as glare, color and overall quality of light into consideration – that battle is just getting started
• Ahead is a whole new world where lighting combined with controls and sensors is used in new ways to improve health, wellbeing, productivity, communications, etc.
• Standards, as is often the case, lag the technology
• The landscape of the lighting marketplace is likely to change as new players and new skill sets become important
• What will never change – you get what you pay for!
Acknowledgement

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