How The Second Lighting Tsunami Will Change Your Business

Dr. John W. Curran

*LED Transformations, LLC*

On behalf of the U.S. Department of Energy and the National Energy Technology Laboratory

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- Attend 90% of this presentation
- Fill out the online evaluation for this session

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Learning Objectives
*How The Second Lighting Tsunami Will Change Your Business*

1. Attendees will explore how the Internet of Things is likely to change the lighting industry and what shape the future business landscape will assume.
2. By examining how complexity of LED/Lighting Control systems can affect the success of energy saving strategies, attendees will discover what system characteristics will be important to their businesses in the future.
3. A number of years ago a major upheaval occurred in the computer industry. Using that as a template, business strategies emerge that will be beneficial to attendees who are looking to thrive in tomorrow’s lighting industry.
4. Attendees will investigate what the needs of tomorrow’s lighting customers will be as well as who is likely to fulfill those needs.

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Course Outline

1. **Trends – Where is the lighting industry presently**
   2. Human Physiology – How the human body reacts to light and color
   3. Lighting Controls – A new world with major consequences
   4. Sensors – More worries
   5. The Future – Built on service
Trends
The Changing Lighting Marketplace – LEDs take over

Luminaire Unit Shipments by Lamp Type, World Markets

Source: Navigant Research

<table>
<thead>
<tr>
<th>Year</th>
<th>LED</th>
<th>HID</th>
<th>Fluorescent</th>
<th>Halogen</th>
<th>Incandescent</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014</td>
<td>30%</td>
<td>50%</td>
<td>15%</td>
<td>5%</td>
<td>0%</td>
</tr>
<tr>
<td>2015</td>
<td>35%</td>
<td>45%</td>
<td>10%</td>
<td>5%</td>
<td>0%</td>
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<tr>
<td>2016</td>
<td>40%</td>
<td>40%</td>
<td>10%</td>
<td>5%</td>
<td>0%</td>
</tr>
<tr>
<td>2017</td>
<td>45%</td>
<td>35%</td>
<td>10%</td>
<td>5%</td>
<td>0%</td>
</tr>
<tr>
<td>2018</td>
<td>50%</td>
<td>30%</td>
<td>10%</td>
<td>5%</td>
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<td>2019</td>
<td>55%</td>
<td>25%</td>
<td>10%</td>
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<tr>
<td>2020</td>
<td>60%</td>
<td>20%</td>
<td>10%</td>
<td>5%</td>
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<td>2021</td>
<td>65%</td>
<td>15%</td>
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<td>2022</td>
<td>70%</td>
<td>10%</td>
<td>10%</td>
<td>5%</td>
<td>0%</td>
</tr>
<tr>
<td>2023</td>
<td>75%</td>
<td>5%</td>
<td>10%</td>
<td>5%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Data Source: Adoption of Light-Emitting Diodes in Common Lighting Applications, Navigant, July 2015

Trends
LED Penetration – In various market segments

Data Source: Adoption of Light-Emitting Diodes in Common Lighting Applications, Navigant, July 2015
### LED Failure Rates – Municipal street light results

<table>
<thead>
<tr>
<th></th>
<th>Street Lights</th>
<th>Area Lights</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number a</td>
<td>Percent b</td>
</tr>
<tr>
<td>Number of LED Products Installed</td>
<td>139,655</td>
<td>0.16%</td>
</tr>
<tr>
<td>Out of Box Failures</td>
<td>219</td>
<td>0.16%</td>
</tr>
<tr>
<td>- Shipping/Installation Damage</td>
<td>43</td>
<td>19.6%</td>
</tr>
<tr>
<td>- Internal Electrical Issues</td>
<td>126</td>
<td>57.5%</td>
</tr>
<tr>
<td>Longer-term Failures</td>
<td>1113</td>
<td>0.80%</td>
</tr>
<tr>
<td>- Human-caused1</td>
<td>221</td>
<td>19.9%</td>
</tr>
<tr>
<td>- Nature-caused2</td>
<td>90</td>
<td>8.1%</td>
</tr>
<tr>
<td>- Component failure3</td>
<td>799</td>
<td>71.8%</td>
</tr>
<tr>
<td>• Individual LEDs failed to light</td>
<td>67</td>
<td>8.3%</td>
</tr>
<tr>
<td>• Power supply</td>
<td>537</td>
<td>67.2%</td>
</tr>
<tr>
<td>• Photocell</td>
<td>85</td>
<td>10.0%</td>
</tr>
<tr>
<td>• Other</td>
<td>125</td>
<td>15.7%</td>
</tr>
<tr>
<td>TOTALS</td>
<td>1,332</td>
<td>0.95%</td>
</tr>
</tbody>
</table>

a Numbers and percentages in a given category may not add due to: respondents not always providing a breakdown on every reported failure; single failures possibly falling into multiple categories; and rounding error.
b Human-caused failures include those from issues such as vandalism, accidents, pinched wiring causing failure after some period of operation, etc. Natural causes include lightning strikes, wind, moisture, etc.
c Not mutually exclusive with the previous two categories.

Source: Memo - Final Results of MSSLC street light failure questionnaire, Bruce Kinsey, April 2015

### Lighting Controls Penetration – With various energy saving systems

<table>
<thead>
<tr>
<th>Control Type</th>
<th>Percent Building with Controls (2012)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Scheduling</td>
<td>16.5%</td>
</tr>
<tr>
<td>Occupancy Sensors</td>
<td>14.6%</td>
</tr>
<tr>
<td>Multi-Level Lighting or Dimming</td>
<td>6.3%</td>
</tr>
<tr>
<td>Daylight Harvesting</td>
<td>2.2%</td>
</tr>
<tr>
<td>DemandResponsive Lighting</td>
<td>3.2%</td>
</tr>
<tr>
<td>Building Automation System for Lighting</td>
<td>3.7%</td>
</tr>
</tbody>
</table>

Source: Commercial Buildings Energy Consumption Survey (2012), US Energy Information Administration, Table B1
**Trends**

**Lighting Controls – In various applications**

<table>
<thead>
<tr>
<th>Category</th>
<th>Penetration (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Office</td>
<td>2.21%</td>
</tr>
<tr>
<td>Retail</td>
<td>0.79%</td>
</tr>
<tr>
<td>Education</td>
<td>2.43%</td>
</tr>
<tr>
<td>Healthcare</td>
<td>2.17%</td>
</tr>
<tr>
<td>Hospitality</td>
<td>1.12%</td>
</tr>
<tr>
<td>Institutional / Assembly</td>
<td>0.67%</td>
</tr>
<tr>
<td>Warehouse</td>
<td>1.33%</td>
</tr>
<tr>
<td>Transport</td>
<td>1.29%</td>
</tr>
</tbody>
</table>

*Source: DLC and Navigant Consulting (2014)*

**Trends**

**Specialty Lighting – Non-conventional uses of light**

- Architainment – using the color capabilities of LED and OLED technologies to provide new and unique lighting environments
- Plant growth – tailoring light spectra to plant needs at various stages of growth
- Productivity of farm animals – improving milk and egg production
- Combining photovoltaic and LED lighting for off-grid systems
Course Outline

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Human Physiology

Color Changing – Applications and features not previously possible
Human Physiology

Lighting Affects Moods – A well known architectural practice

- **Blue** is calming and is often used in office environments as people have been shown to be more productive under this color
- **Red** raises excitement level and is associated with love, warmth, and comfort
- **Green** can improve reading ability and is often used in decorating for its calming effect
- **Yellow** can increase the metabolism and is the most attention-getting color

"To every thing there is a season, and a time to every purpose under the heaven"

Sources: The Bible and The Byrds
Human Physiology

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 both the intensity and CCT of the light

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

Human Physiology

LED Safety and Spectral Content – The real story

- Optical Safety — Can LED light damage retinas?
  - Known as the Blue Light Hazard
  - Besides spectrum, intensity and exposure duration must also be considered
- Material Safety — Can LED light increase the degradation rate of materials (e.g. artwork)?
  - Characterized by the CIE Damage Function
- Photobiological Safety — Can exposure to LED light at inappropriate times (e.g., at night) cause unwanted shifts to circadian cycles, resulting in undesirable consequences?
  - Due to recent discovery, presently there is no standard spectral weighting function for characterizing photobiological potential
  - modeling circadian stimulation with a simple spectral weighting function is generally insufficient

Source: True Colors, US Department of Energy Publication PNNL-23622, 10/14
Human Physiology

LED Safety and Spectral Content – The blue light hazard

Examining the portion of the LED spectrum that lies under the Blue Light Hazard Function shows that typically it is less than corresponding sunlight or halogen spectra.

![LED Spectrum Graph](image)

Equilibrium

- The eyes are most stable when the primary colors (red, green, blue) are within their field of view
- Combinations of complimentary colors also suffice
- The colors do not have to be present in equal amounts

Simultaneous Contrast

- If only a single color is present, the eye will try to generate the missing complement in any nearby achromatic (gray or colorless) area
Human Physiology
The Optic System – Some "magic"

Are the two orange ovals and their gray squares the same colors?

Human Physiology
Healthcare – Tampa General Hospital

Increased use of LED lighting in medical applications

- High color-rendering index (CRI) allows doctors and nurses to accurately assess patient status and condition visually
- Controls adjust the LEDs with customized settings, but with one touch, can be turned to 100 percent keeping staff and patients comfortable while saving money
- Luminaires adjust light output over life of luminaires to keep constant illumination levels
- Use of LED lighting in operating rooms have resulted in a 10°F reduction in temperature on the operating room table.
Human Physiology

Lighting For Safety – Providing visual orientation clues for seniors

Visual and perceptual systems intercept cues from the environment that affect postural control and stability

Source: Mariana G. Figueiro, LRC

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What Drives the Market – Energy Reduction Requirements

Energy Consumption = Input Watts x Operating Time

- Reduce Input Watts
  - Replace equipment with higher efficiency units
  - Incorporate dimming to reduce light output and input power
  - Supplement lighting with natural light (e.g. use of daylight harvesting)

- Reduce Operating Time
  - Incorporate lighting controls to reduce operating time
  - Use of occupancy sensors to limit operating time to periods when lighting is actually required

Source: Solatube
Lighting Controls
Today's Lighting Control Systems — What are the issues?

Solutions in search of problems
• Focus on devices (widgets) and technologies
• Complex configuration requirements
• High total cost of deployment
• Poor user satisfaction
• Lack of standardization
• Limited performance monitoring and continuous optimization
• Frequent misalignment with owner/occupant organizational maturity
• Limited interaction with non-lighting systems
• Difficult to predict performance and energy savings
• Lack of proper training (across the board)
• Low adoption (estimated as < 1%)

Source: "The value of energy data," Poplawski, Michael, DOE SSL Program Connected Lighting Meeting, 11/16/15

Lighting Controls
Lighting Control Topologies — Connection architecture

Star
Bus
Fully Connected
Daisy Chain
Ring
Tree
Mesh

Source: IES TM-22-15
Lighting Controls

Lighting Control Physical Layer – Electrical characteristics

• **RS-232** (currently TIA-232) – electrical characteristics and timing of signals, and the physical size and pinout of connectors for serial binary single-ended data and control signals for point to point connections
• **RS-485** (currently TIA-485) – a network designed to handle a need for communication to a series of devices in a system - fast over a short distance or slower over a long distance
• **Ethernet** – a network technology on which data may be sent and received from each connected unit (frequently called a node). It defines wiring and connection methods as well as basic communication rules for carrying data
• **USB** – developed by a consortium of computer manufacturers to establish communication between devices and a host controller (such as personal computers). The technology was intended to replace a variety of serial and parallel ports used to connect computer peripherals. USB can also serve as the power connection.

Source: IES-TM-23-2011

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Lighting Controls

Lighting Control Protocols – A wide range from various sources

• **0-10 VDC** – front end/user driven method of controlling equipment by means of a current source analog control voltage in the nominal range from 0 to 10 volts positive
• **ACN** – a bi-directional protocol that controls theatrical lighting, audio and effects
• **ASCII** – American National Standard Code for Information Interchange
• **BACnet** – a communication protocol that is specifically designed for the needs of building automation and control systems
• **DALI** – Digital Addressable Lighting Interface is a non-proprietary lighting control protocol
• **DMX512** – Asynchronous Serial Data Transmission Standard for Controlling Lighting Equipment and Accessories
• **EnOcean** – standard for self-powered sensor modules operating over unlicensed frequencies
• **Konnex** – European open standard for home & building control
• **LonWorks** – platform used for automation of building systems including HVAC and lighting
• **MIDI** – Musical Instrument Digital Interface
• **Modbus** – an industrial control protocol
• **RDM** – extension of DMX512 allowing bi-directional communications
• **SMPTE** – time code synchronization protocol
• **TCP/IP** – Transmission Control Protocol / Internet Protocol
• **XML** – Extensible Markup Language is a standard for document mark-up
• **ZigBee** – suite of specifications for high level communication protocols using small, low-power digital radios based on the IEEE 802.15.4 standard for wireless personal area networks
• **Z-Wave** – designed for low-power and low-bandwidth appliances

Source: IES-TM-23-2011
Lighting Controls
Wired vs. Wireless Control Systems — A comparison

Wired Benefits
- Central control — large applications can be controlled with a single keypad rather than banks of switches on the wall
- Reliability of signal transmission — hard wiring of system eliminates the potential for communication
- Greater control - A wired system can give more sophisticated control and flexibility
- Security – unauthorized access is more difficult (although not impossible)
- Fault detection – hard wiring allows easier troubleshooting

Wireless Benefits
- Lower installation cost — with no need to cut open walls, run cable, etc., wireless systems typically have much lower installation costs, particularly for retrofit applications
- Less planning — no in-wall requirements
- Flexibility — easy to change configurations in the future
- Reliability — some systems use architectures that allow multiple pathways for communications

Lighting Controls
Now you have heard everything — hackers and wireless

Trustwave Holdings, an e-security firm, published an advisory notice last week warning Satis smart toilet owners that their toilets could potentially get hacked.

“Attackers could cause the unit to unexpectedly open/close the lid, activate bidet or air-dry functions, causing discomfort or distress to user,” Trustwave Holdings said in its notice.
Lighting Controls

Time Scheduling – The simplest control scheme

Turn off lights after hours or when a space is not normally used.

Source: Steven Mesh
Lighting Education & Design

Lighting Controls

Time Scheduling – Some additional energy savings

Reduce the maximum light level for an entire space or building.

Source: Steven Mesh
Lighting Education & Design
### Lighting Controls

**Daylight Harvesting** – Taking advantage of natural light

- Dim or turn off lights based on available natural light.

**Occupancy/Vacancy Sensing** – Taking occupants into account

- Turn off lights when the space is unoccupied (vacant).

Source: Steven Mesh
Lighting Education & Design
### Lighting Controls

**Personal Control** – Giving occupants a say in their lighting

Dim or turn off lights based on personal preference or needs.

**Demand Response** – Working with the electric utility

Also known as Variable Load Shedding

Dim or turn off lights during periods of peak demand.

Source: Steven Mesh
Lighting Education & Design
Lighting Controls
The Net Result – Combining the approaches

Aggregate strategies for that space, and its resulting energy use.

Lighting Controls
Controls – End user training

Intuitive
Not so intuitive
Lighting Controls
Controls – Not your parent’s wall switch

How much training/customer support will your customers need?
Lighting Controls
Installation Instructions – Relatively simple control panel

Source: Leviton

- Designer/Manufacturer
  - Provides system components that allow simple installation, easy commissioning, intuitive use and hides complexities from end user
- Architect/Lighting Designer
  - Clear recipe book of features and capabilities that may be very different from previous experience
- Project Engineer
  - Understands the complexities of system interactions among components
- Sales and Marketing
  - Provides a vision of what is possible at what price point
- Contractor
  - Has training and experience to install and commission what can be highly complex systems
- Owner/Facility Manager
  - Understands the high value proposition of the system

Lighting Controls
Changing Requirement – New rules for all participants
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Sensors
Lighting Controls – Combining LEDs with sensors

Types of Sensors

- Occupancy/Vacancy Sensors
  - Passive IR – use thermal image to detect activity
  - Microwave – transmits microwave pulses and measures reflections to detect activity
  - Ultrasonic – similar to sonar, uses reflections from bursts of high frequency sound to detect activity
  - Acoustic – microphones which listen for activity
- Photocells/Daylight Sensors – measure ambient light to either turn system on/off or set particular dimming level
- Video cameras – uses change in scenes to detect activity
- Timing – sets on/off or dimming level based on time of day
Sensors

Occupancy vs. Vacancy Sensors — What is the difference?

- **Occupancy sensors** turn lights on when someone enters an area and turns them off a set time after the person leaves
  - preferred for areas where someone entering the area may not be able to turn on the lighting control (e.g. playrooms for small children, laundry rooms where arms may typically be carrying items, etc.)
- **Vacancy sensors** do not turn lights on. Someone entering an area controlled by a vacancy sensor must manually turn the lights on. However, the vacancy sensor will turn the lights off when it senses that person has left the area
  - preferred in areas where the lights should not come on automatically should someone enter the area. For example, children's bedrooms, areas where pets are free to roam, etc. Some building codes require the use of vacancy sensors whenever sensors are used

Sensors

Sensors — Energy savings have a number of elements

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
- **Correct positioning of sensors to avoid false triggering**
  - Vehicle sensing at garage floor entrances
  - Motion of trees, animals in parking areas
- **Proper commissioning to insure operation as intended and periodic recommissioning**
Sensors
Stand-Alone Sensing/Control — Simple/inexpensive

Pros & Cons
+ Sensors are built into the luminaires
+ No wiring required (except for power)
+ Simplest installation
+ Some manufacturers offer RF capability to allow luminaires to provide a minimal grouping function via wireless
+ Minimum commissioning effort
  - Limited control capabilities
  - Limited sensor selection (those provided and installed by the luminaire manufacturer)
  - No building integration

Sensors
System Sensing/Control — Expanded features at higher cost

Pros & Cons
+ Sensors are located based on building structure/control needs
+ Minimum restrictions on types of sensors used
+ Complete control of lighting system which can be tailored to building occupancy and use
+ System can be integrated into a complete building control system (e.g. HVAC, security, etc.)
+ Software control and remote monitoring capabilities
+ Communication with electric utility for load shedding which can provide rate reductions
  - Higher installation costs
  - Extensive commissioning recommended/required
  - Often "closed" systems which limits future expansion to one mfg
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The Future
Personal Lighting – Having it your way

- Individuals gain much more control on lighting environments
  – Having control provides a less stressful atmosphere for employees
- Seamless integration between lighting control systems and HVAC, building automation and security systems
- Use of smartphone technology to allow lighting control systems to recognize who is entering an area and set appropriate lighting level and color pallet preferences
- Ability to match color with activities
- Emphasis on the use of light to improve human experience as medical research establishes firmer relationships between photometric characteristics such as intensity, wavelength and exposure time to physical and mental well being
The Future

Complexity – What makes lighting different

Contemporary lighting systems become more and more complex. The complexity is a direct result of available capabilities of emerging new technologies such as LED\(^1\).

- Lighting technologies change rapidly
- There are infinite combinations of lighting technologies
- The extensive use of software also provides unlimited possibilities
- Technologies and design solutions vary significantly from one application to the next
- Changes in lighting can impact occupant performance
- Use of lighting in non-traditional (and unfamiliar) applications

**The result is that overly complex and poorly understood system often deliver performance that is less than expected**

\(^1\) Controlling Complex Lighting Systems, Wojnicki and Kotulski, AGH University of Science & Technology, Krakow, Poland, 2012

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The Future

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
The Future

Complexity – What might make things better

• Self commissioning software
  – Commission & configure several thousand fixtures in few hours
  – Easy to re-commission by end user
  – No need for manual data entry or stickers
  – Experts needed for only 10-20% of tasks
  – Energy saving ≥ expert-commissioned systems

• Software & user interface to directly empower end-users
  – Personalize & control ambiance
  – Instantly re-configure zones, scenes, download lighting profiles

• Approach
  – Use of software to automate greater than 90% of tasks
  – Mass market IoT micros in each light fixture
  – Intelligent software in each IoT node & server
  – Replace custom installation tools with mobile user interface tools
  – Integrate control & power electronics, wherever possible
  – Use as many sensors as budget will allow

Source: Reducing Configuration Complexity with Next Gen IoT Networks, Kishone Manghnani, DOE SSL Program Connected Lighting 11/15
The Future

Tomorrow's Lighting Control – Way more than lighting

The lighting control systems of tomorrow offer potential benefits beyond traditional energy/cost savings

- New Sources of Revenue
- Data Analytics
- Resource Optimization
- Health Improvement
- Increased Safety
- Productivity Improvements
- Improved Security

Data Source: Michael Poplawski, DOE SSL Program Connected Lighting Meeting, 11/16/15

The Future

Energy Reporting – Why it is becoming important

- You can't (effectively) manage what you can't measure
- Reduce energy consumption
  - Data driven energy management
  - Transactive energy markets
    - "An internet-enabled free market, where customer devices and grid systems can barter over the proper way to solve their mutual problems, and settle on the proper price for their services, in close to real time"  
    - A How-To Guide for Transactive Energy, Jeff StJohn, Greentech Media, 11/20/13
- Enable new market opportunities
  - Pay-for-performance energy efficiency incentives
  - Energy billing for devices currently on flat-rate tariffs
  - Lower cost, more accurate energy savings validation for service-based business models
  - Verified delivery of utility incented energy transactions (e.g. peak and other demand response)
  - Self-characterization of available (i.e. marketable) “building energy services”

Source: "DOE Focus Areas," Poplawski, Michael, DOE SSL Program Connected Lighting Meeting, 11/16/15
The Future
Changing Roles – Across many aspects of the lighting marketplace

- The use of color – in new and unanticipated ways
- Data communications – understanding protocol layers
- Distribution channels – which player in the lighting market has the largest market cap?
- Service and troubleshooting – diagnostic subroutines replacing continuity checkers
- Programming
- Human psychology – becomes a necessary lighting specifier skill
- Changing building codes – continuous push for lower energy usage per square foot while requiring adequate illumination levels will present increasing challenges to the lighting designer

The Changing Business Universe – A shift to software/services

Source: IBM Annual Report 2013
Source: The MIT Center for Digital Business

Hardware is becoming the least significant source of profit for many traditional hardware suppliers
The Future

The Future of IoT – The numbers are staggering

Most market projections peg the potential sales volume in a range of between 1 and 7 TRILLION USD by 2020!

Source: IoT Analytics

The Future

Complexity – What makes lighting different

Does this look familiar?

How about this?

This is the future of the lighting business
Be prepared for it
The Future
Complexity – What makes lighting different

If the rate of change on the outside exceeds the rate of change on the inside, the end is near.

Jack Welsh

Acknowledgement

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Thank You

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Don’t forget...
• 10:15 - 11:30 am – Opening General Session with Doris Kearns Goodwin
• 11:30 am - 5:00 pm – NECA Show Hours