Color is perception

- Perception depends on lighting
- Lighting impacts our entire workflow - from product inception and production to the consumer
- More predictable lighting = more predictable color
In the beginning

Things were pretty simple

- one primary ‘illuminant’
- one ‘artificial’ source
Soon electricity…

… enabled other lighting technologies

- Carbon Arc (1802)
- Incandescent (1835)
...which lead to more lighting technology

- Gaseous discharge (1856)
- Fluorescent tubes (1857)
- HID (e.g. Xenon)
- Sodium vapor
- Metal halide, mercury vapor
- Laser (1960), holographic, etc.
...and our subsequent light-filled world

- Xenon
- Neon signs
- Glow sticks
- Germicidal
- Infrared
- Medical
- Displays
...leading to the more complex, efficient and capable lighting environments

- 1<sup>st</sup> LED (1927)
- Today et. al.
Lighting change - dominant drivers

- Lower purchase costs
- Improved operating efficiency
  - 50 – 90% less energy and heat
  - Longer life (5 – 50x), little or no maintenance
- Expanded capabilities
  - Dimming, color temperature, form factors
- Less environmental impact
  - Toxicity, overall waste, carbon footprint
- Better illumination quality
- And, even, human-centric concerns
  - Comfort, productivity, safety
An energy perspective

Source:

USA Annual Energy Consumption

- Petroleum: 36.9 (36%)
- Natural gas: 31.0 (31%)
- Coal: 13.2 (13%)
- Renewable energy: 11.5 (11%)
- Nuclear electric power: 8.4 (8%)

Total = 101.3

End-use sector:

- Transportation: 28.3 (37%)
- Industrial: 26.3 (35%)
- Residential: 11.9 (16%)
- Commercial: 9.4 (12%)

Total = 75.9

Source:

U.S. Energy Information Administration;
Installed lighting technology

A-Type Submarket Stock Forecast for the Current SSL Path Scenario

Rate of change implications

Table 4.8 A-Type Submarket LED Stock Forecast Results

<table>
<thead>
<tr>
<th>Current SSL Path</th>
<th>LED Installed Stock (million units)</th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Commercial</td>
<td>196</td>
<td>985</td>
<td>2,030</td>
<td>2,980</td>
<td>3,620</td>
</tr>
<tr>
<td></td>
<td>Residential</td>
<td>186</td>
<td>936</td>
<td>1,960</td>
<td>2,910</td>
<td>3,540</td>
</tr>
<tr>
<td></td>
<td>Industrial</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>LED Installed Stock Penetration (%)</td>
<td>Commercial</td>
<td>6%</td>
<td>29%</td>
<td>56%</td>
<td>78%</td>
<td>90%</td>
</tr>
<tr>
<td></td>
<td>Residential</td>
<td>15%</td>
<td>70%</td>
<td>91%</td>
<td>96%</td>
<td>97%</td>
</tr>
<tr>
<td></td>
<td>Industrial</td>
<td>6%</td>
<td>28%</td>
<td>56%</td>
<td>78%</td>
<td>90%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>13%</td>
<td>47%</td>
<td>74%</td>
<td>89%</td>
<td>95%</td>
</tr>
</tbody>
</table>

Light priorities

Human Needs
- visibility
- task performance
- visual comfort
- social communication
- mood and atmosphere
- health, safety, well being
- aesthetic judgment

Economics, energy efficiency and the environment
- installation
- maintenance
- operation
- energy
- environment

Architecture and other building- or site-related issues
- form
- composition
- style
- codes and standards
- safety and security
- daylighting

Credits – International Association of Lighting Designers.
Conflicting priorities

- Purchase cost
- Electrical efficiency

- Capabilities
- Build quality
- MBTF, Serviceability

- Spectral quality (e.g. CRI, MI’s)
- Flicker
Retrofit considerations

- Luminous flux (total light output)
- Light distribution (beam spread)
- Installation
- Rewiring
- External vs. internal drivers
- Dimmer/controls compatibility
- Lamp life rating and method
- Fact vs. fiction
Unique attributes of LEDs

- Energy efficacy
- Spectral qualities
- Longevity
- Thermal sensitivity
- Shock resistance
- Warm-up time
- Batch variation

- Very high
- Tunable
- Variable
- High (affects output, life)
- High
- None
- Significant
Lighting Standards

- International, federal, state and local - each for a specific purpose
- Safety
- Efficiency
- Application
  - graphic arts
  - paints, plastics
  - textiles
  - offices
- Metrics standardized
  - Illumination level
  - Viewing geometry (angles)
  - Spectral qualities
  - Energy efficiency
  - Maintenance, servicing
  - Light source
  - Light distribution
  - Glare, contrast, visual comfort
  - Safety (electrical, biological)
Lighting Related Standards

- Lighting levels & environments
  - ASTM, IES, OSHA
    - Office Lighting
    - Photobiological Safety
- Definition of illuminants - CIE
- Viewing conditions - ISO 3664:2009, 3668; ASTM D 1729-96
- Measurement of luminaires
  - LED Photometric performance CIE S 025/E:2015, IES LM-79
  - LED Lumen maintenance IES LM-80
The Resultant Reality

- A kaleidoscope of lighting
- Customer, supplier, and retailer environments are all changing – simultaneously
- Consequently, the likelihood they match is limited
Approaches

- Make things happen
- Watch things happen
- Wonder what happened
How are communities responding?

- Retailers
- Printers
- Suppliers
- Standards bodies
Progressive Retailers

- Transition strategies for lighting conversions, replacements
- Advanced planning methods and tools
- Integrated, modular, connected lighting
- Multiple sources to detect metamerism
- Supplier specifications and standards including visual inspection
- Employee, supplier and customer education
Trends in Retail Lighting

- Daylight harvesting, dynamic shutters
- IoT - integrated/connected controls
- Tunable fixtures
- Circadian based lighting
- Spatial analytics
- Real-time feedback
Progressive Imaging Services

- Involvement in standards work
- Adoption, implementation, monitoring of viewing standards
- Collaboration with customer’s conditions
- Quantification of instrument errors
- Standardization throughout the workflow
- Inspection under end-use conditions
Lighting and Viewing Environment Suppliers

- Participating, integrating with customers’ workflows
- Integrating defined viewing conditions
- Advanced LED products exceeding viewing standards with multi-illuminates, calibrated,
- Replicating end-user spectral conditions
- Improving smart features
Standards bodies

- Defining new LED illuminants (CIE LED)
- Expanding colorimetric measurement metrics – TM-30
- Improving lighting measurement metrics (LM 79)
- Addressing photo and biological hazards
- Adopting more stringent standards for buildings, efficiency
Communication can be challenging

- “We are looking for 5000K lighting”
- “The CRI needs to be over 90”
- “It needs to match our instruments…”
What to do with what you’ve learned

- Define
- Communicate
- Inspect what you expect
Define your environments

- Measure and define viewing conditions
- If you can’t, scope their range
- Delineate viewing geometry influences on texture, gloss and glare
- Plan for metamerism
  - If ‘colorants’ are identical, metamerism doesn’t exist
  - Most of us must deal with it
Communicate metrics
Photons, Electrons, and Lumens, oh my

- Use existing or well-defined standards
- More than one metric is mandatory
  - CCT – only one metric for white point
  - Chromaticity coordinates – more accurate
  - CRI and TM-30
  - Metameric indices (Mlvis, Mluv)
  - Viewing geometry
Be specific, measure to expectations

- **Illuminants vs. Sources**
  - Illuminant = numeric, artificial definition of light), defined by the CIE – D50, D65
    - (which is *not* CCT – correlated color temperature in degree Kelvin)
  - Light Source – the actual physical artificial light source in use (a real word thing). Measured values and a SPD spectral power distribution curve.
  - Brand-specific sources define a “custom illuminant” e.g. Ultralume 35 or Alto II

- Use good practices to measure conformance
Thank you for attending!

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