

LED Street Light Research Project

Remaking Cities Institute

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Executive Summary

Background

The City of Pittsburgh intends to replace its entire inventory of 40,000 street lights with light-emitting diode (LED) fixtures over the next five to ten years. When fully implemented the project is expected to save annually an estimated \$1.7 million (70% savings) in energy and maintenance costs. In addition the conversion will reduce carbon dioxide emissions by almost 7 million metric tons annually.

Street lighting in the United States evolved from oil and gas lamps in the 17th and 18th centuries to electric lamps in the late 19th century. Electric lamps have since progressed from incandescent to fluorescent to mercury vapor (MV). Today high intensity discharge (HID) lamps dominate street lighting installations. Two HID lamp types predominate: high pressure sodium (HPS), noted for its yellow/orange light, and metal halide (MH) that emits a bright, white light. Recently the trend has been to convert to LED fixtures because of documented savings on energy use and life-cycle maintenance costs.

In December 2010 the City engaged the Remaking Cities Institute (RCI) of Carnegie Mellon University (CMU) to undertake a proof of concept research project to investigate best practices of LED conversion as well as to study other aspects of LED street lights, such as spacing, color, intensity, glare, aesthetics, impact on “dark sky,” controls, energy monitoring, public safety, placemaking, special events, and impacts on drivers, bicyclists, pedestrians, and the elderly and sight-disabled. The RCI study focused on the conversion of 3,100 street lights in the thirty business districts of the City. Three prototypical business districts (from large to mid-sized to small) were selected for detailed study: Fifth and Forbes in Downtown; East Carson Street on the South Side; and California Avenue in Brighton Heights. Four existing City fixture types were studied for conversion to LED: cobra head; shoebox; acorn; and

pendant. Globe fixtures, a fifth type, have been and are being phased out of the City inventory.

The research team was led by the RCI and included C & C Lighting, LLC (Pittsburgh), and Orfield Laboratories, Inc. (Minneapolis).

The project proceeded in three phases: data collection; research; and recommendations.

Data Collection

The RCI team examined the evolution of street lighting technology and the issues around LED conversion, including national and local lighting standards for illumination, including ASHTO, IESNA, FHWA, and the Lighting Ordinance of the City of Pittsburgh enacted in March 2011. The City previously conducted and installed three pilot LED conversion projects (Shadyside, South Side, and Mount Washington).

Measured drawings were prepared for the three selected business districts, including location and type of existing street light fixtures. Photographs were taken of each business district. Nighttime measurements were made by Orfield Laboratories of the existing lighting and glare levels in the three selected business districts and also in the Mount Washington pilot LED project. Orfield also tested the four City standard luminaires in their laboratory.

Focus group meetings were held with stakeholders in each of the three selected business districts. The general consensus was that the ability to change the white light temperature between warm white and cool white for local conditions would be a valuable feature. Colored light was acceptable for accents but not for general

lighting of sidewalks or streets. Lighting building facades with street lights was not desired. However, being able to project light into spaces between buildings and side alleys was recommended.

Research

The RCI team researched seven key aspects of street lighting:

1. *Dimensions of nighttime vision* looked at how the human eye sees at night; how glare affects vision; how uniformity of illuminance affects vision; and age-related vision loss.
2. *Considerations of lighting the public right-of-way* included aspects of placemaking and wayfinding such as intensity, color temperature, color changing, and focal points.
3. *Aesthetic evaluations* examined materials, facade lighting, luminaire style, and standardization.
4. *Performance considerations* included varying viewpoints, illumination levels, glare and light trespass, uniformity, color rendering, ambient light, and safety.
5. *Operational considerations* dealt with energy use, monitoring, durability, reliability, and light output.
6. *Political and social issues* were addressed, including climate change, light pollution, age-related equity, and spatial equity.
7. *Biological/Public Health Considerations* included color temperature and circadian rhythm.

The team reviewed public realm lighting plans in Lyon, France, Quebec City, Canada, Helsinki, Finland, Eindhoven, Netherlands, Colorado Springs, Colorado, Lemgo, Germany, and San Francisco, California, for innovative approaches, best practices, and lessons learned.

Recommendations

The RCI team endorsed the conversion of City street lights to LED technology with two principal recommendations:

- › The light sources *and* the luminaires both must be replaced because the standard City luminaires do not have reflectors or lenses to control glare. Cobra head, shoe box, and pendant luminaires can be replaced with new models that have the proper characteristics. However, the team recommends that acorn luminaires not be retrofitted because it is not possible to control glare or dark sky impact with a fixture that radiates light in all directions. Acorns should be phased out of the City inventory just as the obsolete globe luminaires have been discontinued.
- › All replacement luminaires and new luminaires should be tested and certified to meet the performance criteria set forth in this report.

Below are the base criteria for LED replacement luminaires:

- › The entire luminaire head is to be replaced.
- › Light color is to be white, preferably 3,500 Kelvin, but with an adjustable range from 2,800 to 5,000 Kelvin.
- › The Color Rendering Index must be 80 or greater.
- › The fixtures shall be primarily down-firing. Up-firing fixtures, if used for aesthetic effect, must be aimed at white horizontal reflectors to produce diffused light downward to prevent dark sky intrusion.
- › The LED light source should not be visible to drivers, bicyclists, or pedestrians unless they are directly under the fixture.

- › LED luminaires should be guaranteed for a minimum ten-year life span with no more than a 30% deterioration of illuminance as measured by footcandles.
- › The preferred lighting pattern on the ground shall be overlapping ovals.
- › Luminaires will be placed on existing poles. Typical spacing for luminaires on 25' to 30' poles can vary from 85' to 150.' On 15' to 18' poles the spacing is usually 80.'
- › All luminaires should be control-ready with the ability in the future to be individually monitored and controlled by wired or wireless central networks.
- › Back-lighting of building facades should not exceed a height of 6" above the sidewalk.
- › Contemporary luminaire design is encouraged except in historic districts where luminaire design should be compatible with the local context.

Testing and evaluation of the replacement luminaires should be conducted in a laboratory with proper photometric equipment. Also, field evaluation of installed LED luminaires in the three selected business districts should be conducted using a scoring system that will rate beam spread, color rendering, light intensity, clarity, glare, integration with the surrounding context, visual experience, and luminaire enclosure design.

The study suggests four upgrade options to the above base criteria:

1. Basic controls to allow dimming from 6 footcandles to 1.5 footcandles and adjusting color between 2,800 Kelvin and 3,500 Kelvin.
2. Enhanced Smart Street Lighting Control System to provide real time data on energy use, outages, lamp life, and to enable remote control of strobing, flashing, integration with emergency services, and special event effects, in addition to basic controls for dimming and color adjusting.
3. Accessory color lighting fixture with red, green, blue LED's that can be attached to the existing street light poles for wayfinding, special events, artistic effects, and emergency signaling.
4. A light cueing feature on the luminaires to allow a small amount of light to be visible above the cutoff level to serve as a visual indication that the fixtures are on.

Future steps for the City to undertake include:

- › Develop similar base criteria for the 37,000 neighborhood street lights to be retrofitted
- › Develop and standardize a City LED street light product evaluation and certification program
- › Modify the City of Pittsburgh Lighting Ordinance to reflect the finding of this study and the field results of the business district LED conversion process.



Present-day Pittsburgh

Background

Overview

The City of Pittsburgh currently operates 39,779 street lights using 2,293,748 kilowatts-per-hour, at a yearly electricity and maintenance cost of approximately \$4.2 million dollars. In an effort to address budget issues and environmental concerns, the City intends to replace its nearly 40,000 street lighting fixtures with light-emitting diode (LED) fixtures. The plan is expected to save an estimated \$1.7 million dollars annually in reduced energy and maintenance costs and to reduce carbon dioxide emissions by 6,818 metric tons per year annually.

In addition to reducing their cost load and share of greenhouse gas (GHG) emissions, the City of Pittsburgh is interested in the unique opportunities that LED street lighting and related sensor and control technologies offer for placemaking and wayfinding in business districts.

In late 2010, the City of Pittsburgh engaged Carnegie Mellon University's Remaking Cities Institute (RCI) to investigate the full range of potential options and benefits of a LED street-light replacement program for 3,000 street lights in Downtown Pittsburgh, Oakland and the City's more than 50 neighborhood business districts. From February 2011 to June 2011, an interdisciplinary research team led by the RCI investigated the technological and aesthetic potential offered by LED technology as applied to street lighting scenarios in business districts.

Working with the premise that public street lighting can and should be designed to meet the needs of people of all ages, including those with age-related vision loss, the research includes best management practices and lessons learned from cities where LED street lighting has been installed. The report outlines general recommendations regarding street lighting, as well as technical specifications for replacement LED fixtures on existing luminaire poles. It provides direction on ways to capitalize on the additional

benefits of LED technology, such as the use of control systems for dimming, changing color, emergency events, and the use of accessory color lights for use in wayfinding, placemaking and event planning in business districts. It also suggests ways in which cities can go beyond street lighting to consider all public and private outdoor lighting in a comprehensive manner.

By adopting the recommendations regarding LED street lighting in this report, the City of Pittsburgh will set new standards, nationally and internationally, for transforming a major component of public infrastructure in ways that are fiscally responsible and viable, equitable and in balance with our habitat—and for the same price or less than regular public street lighting schemes.

The Pittsburgh LED Street Light Research Project research team includes Carnegie Mellon University faculty and researchers from the Remaking Cities Institute, School of Architecture, and the School of Drama, as well as lighting consultants from C & C Lighting, LLC in Pittsburgh, and Orfield Laboratories, Inc. in Minneapolis, MN. The research team worked closely with the City of Pittsburgh's Department of Public Works and the Energy and Utilities Manager, Office of Sustainability and Energy Efficiency and City Information Systems.

Goethe's final words: more light. Ever since we crawled out of that primordial slime, that's been our unifying cry: more light. Sunlight, torchlight, candlelight, neon, incandescent, light to banish the darkness from our caves, to illuminate our roads, the insides of our refrigerators. Big floods for the night games at Soldier's Field, little tiny flashlight for those books we read under the covers when we're supposed to be asleep. Light is more than watts and footcandles, light is metaphor. Thy word is a lamp unto my feet. Rage, rage against the dying of the light! Lead, kindly light, amid the encircling gloom, lead thou me on. The night is dark and I am far from home, lead thou me on. Arise, shine, for thy light has come. Light is knowledge, light is life, light is light.

- Monologue by character Chris Stevens, played by actor John Corbett, in Episode 18, Season 4 of Northern Exposure. Written by screen writers Diane Frolov and Andrew Schneider.



Gas lamps; prior to ignition device

Street Lights: A Brief History

The first record of public street lighting dates back to 10th century Spain, when Cordoba, the capital of the Moorish Empire, installed kerosene lanterns along its main streets. Since then, the street light has undergone several iterations in technology, from lanterns filled with tallow, fat, wax, and pith wicks in 15th century Europe and Colonial America, to coal gas lamps in the 19th century and electrified arc lamps and incandescent bulbs in the late 1800s. The past decade has seen the emergence of a new lighting technology that can be applied to street lighting, the solid-state light emitting diode (LED), a super-efficient, long-lasting, compact and versatile light source.

The largest municipal street lighting system in the United States is found in New York City, with over 300,000 outdoor public lights shining along streets, walkways, public spaces and highways. The story of New York encapsulates the evolution of street lighting in America over the last 300 years.

In Colonial America, street lighting was the responsibility of citizens, not government. In New York in 1697, every seven households were required to share the expense of a candle to burn in a lantern suspended on a pole from the window of every seventh house. Lamp lighters maintained the system, lighting the candles from within their glass vessels with torches in the evening and blowing out the flames in the morning, trimming the wicks and replenishing the oil. In 1762, New York installed wooden public lamp posts from which whale oil lamps burned dimly. These were replaced with cast-iron lamps in 1827. For the next thirty years, a calendar was used to identify those nights when the moonlight was expected to be bright and the lamps were kept off regardless of any overcast conditions. By 1893 there were 1,500 electric arc lights illuminating New York streets. Over the next 100 years, new technologies, from incandescent to high intensity discharge (HID)

fixtures, were introduced, each progressively more efficient, safe, and flexible.

In 1999, NYCDOT began updating its high-pressure sodium (HPS) luminaires with more efficient models. From 2001 to 2009, the City converted its incandescent traffic signals to LEDs, reducing energy use by 81 percent. Its 2007 Comprehensive Plan, PlanNYC, called for a 30 percent reduction in greenhouse gas emissions by 2030, a goal surpassed the same year by Executive Order 109 and Local Law 55 requiring the reduction of municipal energy use by 30 percent of 2006 levels by 2017. With street lights accounting for approximately 6 percent of its energy use, NYCDOT is looking towards the new generation of LEDs suitable for street lighting. As of 2010, six LED street lighting pilot projects were underway along major arterials, bridges, and in Central Park, with full scale deployment planned for three sites depending on the test results.

As a global city, New York aims to shape the future of more sustainable street lighting infrastructure by helping to evaluate commercial applications of LED technology via the U.S. Department of Energy (DOE) Gateway Program, and by participating in The Climate Group's (TCG) Light Savers program alongside major international cities like Toronto, London, Mumbai, Bangalore, Hong Kong, and Beijing.

As the story of New York City illustrates, cities around the world are moving rapidly towards the adoption of solid-state lighting (SSL) LED technology wherever possible. However, a review of the literature shows that most cities are not considering the additional opportunities of LEDs as they pertain to performance, place-making, wayfinding, and special event planning, instead focusing solely on cost and emissions reductions through energy efficiency.



Mercury vapor lamp



Moonlight tower with arc lamps



High pressure sodium light

Electric Street Lighting Technologies

› 1880s - 1900s

Electric outdoor lighting was first used in the 1880s with the invention of the open arc lamp, which runs a high current between two carbon electrodes. These energy-intensive “electric candles” shone so brightly that they had to be placed high up on 60 to 150 foot towers and essentially acted as flood lamps.

› 1900s - 1930s

Twenty years later, the lower-power incandescent bulb was invented and deployed on streets in cities around the world. While the incandescent bulb produces a pleasant Color Rendering Index (CRI) of 100, it has a short lifespan and is energy intensive.

› 1930s - 1940s

Low pressure discharge fluorescent lights appeared in the 1930s, but these fell out of favor due to the diffuse and non-directional nature of the light produced, which meant they could only be mounted 20 to 30 feet high. Fluorescent lighting technology also does not fare well in cold climates and has been mostly relegated to use in buildings.

› 1940s - 1960s

The mercury vapor (MV) lamp was introduced in 1948 and widely adopted because of its much brighter light. However MV begins to depreciate immediately while still requiring the same amount of energy. This, coupled with the issue of mercury waste, led them to later be replaced by metal halide (MH), high-pressure sodium (HPS), and induction fixtures.

› 1960s - 1970s

In the 1960s, metal halide (MH) technology was invented for use in industrial operations. It was favored by many for the long-lasting bulbs which created natural light compared to the bluish MV lamps. MH is often still used at intersections because its excellent color rendering allows for better visibility and contrast.

› 1970s - 2000s

In the 1970s, high pressure sodium (HPS) lights were unveiled and have since become the most dominant type of street lighting in America, imbuing cities and skies with an orange hue. Induction lamps came into use for outdoor lighting in the late 1990s and were considered a very promising technology. Similar to high-quality fluorescent lights, induction lamps are based on gas discharge technology. The advantages of induction include instant strike and restrike, color stability, high CRI, good vibration resistance, low energy use, and a very long life, with rated lifetimes of up to 100,000 hours. However they contain mercury, are sensitive to higher temperatures, and are currently not dimmable.

HPS cobra head fixtures have remained the dominant lighting technology and luminaire style, typically activated by a photosensitive cell.

› 2000s - present

Amid growing concerns about rising GHG emissions and electricity costs, cities began testing solid-state lighting (SSL) LED lighting across a range of applications including traffic lights, parking garage lights, and street lights. SSL became a research



LED lighting embedded in pedestrian bridge



LED lighting technology for public square



LED lighting technology camouflaged as foliage

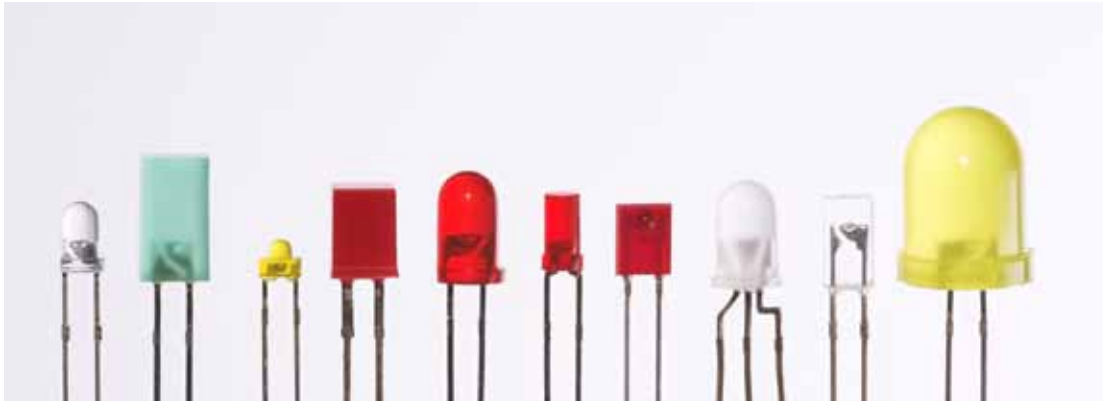
and development focus of the U.S. Department of Energy. In the U.S., the LED City® program emphasizing the energy and maintenance cost savings of LED lighting for municipalities was created, and The William J. Clinton Foundation launched the Clinton Climate Initiative (CCI) to encourage cities to reduce their carbon emissions by adopting LED technologies, among other actions. In Europe, LUCI (Lighting Urban Communities International) was formed with a focus on a comprehensive and sustainable approach to urban lighting. A summary of these and other urban lighting initiatives and networks is located in Appendix B.

Milestones in Public Street Lighting

- › 9th century, kerosene lamp invented in the Arab Empire
- › early 15th century, lanterns filled with tallow, wax, pitch or fat installed on London’s streets
- › 1667, the “Sun King”, Louis XIV, has 2,700 lanterns installed in the streets of Paris
- › 1762, New York installs wooden public lamp posts with whale oil lamps
- › 1892, gas lighting invented in Britain
- › 1807, gas first used to light the Pall Mall section of London
- › 1816, first chartered gas company founded in Baltimore in 1816, followed by Boston and New York City
- › 1816, whale oil street lights installed in Pittsburgh
- › 1880, Wabash, IN, the first city to be lit solely by electricity, with the “Brush Light” featuring four 3,000 candlepower open arc lamps
- › 1880s, electric street lighting system installed in Pittsburgh using incandescent bulbs
- › 1948, mercury vapor (MV) street light invented
- › 1957, the popular high-mast ‘cobra head’ fixture is unveiled
- › 1970, high pressure sodium (HPS) introduced
- › 2007, LED City® program created with the first outdoor LED lighting pilot project in Raleigh, NC



LED streetlight example



Individual LED diodes



Individual LED diodes

LED Street Lighting Technology

In spite of improvements in the efficiency of lighting technologies since the early 20th century, outdoor public lighting systems (streets, parks, public spaces, etc.) can still account for as much as 40 percent of a municipal government's total electricity use. Lighting manufacturers are responding to cities' concerns for reducing costs and greenhouse gas (GHG) emissions by developing more efficient lighting products integrated with sensor technologies, control systems, artistic accessories, and renewable energy components.

While LED technology offers a wide range of unique potential benefits, a review of the literature finds that cities are primarily interested in the energy-reducing promise of LEDs for street lighting and traffic light applications with little focus on the performance issues or aesthetic and placemaking opportunities presented by LEDs and street lighting in general. This emphasis is in response to the high priority concerns of global climate change and financial restraints of governments across all levels.

The U.S. Department of Energy (DOE) estimates that converting to LED lighting over the next two decades could reduce energy consumption by one-quarter, saving \$120 billion in energy costs and diverting 246 million metric tons of carbon emissions. While older technologies are concurrently being improved, LED lighting sources are expected to continue to surpass other technologies in terms of efficacy. As a result, the *Energy Policy Act of 2005* (EPACT 2005) and *Energy Independence and Security Act of 2007* (EISA 2007) mandates the DOE to expedite the development of solid-state lighting (SSL) technology with an emphasis on advancing core technology research, product development, and manufacturing support. The following special characteristics of LEDs make them especially useful in outdoor applications.

LED Advantages

Solid-state lighting technology uses semiconductor light-emitting diodes (LED), organic light-emitting diodes (OLED), or polymer light-emitting diodes (PLED) rather than electrical filaments, plasma, or gas to create light. When it comes to street lighting, LEDs have several distinct advantages over traditional lighting technologies:

› **Compact size**

The light output of individual light-emitting diodes is low compared to incandescent and compact fluorescent bulbs. However the compact size of diodes means that multiple diodes can be clustered together into an LED array. Individual LEDs are also becoming more powerful, with a higher lumen output. As a result, LED arrays have the potential to have a much lower profile than other lighting technologies while using less energy.

› **Durability and shock-resistance**

Solid-state lighting technology does not contain delicate glass enclosures or filaments. LEDs are made of polycarbonate which is vibration resistant, making them ideal for road-side applications.

› **No infrared (IR) or ultraviolet (UV) emissions**

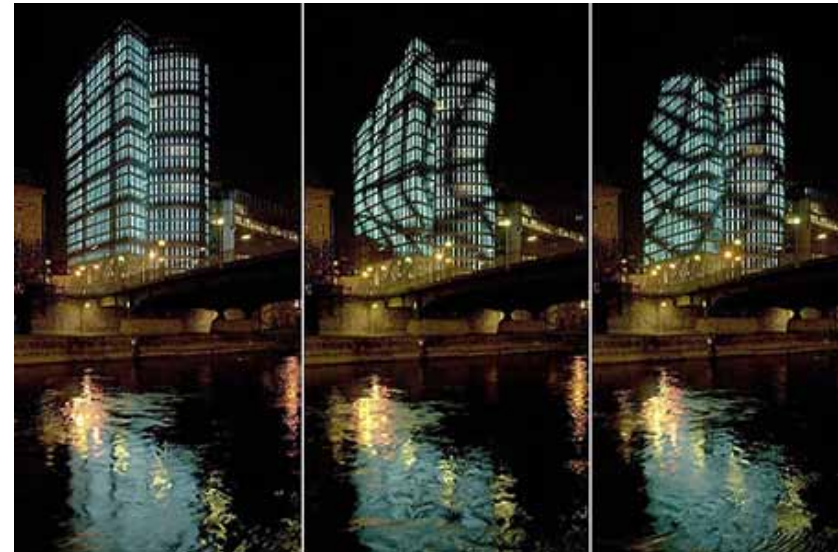
SSL products do not emit UV or IR radiation. UV radiation can damage fabrics and cause eye and skin damage. IR radiation can potentially cause burns to materials or skin with excessive contact.

› **Directional light**

Traditional lights emit light in all directions while LEDs emit light in a specific direction. This reduces the need for reflectors and diffusers, resulting in less wasted light and more efficiency.



Unique application of LED lighting



Unique application of LED lighting

Typical Rated Life of LEDs and Traditional Light Sources

Light Source	Typical Rated Life (hours)*
Incandescent	750 - 2,000
Halogen incandescent	3,000 - 4,000
Compact fluorescent (CFL)	8,000 - 10,000
Metal halide	7,500 - 20,000
Linear fluorescent	20,000 - 30,000
High-Power White LED	35,000 - 50,000**

*Source: lamp manufacturer data

**Depending on drive current, operating temperature, etc. some manufacturers are claiming useful life (L70) values greater than 100,000 hours

› **Lower operating costs: energy efficiency**

LEDs use 50 to 90 percent less energy than other light sources while maintaining the same light output.

› **Lower operating costs: longer life**

LEDs have two to three times longer life than conventional light sources (except induction). Estimates vary because the technology is new and constantly improving, but it is commonly reported that LEDs can last 20 to 30 years depending on the quality of the product, power usage, and other factors. However, the practical LED life expectancy for street lighting application is typically estimated at 10 years, when a 30% lumen deterioration is anticipated. The reduced re-lamping costs of long-lived LEDs is a contributing factor to the lower maintenance cost of LEDs. A longer life also means less landfill waste.

› **Wide color temperature range**

White LED light sources are available with a fixed color temperature (CT) and color rendering index (CRI), typically from 3,000 to 6,500 Kelvin (K). A further option are white light LEDs arrays that can be continuously controlled to offer warm (2,700 - 3,000 K) to cool white light (5,000 K+).

› **Control options**

LEDs are highly modifiable. Control systems can manipulate LED color temperature, color hue and light intensity (dimming). Using sensors, it is possible to control shutdown and resume operation, detect lumen depreciation and sense occupancy.

› **No toxic metals or chemicals**

One of the pitfalls of other street lighting sources, including those that are more energy efficient, is that they contain mercury, lead, and other toxic chemicals. While a single bulb may not pose a

serious contamination threat, the cumulative effect of the estimated 500 million street lights in use worldwide finding their way into landfills on a three to five year cycle poses an enormous pollution problem. As LEDs do not contain hazardous waste, they can be completely recycled.

› **Monochromatic light**

LEDs emit nearly monochromatic light, making them highly efficient for colored light applications. As a result, LEDs can produce a full spectrum of color for celebratory and aesthetic purposes.

› **No burn out**

Rather than burning out, LEDs gradually dim over time. LEDs are measured on the L₇₀ standard, which indicates the average hours of operation until the light output (lumens) deteriorates to 70 percent of its original quantity.

› **Near instant-on and rapid cycling**

LED lights achieve 100 percent brightness nearly instantly when activated. They are also unaffected by repeatedly being turned on and off (rapid cycling), unlike traditional lighting technologies which have a shorter lifespan and higher energy needs.

› **Good performance in the cold**

In colder temperatures, LED lights perform more efficiently and last longer.

› **LEED ND point contribution**

The Leadership in Energy and Environmental Design for Neighborhood Development's (LEED ND) Green Infrastructure and Buildings (GIB) category includes a credit for Infrastructure Energy

LED example assembly for thermal management



Unlike many available lighting products, LEDs will not burn skin

Efficiency (GIB Credit 13). This credit promotes the use of LED technology in traffic lights and street lights as a means for reducing overall energy use in a development.

LED Street Lighting Concerns

During the past decade, the cost, color performance, light output, efficacy, reliability, lifetime, and manufacturability of SSL technology has greatly improved. For example, the dollars per kilolumen cost of LED packages has declined at a rate of 25 percent per year since 2005. The DOE estimates that LED lighting packages will reach their maximum efficacy, defined as the desired illuminance level and lighting quality at the lowest practicable energy input, of around 250 lm/W by about 2020, up to 15 times that of incandescent lighting.

In spite of these improvements, LED technology as applied to street lights has many of the problems experienced with traditional street lighting as well as some additional issues:

› Comparatively high purchase cost

The current purchase cost of LED lighting products is higher than standard options and varies widely, with good quality products at a cost premium. However, the DOE reports that the cost per lumen of LEDs falls by a factor of 10 every decade while the amount of light generated increases by a factor of 20. From 2009 to 2010, the prices for warm white LED packages declined by half, from approximately \$36 to \$18 per thousand lumens (kilolumens/klm). Prices are expected to fall to \$2/klm by 2015. When operational costs, such as electricity, maintenance, and lamp replacement, are considered, the overall value of LEDs rise.

› Early technology

LEDs have been used in outdoor lighting applications for less than 10 years. As such, they have a short history over which to benchmark their performance.

› Thermal management

While LEDs will not burn skin like some lighting products, only 20 to 30 percent of the power created by white LEDs is actually converted into visible light (lumen/lm); the rest, 70 to 80 percent, is converted to heat. Excess heat affects both the short- and long-term performance of LEDs. Amber and red LEDs are the most sensitive colors while blue is the least. As a result, the short-term (but reversible) effects of overheating include color shifting in addition to reduced light output. The long-term effects are accelerated lumen depreciation and a shorter useful life.

LED lights include heat sinks that are often integrated into the design of the fixture, for example converting the chassis into a heat diffusing element. Higher quality LED products will have a better heat diffusing component. Thermal management of high-power LEDs is a priority for solid-state lighting (SSL) research and development.

› Inconsistent color

The need for color consistency spans all illumination technologies. With LEDs specifically, color (including white) is produced by mixing red, green, and blue LEDs. The wavelength distribution of red, green and blue LEDs is narrow, which allows for a very pure, saturated color. However any shift in the dominant wavelength, particularly with green, will create color inconsistency. It is impossible for manufacturers to produce uniform color points in white LEDs. Manufacturers overcome this issue by sorting their LEDs into



Glare produced by LED streetlights as a result of poor fixture design

color bins based on identical or very similar specifications for color and flux. Customers may then specify from which color bins they want to purchase. Reputable LED manufacturers provide binning so that LED fixtures bought at one time will be identical to LED fixtures coming off of the production line at any other time. Light fixture customers who use a wider collection of color bins will be able to purchase their LEDs at a lower cost than those who are restricted to a single bin.

› **Glare**

Glare is an issue with LED street lighting. The RCI research team's literature review and interviews with manufacturers and municipal agencies in cities with LED replacement projects indicate that the emphasis is being placed almost entirely on energy savings, to the exclusion of visual quality issues. The substantial glare caused by LEDs is not typically included as a measurable criteria in evaluation processes, and when it is, the tools of measurement are inadequate. As a result, glare persists as an issue.

› **Measurement**

It is very difficult to use common light measuring tools to measure LED lighting accurately, especially luminance (brightness). As a result, the performance quality of LEDs is often overstated.

› **Evaluation**

LED streetlights often look better to the public when compared with HPS HID street lighting, and this is why most sales of LED street lighting use the orange hued HPS HID lighting for comparison, to create a negative bias against HID lighting. If the comparison were between MH HID (Metal Halide), the HID would often win the comparison, because its color accuracy is similar to LED and many HID luminaires are not as bright as LED luminaires, thus producing less glare. And there are problems with street-based

opinion surveys of lighting. The public is informed that LEDs save energy and are better in quality (often false) and that they are more accurate in color (often false). This is why the CMU team was careful to evaluate glare for LED luminaires and to select a color range that pleasantly renders colors at night.

› **Energy intensive production process**

In contrast to HPS, MH, and induction bulbs, LEDs have a much longer life, do not contain mercury, lead or other toxic chemicals, and are completely recyclable. This translates into less localized hazardous waste at the end of the product's life cycle. However, the LED production process is energy intensive and does include dangerous chemicals in the manufacture of its semiconductors. Moreover, the majority of LEDs are produced in countries with significantly lower standards regarding labor rights and environmental standards.

In spite of this production issue, a 2009 life cycle analysis (LCA) of four lighting technologies, including LEDs, conducted by the Mascaro Center for Sustainable Innovation at the University of Pittsburgh, found that LEDs remain the better choice in terms of overall environmental impacts.

› **Overlooked potential**

While architects and artists are exploring the use of LEDs and organic light-emitting diodes (OLEDs) in building skins and building facade screens, cities adopting LED street lighting technology are not using its unique and beneficial characteristics to its fullest potential. These cities typically ignore additional applications such as dimming, variable color treatment, and emergency communication functions. The aesthetic and placemaking potential of LEDs has also generally been overlooked.



New York City street by night



LED and HPS lighting comparison

Lighting Standards in the U.S.

In the United States, local roadway lighting is governed by local codes, and state and Federal roadway lighting is regulated by the respective state and Federal departments of transportation (DOTs). State roadways that travel through a municipality are subject to local standards. Cities are not required to have lighting codes but many have language on lighting in their regulatory documents, including the City of Pittsburgh as of March 2011.

Roadway lighting standards are based almost exclusively on vehicular traffic safety considerations. Benefits of street illumination for drivers include easing the flow of traffic, reduction of nighttime accidents, visibility of adjacent uses, and general way-finding assistance. In rural areas and on highways, street lights are not normally used to illuminate the road because vehicles have headlights. Rather, street lighting is used to highlight hazards outside of the headlight's beam and reveal signage. In riskier environments, such as urban streets and intersections where there are pedestrians and cyclists, street lights take on a different role.

Perhaps due to the cultural dominance of drivers' interests in the U.S., traffic planning in many cities prioritizes the facilitation of vehicular traffic above all other modes. The infrastructure needs of pedestrians and cyclists, such as crosswalks, bikeways and indeed safe lighting, are often overlooked. For example, in many cities, there are no minimum lighting requirements for sidewalks, only for roads and parking garages. A more holistic and equitable approach to roadway lighting would include illumination from curb-to-curb, intersections, tunnels, bridges, and parking facilities, as well as sidewalks, pedestrian and cyclist pathways, and trails.

Municipal lighting regulations and codes are typically based on the American Association of State Highway and Transportation Officials (AASHTO) guidelines.

› **American Association of State Highway and Transportation Officials (AASHTO)**

The American Association of State Highway and Transportation Officials (AASHTO) provides guidelines for street lighting based on traffic volumes and other criteria, as well as for luminaire design and construction. Its primary publication is the *Roadway Lighting Design Guide* (2005), an update to the 1984 *An Informational Guide for Roadway Lighting*. Cities may also look to the following resources for additional guidance.

› **Illuminating Engineering Society of North America (IESNA)**

The Illuminating Engineering Society of North America (IESNA) has two publications: the 10th edition *Lighting Handbook* (2011) and *American National Standard Practice for Roadway Lighting*.

› **U.S. Department of Transportation, Federal Highway Administration (FHWA)**

The United States Federal Highway Administration's (FHWA) study on lighting design concepts is the *Roadway Lighting Handbook* (1978, 1983).

› **International Dark-Skies Association (IDA)**

The non-profit advocacy organization International Dark-Skies Association (IDA) has several free publications including *Municipal Guidelines for Lighting in the Right-of-Way* (2008) and *Outdoor Lighting Code Handbook* (version 1.14, 2002). The IDA and the Illuminating Engineering Society (IES) recently released a *Model Lighting Ordinance* (MLO). The MLO is a template free for use by municipalities in developing outdoor lighting standards that reduce glare, light trespass and skyglow.



Cobra Head



Shoebox



Acorn



Pendant



Globe



Shoebox fixtures



Acorn fixtures

Existing Infrastructure

The City of Pittsburgh's nearly 40,000 street luminaires are owned, operated, and maintained by the City. Energy is supplied by Duquesne Light Company at a flat rate based on wattage. The wooden poles used for mounting the majority of the City's street lighting fixtures are owned and maintained by Duquesne Light or the local telephone company, Verizon. All steel poles and decorative luminaires are owned and maintained by the City. All streetlights are Type 3 Distribution and their on/off function is controlled by photo cells. Most luminaires are on a 120 voltage circuit, with some on a 240 voltage circuit. There are 200 metal halide (MH) 100 Watt (W) lamps in use and two LED installations along Grandview Avenue on Mount Washington and Walnut Street in Shadyside. Manufacturer-donated LED fixtures are also installed in three large city parks. All other bulbs are high-pressure sodium (HPS). HPS wattages are mostly 70 W, 100 W, and 150 W, with some 250 W and 400 W. The spacing of poles varies.

There are five main street light fixture types currently in use in Pittsburgh:

› **Cobra Heads**

High-mast GE cobra heads are found on neighborhood streets and along commercial roads. Cobra heads are typically affixed at a height of approximately 25' to wooden poles via 4' to 8' arms. Cobra heads make up approximately 93 percent (37,000 units) of all fixtures in Pittsburgh.

› **Shoebboxes**

Full cut-off down lighting shoebox luminaires are found at selected intersections in Downtown Pittsburgh. These are either free-standing steel pole luminaires or are attached to traffic lights at a height of approximately 25' to 30'.

› **Acorns**

Acorns are post-top fixtures mounted on steel poles at a height of 15', 12' or 10'. They are used as pedestrians-scale lighting in business districts, and their style harkens back to 19th century gas lanterns.

› **Pendants**

Also called teardrops, pendant fixtures are mounted on steel poles at approximately 25' to 30' from the base.

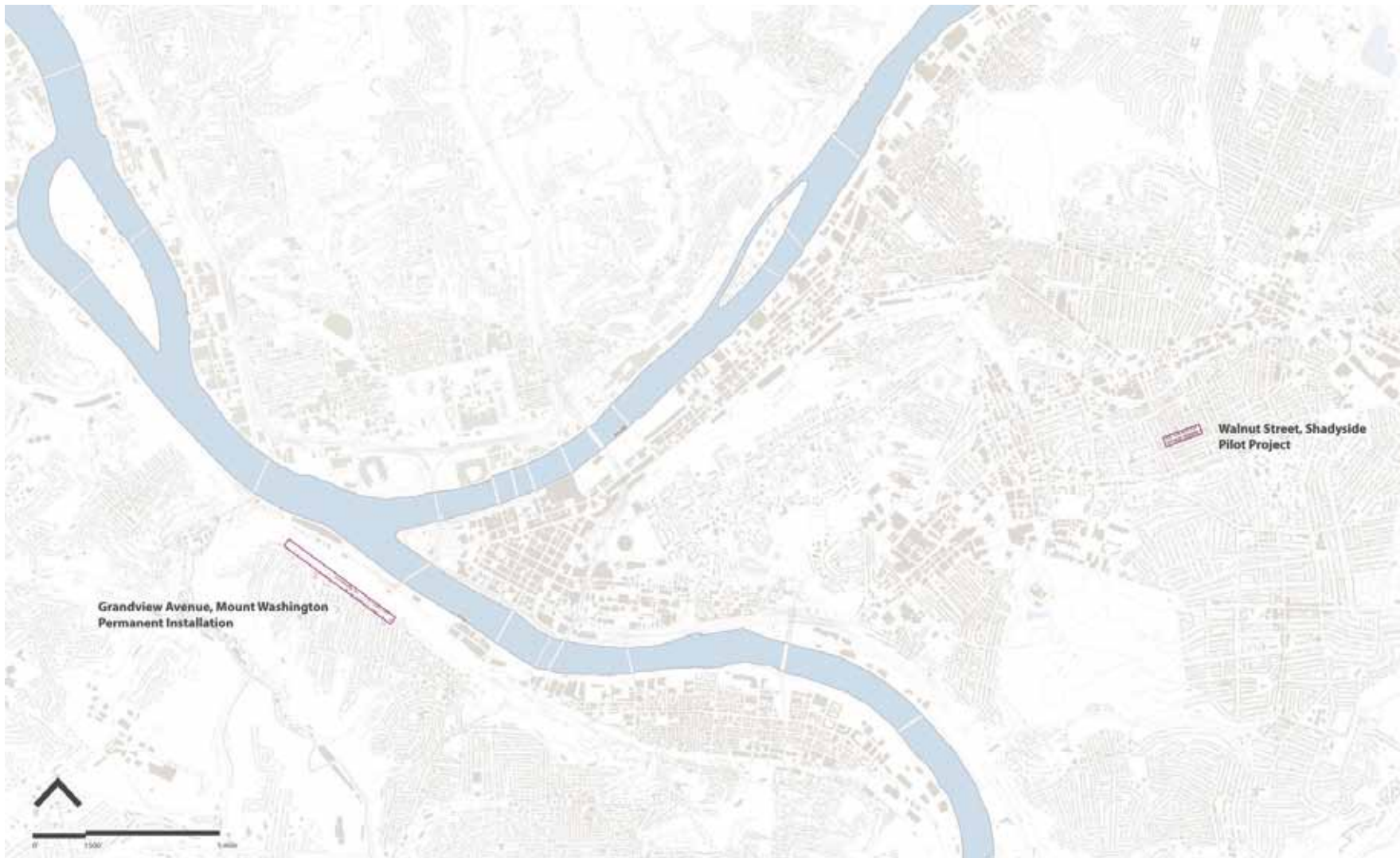
› **Globes**

Globe lights are post-top fixtures mounted at a height of 15', 12', or 10'. Depending on the fixture, there may be one to eight globes mounted on one pole. They are often used for pedestrian scale lighting in business districts, including downtown Pittsburgh. Locally they are referred to as "lollipop" fixtures.

There are an additional 500 to 1,000 other fixture types in use throughout the city. The main fixture manufacturers used are GE, Holophane, King and Sterner. Pole manufacturers are Sterner, Valmont, Holophane and Union Metal.

LED Use in Pittsburgh

The City of Pittsburgh began retrofitting all traffic signals and accompanying crosswalk signals with LED light fixtures in 2006. To date, the City has updated 3,668 traffic lights at nearly 800 intersections with LED fixtures, resulting in 958,945 kWh of annual energy savings and a CO₂ reduction of over 1,000 tons.



Current LED use in Pittsburgh

Since 2008, the City's Office for Sustainability has been investigating the use of LED technology for street lighting in two pilot projects, one permanent LED installation, and plans for the LED retrofit of 3,000 cobra head fixtures in 30 business districts by early 2012.

› **Walnut Street Pilot Project, Shadyside**

In May of 2008, the City of Pittsburgh installed a LED street light pilot project using existing globe lights on one side of Walnut Street in Shadyside. This project allowed for the public to compare the quality of light between two technologies, mercury vapor (MV) and LED.

› **South Side Pilot Project**

South Side pilot project? 2010? [UNABLE TO OBTAIN MORE INFORMATION]

› **Grandview Avenue Permanent Installation, Mount Washington**

Grandview Avenue is an important focal point for the City of Pittsburgh. Many iconic images of Pittsburgh include the Mount Washington hillside and inclines, or feature the Golden Triangle as viewed from Grandview Avenue atop Mount Washington.

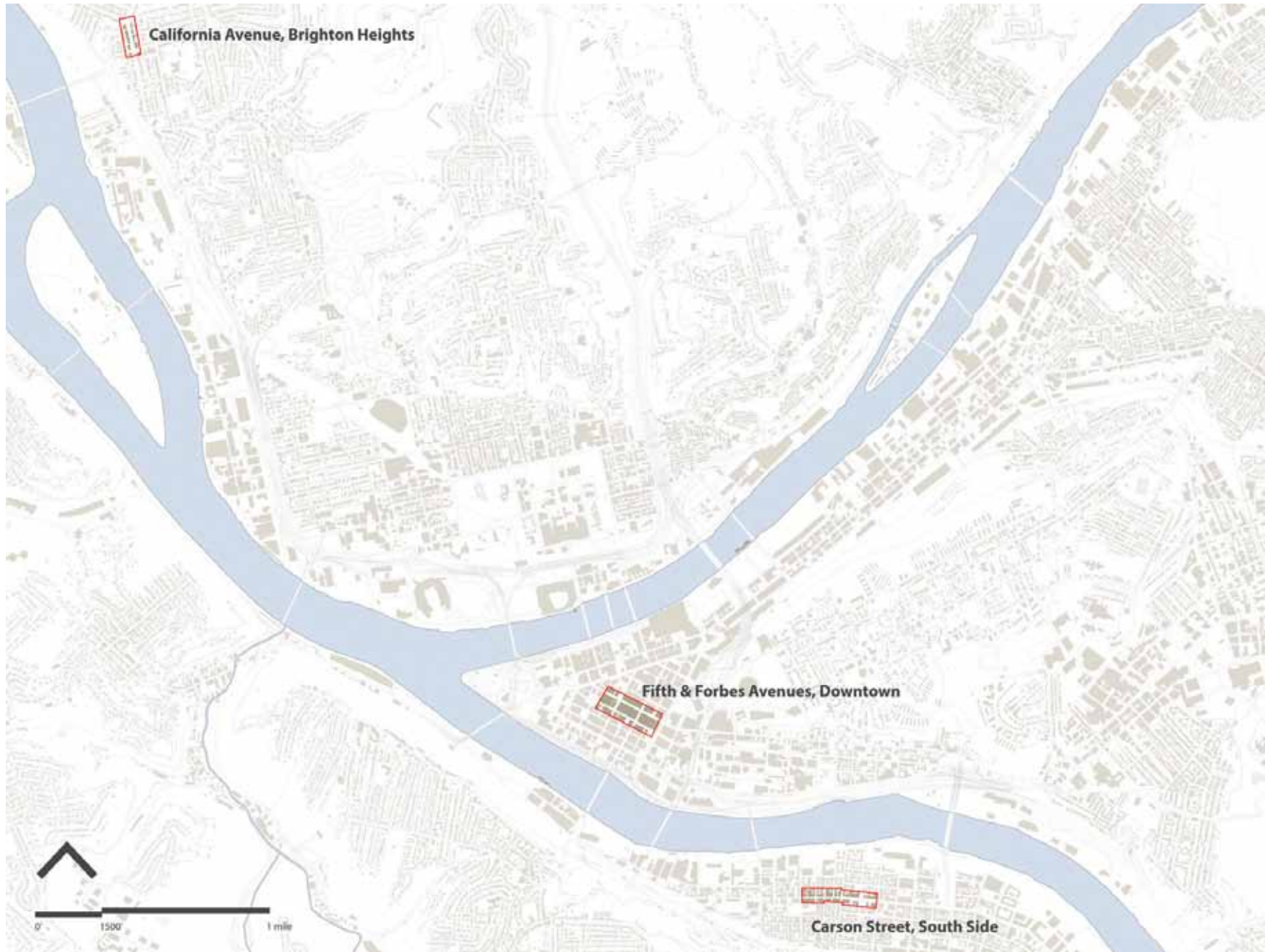
With the mercury vapor (MV) lighting along Grandview Avenue aging, the City of Pittsburgh decided to replace approximately 85 street lights from McCardle Roadway to Shiloh Street with more energy-efficient luminaires. A \$400,000 grant from Senator Wayne Fontana allowed for the testing of three lighting systems: 70 W metal halide (MH), 85 and 165 W induction, and 47 and 75 W LED.

Ultimately, the LED option was chosen. Fifty-one globe lights were replaced with the new City standard acorn luminaires and 34 globe pendants were replaced with new City standard pendant luminaires on new poles. RCI research team members from Orfield Laboratories in Minneapolis performed photometric measurements of this LED installation in February, 2011, the results of which can be found later in this study.

Pittsburgh Lighting Code (2011)

In March 2011, the City of Pittsburgh City Council approved the city's first street lighting ordinance, Title Twelve-Lighting Code of the Pittsburgh Zoning Code. The legislation is intended to ensure minimum standards for street lighting and the equitable distribution of street lighting across neighborhoods during the upcoming LED conversion process. The Code was written by Pittsburgh-based Powerhouse Design Architects and Engineers Ltd. It follows the American Association of State Highway and Transportation Officials (AASHTO) and Illuminating Engineering Society of North America (IESNA) standards, as well as sustainable practices outlined in the *Pittsburgh Climate Action Plan*.

The City is also embarking on its first Comprehensive Plan, PLANPGH, a vision for Pittsburgh's development over the next 25 years. Urban lighting will be addressed through both the PLANPGH DESIGN (urban design) and PLANPGH MOVE (transportation) public consultation processes. Each of those components will produce a manual that will address the design of the public realm, including street lighting.



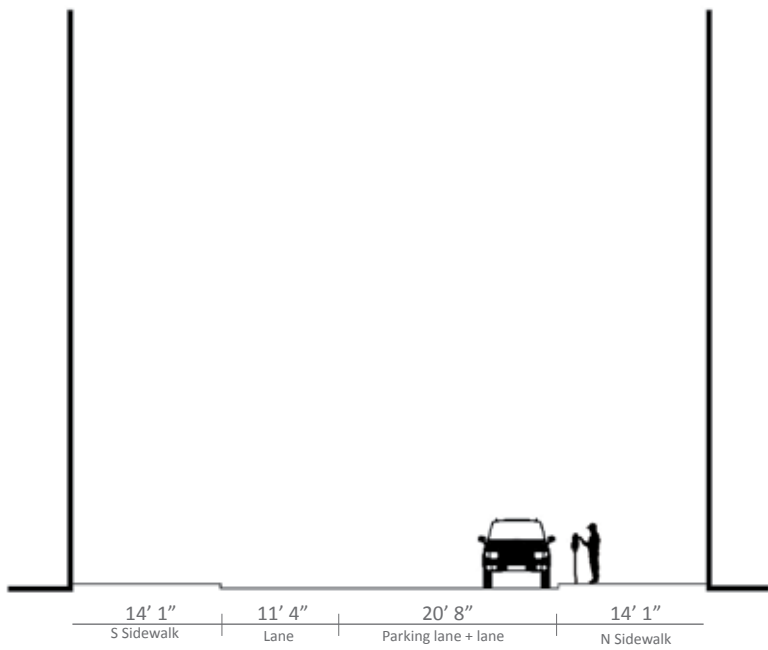
Business District Case Studies

Three test sites that represent the range of business district lighting conditions in Pittsburgh were selected for a more detailed understanding of existing street lighting conditions:

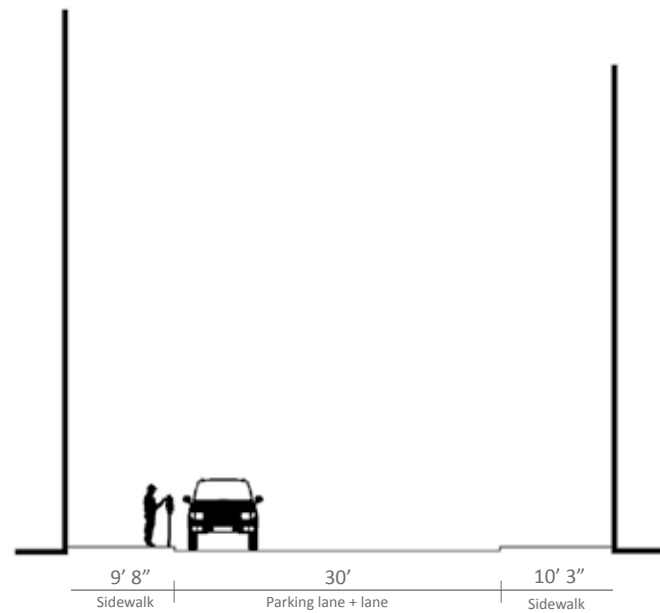
- › Fifth and Forbes Avenue, Downtown Pittsburgh (Central Business District)
- › Carson Street, South Side (Mid-Size Business District)
- › California Avenue, Brighton Heights (Small Business District)

The sites were subjected to photometric measurements by RCI research team members from Orfield Laboratories in February 2011. Focus group research on attitudes about business district street lighting were conducted in April 2011 after preliminary findings were presented to City Council.

On the following pages the existing conditions of the three business districts are documented.



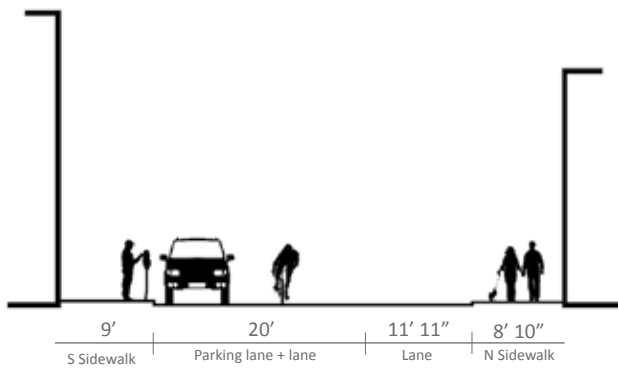
A Fifth Avenue



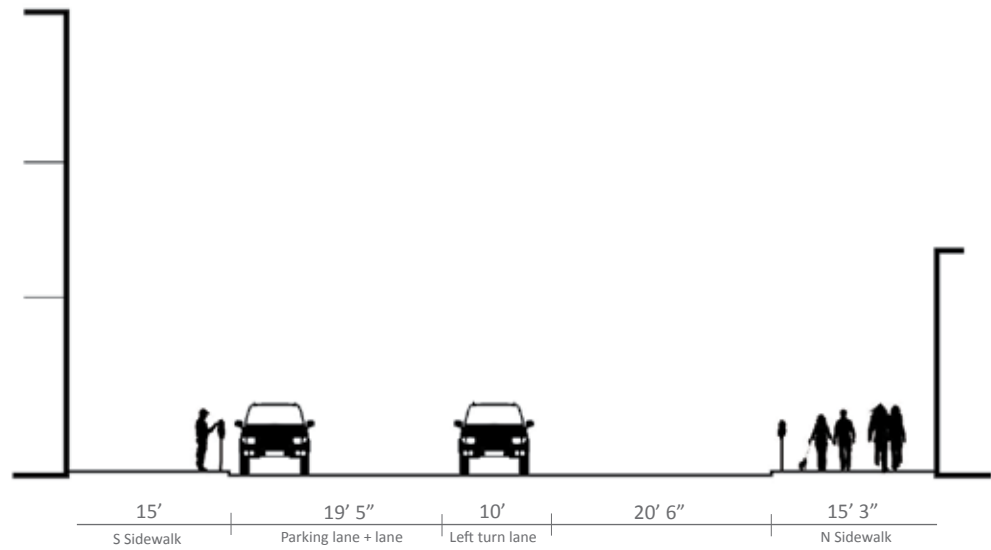
B Forbes Avenue

Central Business District: Fifth and Forbes Avenues





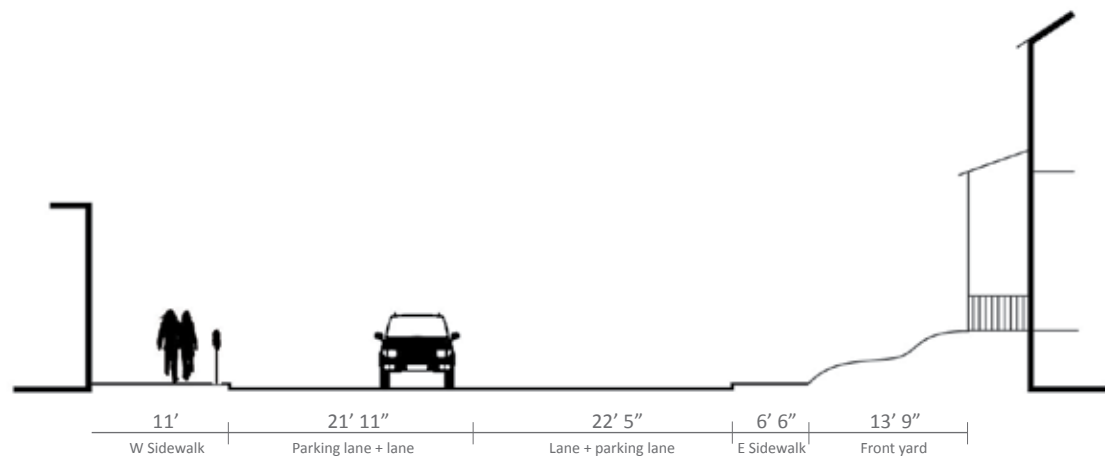
A East Carson Street (west of 17th Street)



B East Carson Street (east of 17th Street)

Mid-Sized Business District: Carson Street





A California Avenue

Neighborhood Business District: California Avenue

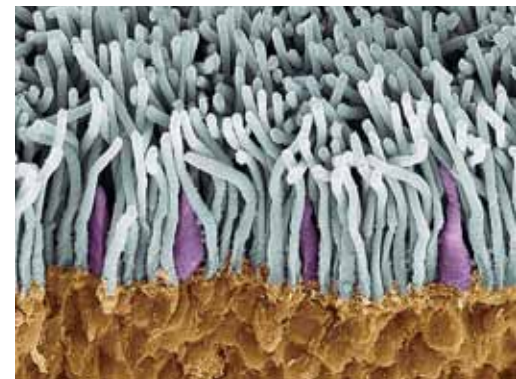




Undilated pupil, daylight



Dilated pupil, night



Rods and cones

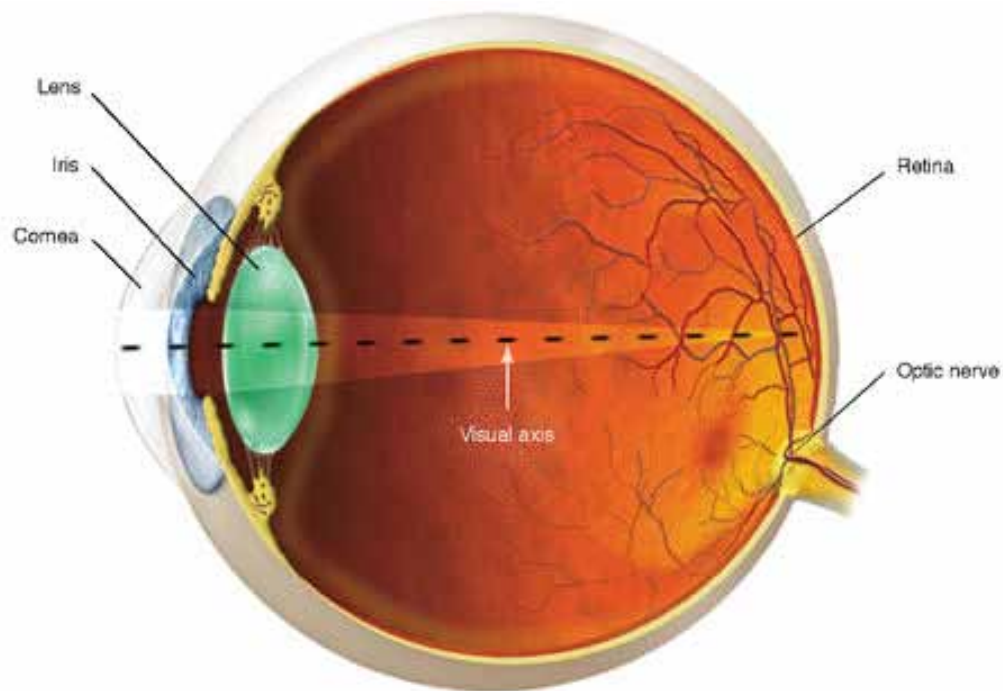


Diagram of the eye

Modes of Human Vision

Humans can see in drastically different lighting conditions, from near total darkness to bright sunlight. Human vision is enabled by three primary modes, each of which uses the eye's complementary system of cone cells or rod cells (or a combination of both):

- › In normal light, where the luminance level is 1 to 106 candelas per square meter (cd/m^2), cone cells dominate human vision (photopic vision) and there is good visual acuity and color discrimination
- › In very low light, monochromatic vision (scotopic vision) takes place
- › In semi-dark conditions, such as a full moon or a heavily-lit commercial district, a combination of photopic and scotopic vision takes place (mesopic vision)

How the Human Eye Sees at Night

The eye is an extraordinarily complex sensory organ. While images projected onto human retinas are two-dimensional and upside-down, the human eye is able to perceive a three-dimensional image, right-side up. Human vision also allows for the ability to perceive distance through "binocular" vision.

In addition to the ability to see the world in three-dimensions and to have depth perception, the healthy human eye can see in an incredibly wide range of lighting conditions. The sensitivity of the human eye to such extreme levels of light varies across nine orders of magnitude or a difference of 1,000,000,000. At any given moment, the eye can only sense a contrast ratio of about 1,000.

The eye has three mechanisms to compensate for changing illumination levels:

- › The pupil dilates or contracts to let in more or less light depending on available light

- › The eye switches from cone cells under photopic (abundant light) conditions to rods which are more effective under scotopic (dim) conditions
- › Rod cells change their sensitivity to light according to illumination levels in a process of visual adaptation

The process of visual adaptation from bright light to complete darkness takes about 20 to 30 minutes, and from complete darkness to bright light around 5 minutes. The difference in adaptation time is due to the rods' greater sensitivity to light. During this time, the eye's perception of color changes as well, since cones are better suited to seeing a wide range of color.

How Glare Affects Vision

Glare is a condition experienced by the eye. It is influenced by the eye's adaptive ability and the angle between an object of focus or task and the glare source. The human eye has not adapted over time to deal with nighttime glare since it does not exist in natural nighttime conditions. Glare is often divided into two types: discomfort glare and disability glare. Discomfort glare creates an instinctive reaction to look away from a bright light source or difficulty in seeing an object or task. Disability glare makes the task impossible to view. A camera flash is an example of discomfort glare while the experience of being unable to look forward when driving westward at sunset is an example of disability glare.

"Night blindness" (Nyctalopia) is a condition in which the eye sees poorly in dim light and has difficulty adapting from bright light to low light. Night blindness is experienced disproportionately by men. Its causes can be congenital, disease, or cataracts, or it can be the result of refractive "laser vision correction" surgery.



Overlapping ovals of light

Emphasis on uniform street lighting

How Uniformity of Illuminance Affects Vision

At night, the human eye loses the advantage of color and contrast, affecting depth perception and peripheral vision. Lighting and shading--the way that light reflects off of an object and the shadows cast by objects--become important cues for the brain to determine the shape of objects and their position in space.

Lighting standards and many lighting regulations require uniformity of illuminance between poles in a misguided attempt to replicate daylight conditions and improve visibility. However, the focus on uniformity in street lighting in general reduces visual acuity by eliminating contrast and increases glare by requiring light sources to be affixed higher up on the pole to shed light evenly across its lightshed. For example, oncoming headlights are more visible against a black background than a grey one. The contrast provided by uneven light patterns creates greater awareness of the oncoming vehicle. This is supported by public visual preference studies in which overlapping ovals are preferred over a uniform lighting pattern.

Age-Related Vision Loss

As people age, their vision inevitably changes. Changes usually involve the eye itself, the surrounding muscle and the central nervous system. Commonly, the lens of the eye grows increasingly opaque and rigid, creating a cataract, and the muscles surrounding the eye weaken. The Centers for Disease Control and Prevention (CDC) estimates that by 2020, the number of people aged 40 or older with cataracts is expected to rise to more than 30 million. While cataracts are treatable with surgery, their onset is often slow, resulting in many undiagnosed cases and impaired vision. Normal vision changes associated with aging include:

› **Reduced visual acuity**

Normal visual acuity is measured as 20/20. A change from 20/20 to 20/100 means that a person will need to be 20 feet from an object that a person with 20/20 vision can see at a distance of 100 feet. Glasses and contact lenses can correct vision.

› **Diminished accommodation**

This is the diminished ability to focus on objects due to muscle weakness, making it difficult to shift focus from objects that are near to distant.

› **Decreased color vision**

Decreased perception of color may occur as the lens of the eye becomes more opaque. This can affect depth perception if the color of different objects is the same or similar (typically problematic are greens and blues).

› **Slowed rate of visual adaptation**

The need for greater illumination increases as the lens becomes thicker. This also affects the rate of visual adaptation from darkness to bright light and vice versa. Normal visual adaptation from darkness to bright light, for example from darker road conditions to sudden glare, takes around 5 minutes but will take longer for older persons.

Implications for Street Lighting Design

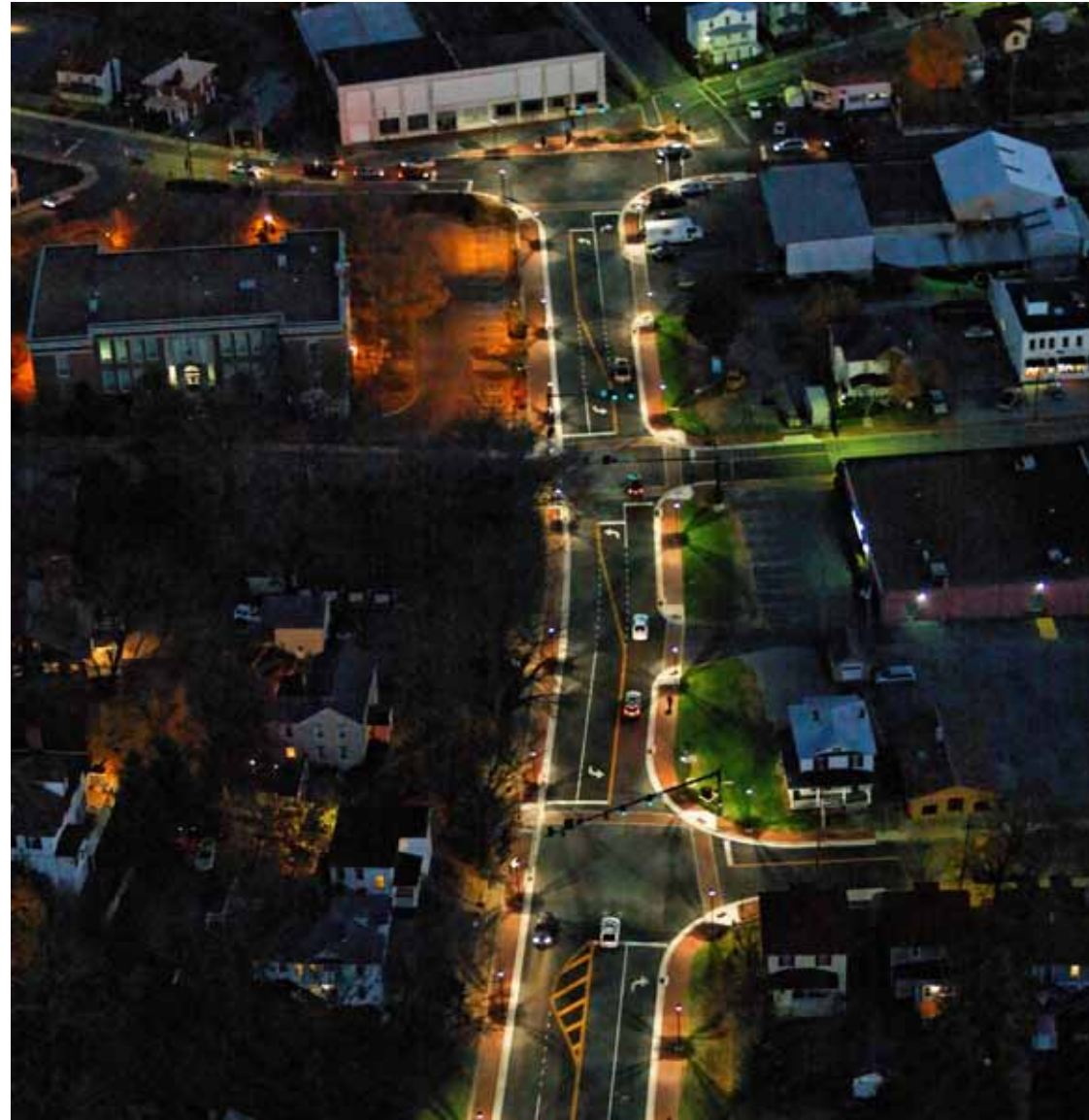
It is not possible to try and replicate photopic conditions at night. Rather, it is better to eliminate glare and to provide the minimum lighting levels possible in an attempt to meet the visual comfort probability, defined as the percentage of people that will find a certain scene (viewpoint and direction) comfortable, with regards to visual glare.



Streetlights on during the day, Pittsburgh 1940

A century ago, a pall of smoke lay so thick over town that streetlights burned all day. As Pittsburgh continues an evolutionary course that has taken it from trading post to transportation hub to industrial goliath, we salute its reinvention into one of America's most scenic and livable communities. In the life of a city, there's nothing more beautiful, or inspiring, than a renaissance.

USA Today



Highlighting main corridors for wayfinding

Overview

There is a wide range of important aesthetic, performance, operational, and ethical decisions that must be made when deciding on a street lighting package and installation configuration. These include determining the lighting level required to accomplish the objective; balancing the cost, energy efficiency, maintenance regime, and life cycle of the product chosen; choosing a fixture and pole style; addressing sky glow and light trespass through cut-off options; consideration of control systems such as motion sensors, timers, or light sensors; deciding on a light curfew if appropriate; deciding on pole height and spacing; and evaluating the effect of lighting on nearby ecological habitats, such as parks, greenways, and riparian corridors.

This study takes the position that street lighting in business districts is about more than lighting the roadway to the benefit of vehicular traffic. The entire public right-of-way, including vehicular travel lanes, bicycle lanes, sidewalks, and setbacks, along with adjacent buildings, structures, and materials, must be considered as a whole. Opportunities for placemaking, wayfinding, and event lighting should also be considered.

Placemaking and Wayfinding

Street lights are but one of the many nighttime lighting sources found in a city. Additional urban lighting sources can be found in the public right-of-way and on private property, including monument and civic architecture facade lighting, storefront lighting, marquees and storefront signs, architectural lighting on building facades, parking lots and garages, public space lighting, sports field lighting, organic light-emitting diode (OLED) building “skins,” security lights, non-digital billboard signage, and digital billboards. All of this lighting can be regulated to reduce glare and an overlit urban environment, and to reduce night sky light pollution.

Beyond regulation, there is the potential to harness the variety of lighting sources more proactively by considering how they may interact more harmoniously by developing a city-wide Lighting Master Plan.

When it comes to street lighting specifically, there are many opportunities for contributing to the aesthetic quality of a street. The City of Pittsburgh has recently branded itself as “Pittsburgh is Art,” with annual festivals, regular gallery crawls, and other celebratory occasions focused on the creative industries. Light is also art; it can be used as an additional material with which to frame space, transform buildings, and create magical and unique place-based experiences.

The special properties of light, rhythmic placement of luminaires, and luminaire style has the potential to enhance a business district or residential neighborhood, as well as individual buildings and structures, public spaces, pedestrian and cyclist pathways, bridges, parkways, and waterfronts.

› Intensity

Using control systems, the intensity of street lights can be adjusted to not only save energy but also to highlight certain streets and provide cues to people that a particular street is residential (less bright) or commercial (brighter). Intensity of light can also be moderated to indicate activity during special events. A further use of intensity is to provide illumination for emergency or evacuation situations.

› Color Temperature

Color temperature in an LED array that can range from 2,800 (a very warm yellow light) to 6,500 Kelvin (a very bright, cool white light). The interplay between color temperature and surrounding materials

Use of color temperature and color changing for lighting the Chateau Frontenac (Quebec) and Pittsburgh's Festival of Lights accentuates building materiality and achieves placemaking through lighting design.



and landscape is highly contextual. By introducing dual color temperatures into a street lighting fixture, there is the flexibility to create a warmer or cooler mood in residential and commercial areas, depending on preference and surrounding material colors. Contrasting color temperatures can also be used to emphasize focal points to dramatic effect.

› **Color Changing**

In addition to warm and cool color temperatures, LEDs also come in red, amber, blue, and green, allowing for a wide range of color mixing. Colored lighting can be used to help with wayfinding and to render a special ambiance during celebratory occasions. A linear LED color changing accessory piece can be added to existing poles, or pedestrian-lighting can be colored. Static color can be used to direct the public along specified paths, such as a route bookended by important destinations, or to denote a gallery crawl. Linear color changing accessory pieces can also be programmed to create “chasing” color to signify special occasions or even emergency routes.

› **Focal points**

Focal points in the public right-of-way can be highlighted at various scales, depending on the viewpoint. They can be as small as decorative cornices on a building or as large as river edges and escarpments. Creating nighttime focal points aids with wayfinding by drawing attention to unique buildings, public art, cultural and natural artifacts, and public spaces seen from afar, up close, and along the way. Color temperature can further help define focal points.

Additional Aesthetic Considerations

› **Materials**

The material context should be considered when choosing a color temperature for street lights. Warm toned materials, such as sandstone and brick, are flattered by warmer white light while cooler toned materials, such as granite and steel, will appear more beautiful with whiter light. The color of ground surface materials will also have an impact on illumination levels. For example, darker pavement color will absorb light while snow has a high reflective quality. A benefit of LEDs is that the intensity of lighting can be dimmed when needed. Even rain can have an effect on illumination of the street as light reflects off dark, rain-covered asphalt, creating glare.

› **Facade lighting**

Facade lighting can be used to highlight interesting architectural details and to draw attention to buildings that have special meaning, such as civic and heritage buildings. However when it comes to street lights, it is important to limit the amount of light that trespasses onto adjacent buildings for a number of reasons. Light trespass can be a serious annoyance for residents whose interior space is affected by street lights with insufficient cut-off. Light trespassing on a building may also interfere with a property owner’s attempts to control the nighttime aesthetics of their building via their own architectural lighting scheme. Street lights that wash the facades of buildings only serve to contribute to an overlit nighttime environment, the waste of energy, and the reduction of the overall lighting quality.

In their article, “Close encounters with buildings”, authors Jan Gehl, Lotte Johansen Kaefer, and Solvejg Reigstad explain the dynamics of pedestrian-scale facade design. At 3 feet from a

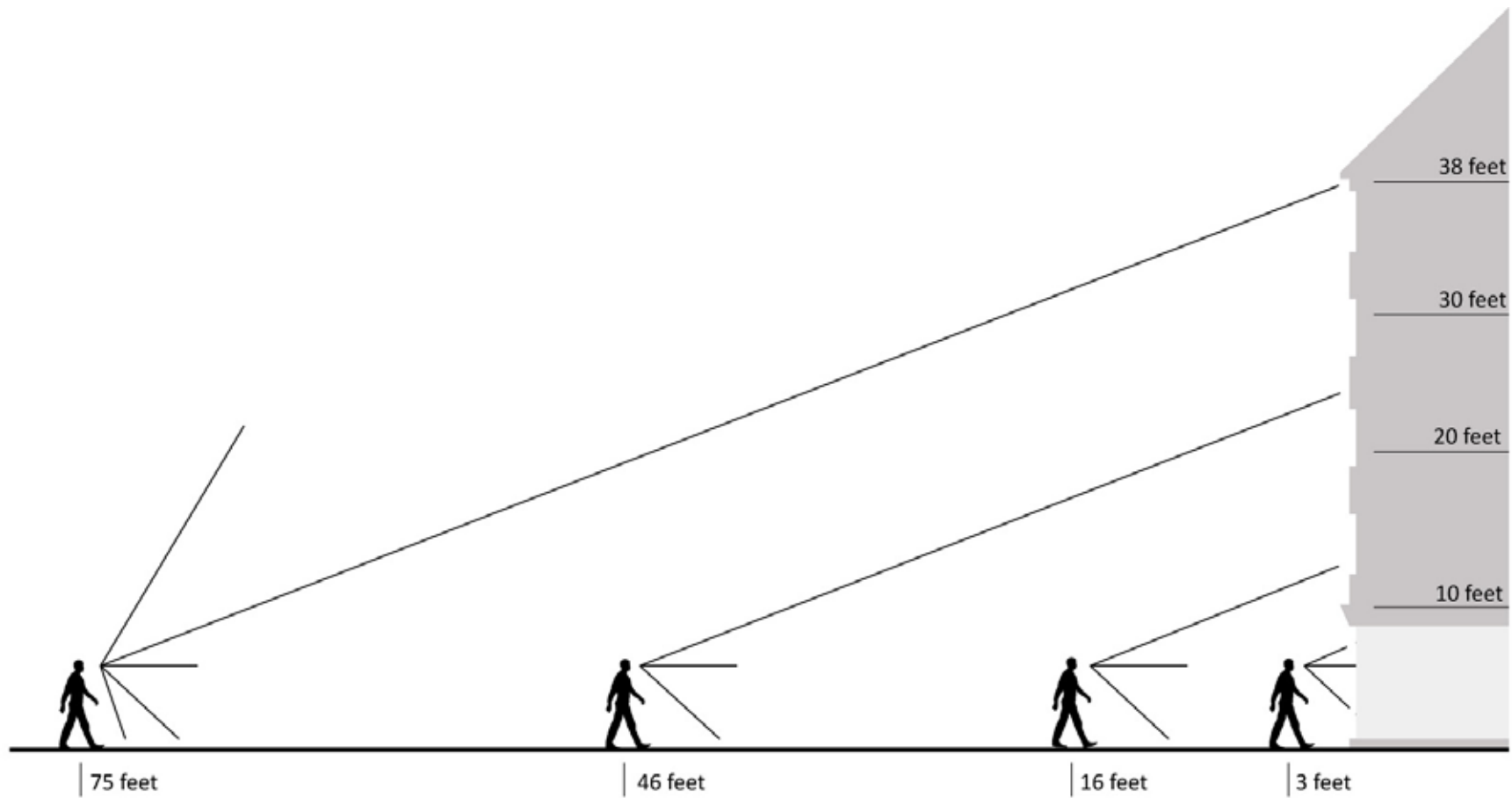


Diagram from "Close encounters with buildings"

building, pedestrians can see less than 10 feet of the building facade. At 16 feet, pedestrians see about 11 feet high up a building facade. As such, there is no need to illuminate the upper floors of building facades for security reasons. Guidelines for sustainable facade illumination should be made available to commercial and residential property owners, as well as businesses.

› **Luminaire style**

The choice of luminaire styles is a combination of illumination performance standards, the quality of product, and its aesthetic contribution to the streetscape. Luminaires that replicate the 19th century gas lamps, such as acorn fixtures, are often favored for historic districts and pedestrian-oriented lighting. However, these luminaires create dangerous levels of glare for motorists as explained in the next section on performance considerations. Contemporary styles often provide better visual performance and have been successfully integrated into historic environments. Luminaires and poles can also hold signage, banners, flowers, or vegetation.

› **Standardization**

As reported elsewhere in this report, the City of Pittsburgh currently uses five types of luminaire fixtures for street lighting: cobra heads, pendants (or teardrops), shoeboxes, acorns, and globes. In the 1990s, the City adopted standard street lighting fixtures for Downtown, commercial, and riverfront applications with the intention of creating a definitive set of universal lights while minimizing the number of lamp types.

Current design thinking has evolved from that position. Distinctive street lighting fixtures and poles are now used to identify special locations and support placemaking. As an example, some business

districts have replaced high-mast cobra head fixtures with teardrop fixtures and/or acorn fixtures for sidewalk illumination. While teardrop fixtures signify a more distinguished design with a semi-historical appearance, and acorn fixtures provide sidewalk-scale identity and a nostalgic design, both fixture types disperse light in all directions, are inefficient, and produce glare and light trespass. The City's new Comprehensive Plan's Design Manual is intended to incorporate street lighting design standards and their place-making qualities, while attempting to reconcile the desire for more aesthetic luminaires with the realities of cost and maintenance for the Department of Public Works.

Performance Considerations

› **Varying viewpoints**

The pedestrian viewpoint is different from that of the driver or cyclist. Lighting for each of these public right-of-way users should be considered separately with standards for fixtures of varying height and lighting intensity.

› **Illumination levels**

In the 1930s, with the spread of electrification and the consolidation of utilities, street lights became a convenient way to off-load excess energy from the grid at night when power demands dropped significantly. This intentionally inefficient system became the norm for nighttime outdoor lighting levels, a standard that has not been revised since, even though the need for off-loading excess energy ended in the 1970s. What is now assumed as a safety measure is in fact the forgotten remnant of an obsolete energy practice in a context of reversed energy availability.



Light trespass and glare from bare lamps

Another factor is the surrounding reflective value of materials, such as sidewalks, and weather conditions, particularly rain and snow. Reflective surfaces impact illuminance, increasing available light by up to three times. When sensors and control systems are in place, lights can be dimmed accordingly.

› **Glare and light trespass**

Glare refers to the difficulty of seeing in the presence of bright light, such as direct or reflected sunlight or artificial light. “Light trespass” is measurable light that falls off the right-of-way; for example, light that extends onto the facade of a building, into windows, or into the sky.

Currently, luminaires come with varying degrees of cut-off angles, from no cut-off to a full cut-off (180 degrees). A full cut-off luminaire is one that allows no direct light emissions above a horizontal plane through the luminaire’s lowest light-emitting part. Full cut-off does not allow any of the light to escape the fixture above 90 degrees and is the standard promoted by the International Dark-Skies Association, but full cut-off does not necessarily eliminate glare from the ground. Bare lamps, such as the light source within an acorn fixture, have no cut-off and shed light indiscriminately. These are not only wasteful of energy; they also create blinding glare and are a cause of night sky light pollution. The City of Minneapolis has recently banned acorn fixtures for these reasons.

To create uniformity of illumination along a roadway, or in some cases to reduce costs by using fewer luminaires, light fixtures are often mounted higher than is ideal. This results in a greater area of coverage for each luminaire, but the lack of adequate cut-off makes the light source more visible, thus creating glare.

When glare and light trespass are due to fixture design, they can be solved through the use of inexpensive reflectors on luminaire

heads to shield or diffuse excess light. Glare and light trespass are already being addressed in areas where excess lighting is a danger, for example around airports.

› **Uniformity**

When the goal of street lighting is to light a roadway continuously, such as in an urban context or on fast, multi-lane streets, traffic engineers have focused on creating consistent lighting along the route by placing bright lights on high poles at close, regular intervals. Wider placement of luminaires requires repeated eye readjustment and creates eyestrain and temporary blindness when entering and leaving light pools.

As with all street light types, LED luminaire design has often been influenced by lighting standards that require uniformity of coverage and brightness for the space between poles. However the focus on uniformity in street lighting in general reduces visibility by eliminating contrast, and increases glare by requiring light sources to be affixed higher up on the pole in order to shed light evenly across its lightshed. This also reduces the potential for energy savings by having brighter fixtures placed high on poles and closer together. A pattern of overlapping ovals is recommended by the RCI research team because it provides contrast and shading.

LED lighting manufacturers are legitimately promoting their products as energy saving lighting. Manufacturers are also promoting the ability of LED lighting to be more uniform than HID lighting, as the sources built into these luminaires can be more accurately aimed to provide uniformity. Yet many HID luminaires are lower in glare than many of the newer LED systems.

LED lighting has two uniformity problems. The first is that uniformity is often less energy efficient than non-uniformity. The second is that the visual metaphor that observers are used to is non-uniformity; that is, lighting that drops off between lights.



Color rendering of LEDs as compared to HPS

This provides what many lighting professionals consider to be a more spatially refined view of nighttime scenes. People are used to light-dark contrasts and shadows. Although it is easy to design high uniformity into lighting, uniform lighting has not been adapted in most preferred environments, such as homes, churches, auditoriums, museums, etc. Uniformity washes out contrast and shadows, and it creates less interesting environments.

It is the view of the RCI that the uniformity of LED street lighting results in higher glare, more energy use, and a poor human preference response.

› **Color rendering**

LED lighting is capable of adjusting color and color temperature. While lighting codes specify that street lighting shall be a white light, LEDs are capable of an infinite number of colors. Even white light has many variations, from warm to cool depending on color temperature. Most people are comfortable with lighting that ranges from 2,800 Kelvin (warm, equivalent to incandescent lighting) to 5,000 Kelvin (a cool bright light with some blue tinting, equivalent to metal halide lighting). Fluorescent lighting is around 3,800 Kelvin. The majority of people are comfortable with a color temperature of 3,500 Kelvin for street lighting as a good balance between warm and cool.

Safety officials are critical of HPS lighting as its orange light skews other colors, for example turning reds into brown, making critical repairs to color-coded electrical wiring in an emergency situation difficult.

There is mounting scientific evidence that suggests exposure to light at night is disruptive to the human endocrine system, as well as to the systems of other biological life. Human epidemiological studies and animal research suggests that normal circadian processes are reset by blue light wavelengths, halting

the tumor-suppression function of the hormone melatonin. This hypothesis is supported by the significantly higher rates of breast and colorectal cancer among night shift workers and studies with laboratory rats. It is also bolstered by the discovery in 1998 of a new photoreceptor in the eye that is especially sensitive to blue light. It is now suspected that desynchronized circadian rhythms due to nighttime light exposure may play a role in tumor-based cancers, diabetes, obesity and depression. In 2007, the World Health Organization (WHO) decreed night shift work as a risk factor for breast cancer.

While the link between cancer and exposure to night lights is still indirect, public health researchers in this area of study recommend reducing exposure to blue light at night, both indoors and outdoors, as a precautionary measure. For this reason, they favor HPS lighting because it has less blue light emissions. Thus, when considering LEDs, the recommendation is for fully-shielded light sources with a color temperature of 3,500 K or below.

› **Ambient light**

Moonlight and seasonal conditions can create significantly different ambient lighting conditions. For example, summer foliage on street trees can filter a certain amount of light, while in the winter barren trees allow light to pass more freely and snow-covered ground can reflect light. The moon orbits around the Earth on a 30-day cycle, reflecting sunlight from the parts of its surface hit by the Sun's light and creating varying levels of natural ambient lighting depending on cloud cover. Outdoor illuminance levels for a full moon on a clear night is .25 lux (or .25 lumen per square meter or 0.023 footcandles). A fully overcast sunset or sunrise yields 40 lux while illuminance levels at midday on a typical overcast day are between 10,000 and 25,000 lux. The brightest sunlight



Night lighting is often concerned with security. Floodlights (above) are often used but create glare and deep shadows.

Proposals to highlight pedestrian crossings (left) are part of the consideration for night lighting.



will generate up to 130,000 lux. Office lighting is typically set at 320 - 500 lux (320 - 500 l/m² or 29.8 - 46.5 footcandles). Researchers are now developing sensor-controlled lighting that can adapt light output according to varying natural ambient lighting conditions.

› **Safety**

A major task of street lighting is to increase safety for motorists and pedestrians, particularly at intersections where pedestrians may be crossing. A consistent concern is that high-mast street lights, particularly those garnished with HPS bulbs, do not adequately provide contrast between the pedestrian and the background. One approach to improving the illumination of pedestrians at crosswalks is to use bollard posts with linear light sources to illuminate the pedestrian. Metal halide fixtures have long been used at intersections because their better color rendering allows for better visibility and contrast. In addition to lighting, there are numerous other urban design techniques for improving the safety of pedestrians and cyclists at crosswalks.

Street lighting also has an impact on the ability of emergency and utility personnel to perform their work at night. Emergency personnel report having a hard time seeing color properly under HPS lighting. This is an issue when work crews must identify colored electrical wires, for example.

Another safety consideration is the effect of street lighting schemes on closed-circuit television (CCTV) systems. Many cities, including the City of Pittsburgh, have installed a CCTV cameras throughout the city for various purposes, including crime monitoring and homeland security. Cameras are located on buildings, light poles, and utility poles. In Pittsburgh, there are two types of cameras: homeland security and privately-owned. The City relies on privately-owned cameras to assist with crime, typically in partnership with neighborhood block groups. LED lighting, with its potential for bright light and glare, needs to be designed to be

compatible with the camera performance. In some cases, cameras may also need to be repositioned for enhanced views.

Safety officials generally prefer uniform light along the street, believing that uniform light eliminates shadows and adds to clarity. As a result, most lighting codes are written with uniformity objectives. However, as reported elsewhere in this study, the human eye requires shadows in order to perceive shapes and depth. While the use of bright lights is believed to reduce accidents, it actually creates dangerous conditions for drivers, especially when night vision is affected by sharp differences in illumination. Bright lights are particularly hazardous for older persons because the human eye's accommodation reflex slows with age.

Security lighting, such as harsh flood lights that wash over an area, often create blinding glare and deep shadows. While intuitively, it may seem that more lighting will result in less outdoor criminal behavior, studies do not support this belief. The bright light and glare created by severe lighting disparities actually impairs people's vision so that they are less able to take account of their surroundings.

Nighttime lighting does provide psychological comfort for society's more vulnerable members. When designed properly, lighting can be an effective tool in promoting outdoor safety. Crime Prevention Through Environmental Design (CPTED) researchers recommend that outdoor lighting be used to help with "natural surveillance" and "natural territorial enforcement" strategies. Specific tactics include:

- › Avoid poorly placed lights that create blind-spots for potential observers and miss critical areas
- › Ensure potential problem areas, such as stairs, entrances and exits, ATMs, bus stops, dumpster and recycling areas, are well-lit (but not overly lit)



Carbon Dioxide Emissions of Streetlights

Number of street and area lights in U.S.	131 million
Number of streetlights in U.S.	34.7 million
Metric tons CO ₂ per kWh	0.00718
Metric tons CO ₂ street and area lights	128,019,400
Metric tons CO ₂ streetlights	33,910,482

table from Mascaro Report (Pitt) 2009

- › Use shielded or cut-off luminaires to control glare
- › In pedestrian areas, place lighting at heights that will illuminate the faces of the people in the space
- › Use lighting to identify property ownership and define public, private, and semi-private space

Operational Considerations

› Full life cycle cost

When the full life-cycle of a lighting fixture is considered, LED technology has been found to be the least costly and least environmentally harmful lighting source available. Life cycle assessment (LCA) is a standardized scientific approach to measuring the entire life cycle of a product, including the raw materials used, the manufacturing process, and the use and disposal or recycling of the product. An LCA accounts for all inputs and outputs, such as waste and emissions. The LCA takes into account the “negative externalities” associated with a product, such as pollution and waste, costs which are borne not by the manufacturer but by the public.

A 2009 comparative life cycle assessment of available street light technologies by the University of Pittsburgh’s Mascaro Center for Sustainable Innovation found that induction and LED technologies were comparable in terms of the environmental impacts of their manufacture, lower energy use, and lower maintenance costs due to long-lasting bulbs. However the efficiency of induction technology appears to have been maximized while that of LED lighting is increasing rapidly. For example, the U.S. Department of Energy (DOE) reports that every decade, the amount of light generated by LEDs increases by a factor of 20 while the cost per lumen falls by a factor of 10.

› Energy use

LED technology’s low-energy profile can further be enhanced by the use of control systems and sensor programs that allow for user-control of street lights in certain contexts. Luminaire light output may also be reduced when there is sufficient natural ambient light.

While there is no standard definition of the term application efficiency, we have introduced this phrase to denote an important design consideration: the desired illuminance level and lighting quality for a given application should be achieved with the lowest practicable energy input. Light source directionality and intensity may result in higher application efficiency even though luminous efficacy is lower relative to other light sources.

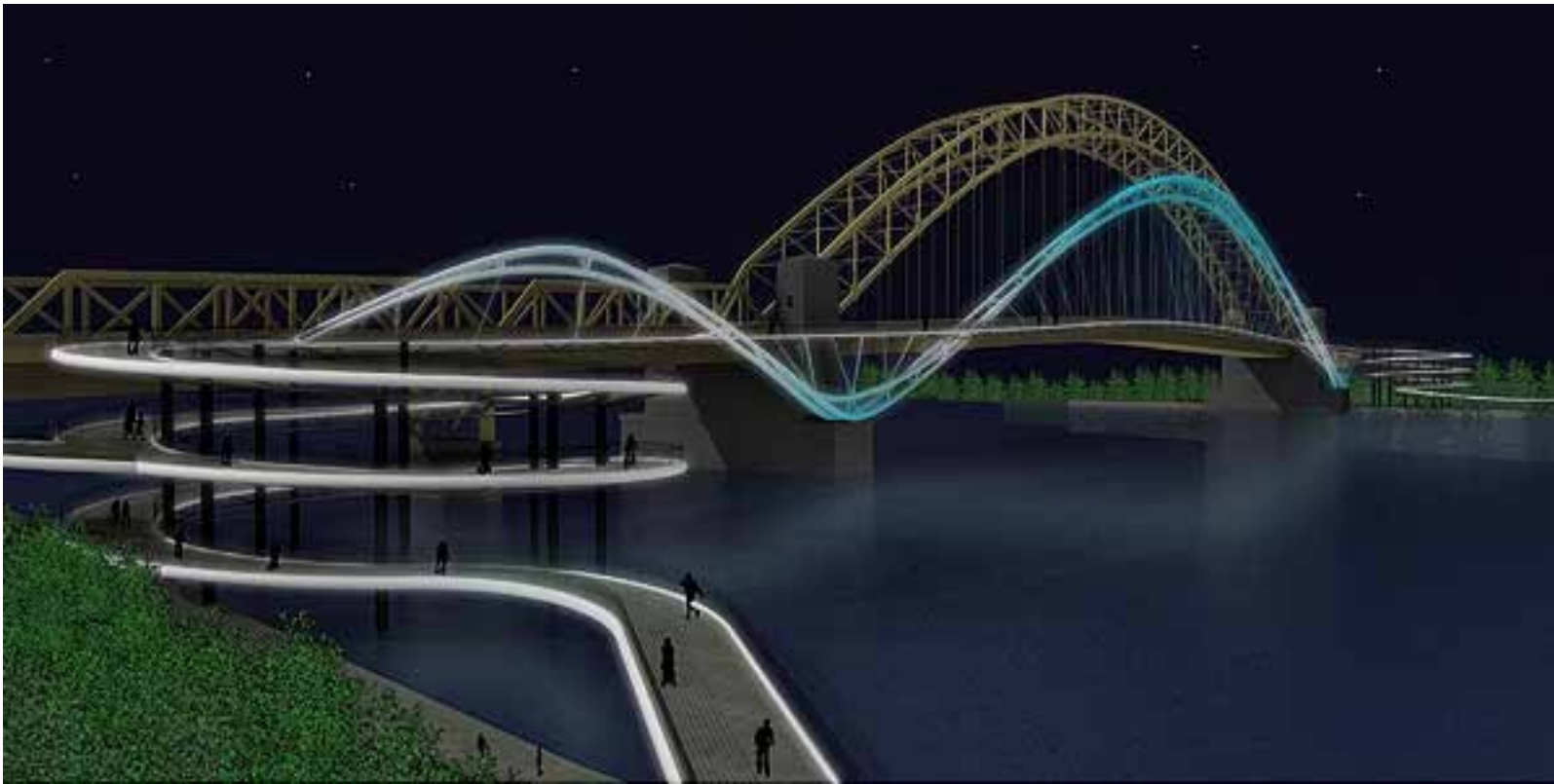
LED lighting is increasingly emerging as a way to capture energy efficiency savings around the world.

There are more than 131 million street lights in the United States alone, producing 128 million metric tons of carbon dioxide pollution annually. Ninety percent of these lights are HPS. One percent are LEDs.

The Mascaro Center Study predicts that electricity savings from light-emitting diode -- or LED -- lighting would offset negative environmental impacts of the LED manufacturing process by a factor of 10.

That means the City of Pittsburgh, which spends \$4.2 million annually on electricity and street light maintenance, could save \$1 million each year in energy costs and \$700,000 in maintenance costs with LED lighting. The Mascaro Center Study further notes that:

- › 22% of all energy generated in the U.S. is used for lighting, with 8% of that used for public outdoor lighting:
- › 90% of power used for light bulbs produces heat, not light.



LED installation proposal, Westend Bridge

- › LEDs are the most efficient, durable, long lasting and environmentally clean lighting source to date. LEDs typically last 10-12 years, reducing maintenance costs and waste

- › Low wattage make LEDs good solar power candidates

According to the US Department of Energy, in the next 20 years rapid adoption of LED lighting in the U.S. can:

- › Reduce electricity demand for lighting by one-third

- › Eliminate 258 million metric tons of carbon emissions

- › Avoid building 40 new power plants

- › Create financial savings that exceed \$200 billion

- › **Monitoring/addressing**

Since LED lighting is electronic, it can be remotely controlled or addressed on an individual fixture basis, on a series basis such as a particular street, on a city-wide basis, or any combination. Control methods include sending electronic signals by radio frequency (RF), internet (WiFi), or simply by hard wiring. Safety officials feel the control possibilities of LED street lighting offer a variety of communication methods to alert fire and police. For example, the fixture closest to a 911 incident may flash on-and-off. Light intensity can also be increased to provide additional light when needed. Controls can be used to identify each street light's location to measure power usage on an individual basis, to signal when replacement is needed, to identify burned out or damaged fixtures, or to adjust color temperatures to accentuate warmer or cooler hues.

- › **Durability**

AASHTO provides standards for the durability of luminaires in general. As a solid-state (SSL) technology, LED arrays are more able to hold up to shocks and vibrations. The City of Pittsburgh's Department of Public Works (DPW) has reported that test LED fixtures installed in recent years are more durable than the city's current lighting fixtures.

- › **Reliability**

Storm events knock out street lights and traffic signals, requiring Public Safety to assign police officers to critical intersections on a 24/7 basis for at least 24 hours and sometimes longer to direct traffic. At critical locations, backup batteries can be used for LED fixtures.

- › **Light output**

Emergency responders require street lighting to be bright enough for emergency situations. While street lighting will need to meet minimum Lighting Ordinance footcandle standards, the amount of light may not be enough under certain emergency circumstances. The ability to increase LED light output at intersections via addressable controls is an advantage of the technology.

Political Considerations

In addition to aesthetic, design and operation aspects, there are also important environmental and equity considerations that factor into decision-making for street lighting systems. In many ways, these are the "legacy" decisions that represent the values of contemporary society and its policy-makers.

- › **Climate change**

Infrastructure choices have an enormous impact on the environment and the fall-out of decisions made today will be inherited by future generations. There is no more pressing issue of generational equity than that of climate change, whose effects are unpredictable and possibly irreversible.

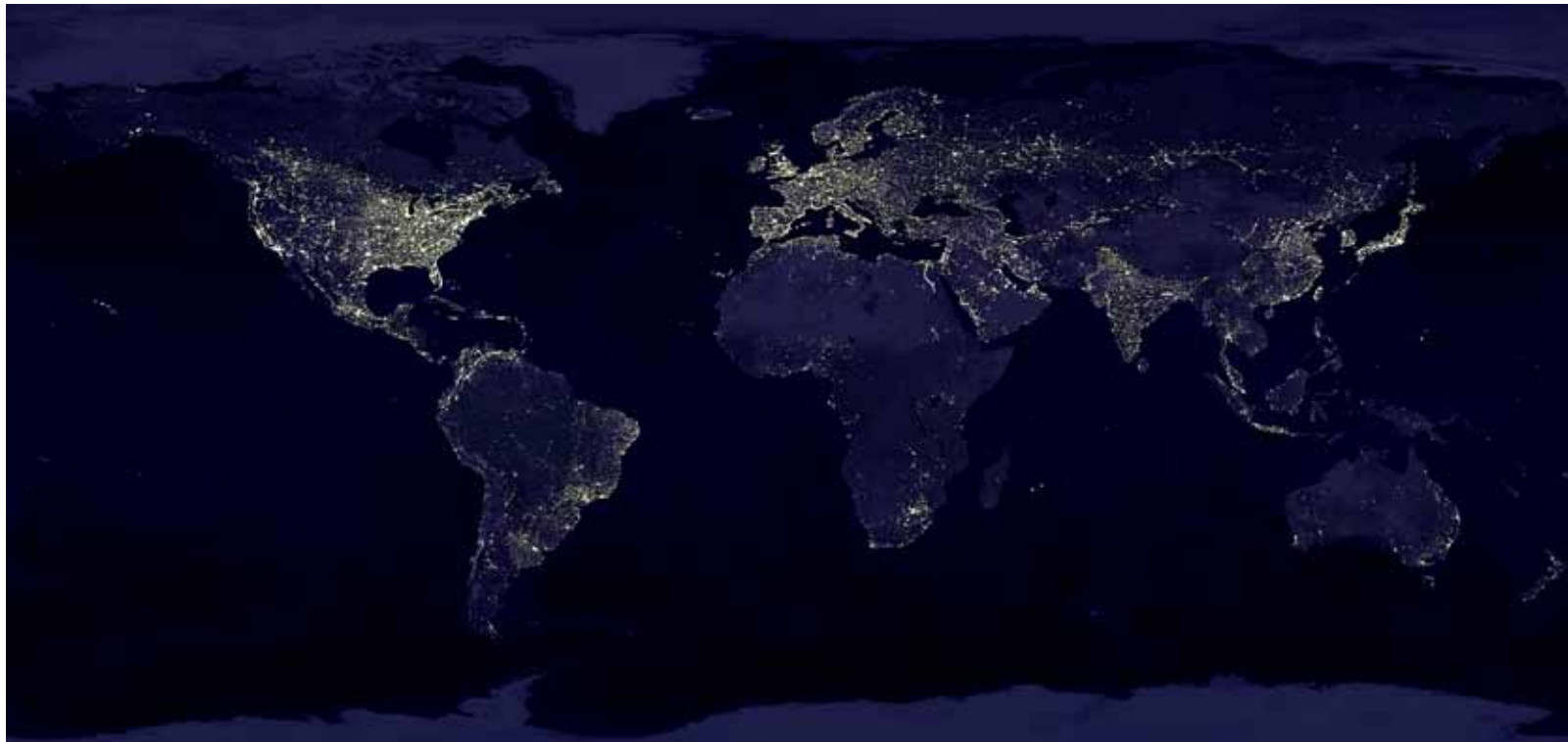
The *Pittsburgh Climate Action Plan* (2008) calls for a 20 percent reduction in greenhouse gas emissions below 2003 levels by 2023.

The discoveries provided through technology and the sense of direct personal and visual observation go hand in hand. . We are losing that personal tie experienced during the 60's decade with the accelerated space exploration program. We are losing some of the awe of our being whenever we cannot look up and see some of the wonders of our universe.

Dr. Kermit Duckett, University of Tennessee physicist and astronomer



Light pollution, Hong Kong



Light pollution as seen from outer space

The *Plan* recommends retrofitting street lamps with more efficient LEDs, estimating that energy use would decrease by 50% from 2,288,663 kWh to 1,144,332 kWh per year, diverting 1,311 tons CO₂ emissions.

› **Light pollution**

Light pollution is possibly the easiest form of pollution to prevent since it is easily controlled through proper fixture design. Additionally, much of it, such as street lights, is directly under the control of the public sector or is subject to regulations. Yet light pollution is growing at a rate of 4% globally, faster than population growth.

Light pollution is defined as excessive and ineffective light, such as light coming from an exposed bulb. Sky glow describes the large-scale brightening of the night sky due to the cumulative effect of the illumination of street lights, outdoor advertising, buildings, parking lots, airports, and other sources bouncing off of microscopic particles suspended in the air that is then reflected back to Earth.

Sky glow prevents a clear view of the night sky landscape for hundreds of millions in urbanized areas around the world and can be seen from outer space. Night light pollution is problematic on a number of fronts, none more serious than its impact on human and ecosystem health. Night light pollution:

- › disrupts ecosystems and natural ecological processes such as migration
- › affects human circadian rhythms (the American Medical Association resolution 516 supports the reduction of light pollution and glare)
- › wastes energy
- › reduces the visibility of stars
- › threatens astronomical research

Guided by a simple idea--“light what you need, when you need it,” the International Dark-Skies Association (IDA) lobbies governments and provides technical support to advocacy groups working to reduce and eliminate light pollution. The IDA considers the night sky as our shared natural heritage and believes that everyone has a right to observe a dark sky.

With 58 chapters in 16 countries, the IDA works with members of CPTED (Crime Prevention Through Environmental Design), conservation officials, field ecologists, health professionals, planners and policy-makers, astronomers, and educational institutions on research, advocacy, and education of issues of night light pollution and prevention. The IDA also offers a third party rating system program which uses photometric tools to measure a light fixture’s impacts on dark skies. Over 300 fixtures types (featuring more than 1,000 options) from 100 manufacturers have received the IDA Fixture Seal of Approval for uses ranging from parking, facade /sign, roadway, security, service stations, sport/event, and residential.

The IDA and the Illuminating Engineering Society (IES) recently released a *Model Lighting Ordinance* (MLO). This free template is designed to help municipalities develop outdoor lighting standards that reduce glare, light trespass, and skyglow. It uses five lighting zones to classify land use with appropriate lighting levels for each, from LZ0, (pristine natural environments) to LZ4 (areas of extensive development in the largest cities). The MLO also limits the amount of light used for each property and uses the IES’s new TM-15 -11 “BUG” (Backlight, Uplight and Glare) classification of outdoor lighting fixtures to guarantee that only well-shielded fixtures are used. Uplighting is not allowed for area and street lighting in any zone.



Light pollution, Toronto

There is an established link between exposure to bright lights at night and cancer rates, particularly breast cancer (melatonin production is disrupted, leading to excess estrogen which in turn promotes tumor growth).

› **Age-related equity**

Aging is a major equity factor that is given little consideration. As people age their eyesight diminishes and glare becomes an even more serious problem. Seniors require more light for basic tasks of daily living than those in their twenties or thirties. Glare can be dangerous and is often blinding to seniors when confronted with street lighting that shines directly into one's eyes. Lighting standards should follow "universal design" principles and be equitable to all persons, no matter their age. Designing comfortable and adequate street lighting for elderly drivers and pedestrians would provide equitable street lighting for all persons.

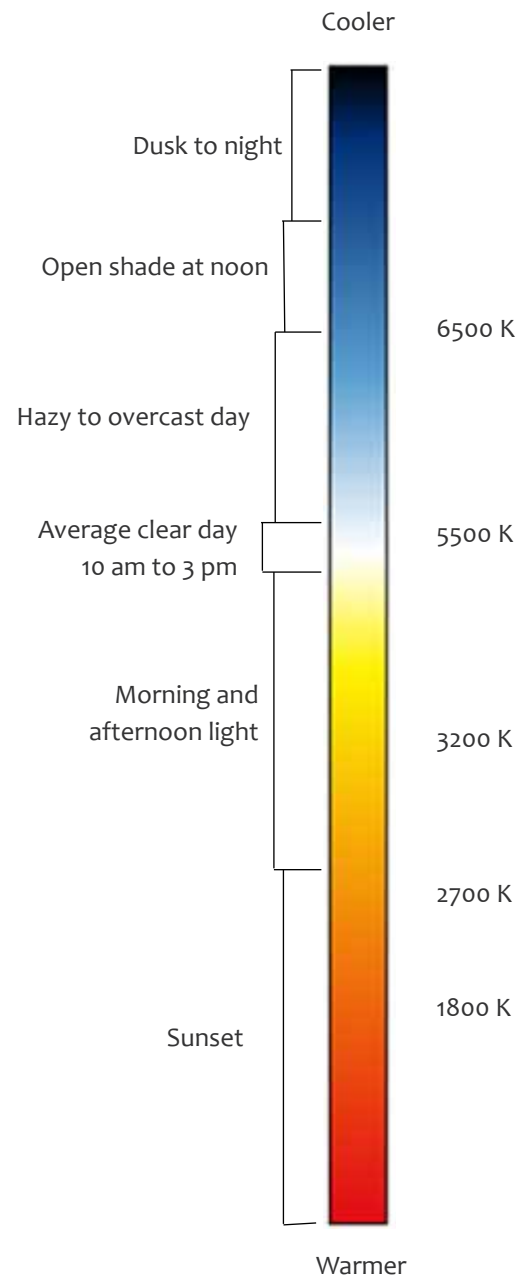
› **Spatial equity**

Not all business districts are similarly lit. This is more a function of availability than a deliberate plan. In most locations, the City of Pittsburgh does not own the street lighting poles and leases Duquesne Light Company utility poles for that purpose. The amount of street lighting is dependent on the number and spacing of utility poles whether they are in commercial, industrial, or residential areas. Utility pole spacing is further apart in residential neighborhoods and is often located in alleys as well as streets. The number of utility poles in a specific location is more a function of the density and intensity of use and electrical load. Denser locations, such as Downtown or intensely developed commercial areas, require more utility poles and thus offer the opportunity for more street lighting fixtures. Inequality results, with small neighborhood business districts receiving less street lighting than dense commercial districts.

Fortunately, many of the business district streets have been improved, often with new sidewalks, street furniture, signage, street trees, and street lighting. New, free-standing light poles and light fixtures have replaced the utility pole lights. At Downtown intersections, new shoebox light fixtures have been located atop 30' high signal poles. Outside of Downtown, new teardrop light fixtures often replace former cobra heads atop new 25' high poles and acorn light fixtures are often installed along the sidewalk atop new 15' high poles. Often pole and light fixture spacing is changed for more even spacing, more even illumination, and more intensity. Funders of these business district improvements may be the City or the Urban Redevelopment Authority through community development block grants. Often well-organized local business associations will lobby for improvements. Business districts without strong business or political strength may be bypassed in improvements.



LED color temperatures



Biological/Public Health Considerations

› Color Temperature and Circadian Rhythm

Bright white light suppresses melatonin, the hormone that regulates tumors. Blue light wavelengths are to blame, because they “reset” the circadian clocks of humans, animals, and plants even at very low levels of blue light. This might account for the significantly higher rates (30-60%) of breast and colorectal cancer in night shift workers.

Fully blind people whose melatonin production is never altered have lower incidences of breast cancer. Moreover, remaining in darkness for 8 hours a night is supposed to be ideal for melatonin to work its tumor-suppressing magic.



Placemaking example, Quebec City's Bunge grain silos

Lighting Plans: Comprehensive Planning for Urban Lighting

Public lighting is a highly complex component of a city's infrastructure that is only occasionally considered in a coherent manner through a lighting master plan. A well-designed and executed city-wide lighting master plan is a policy and design document that allows for the coordination of all aspects of outdoor lighting, including operational, cost, performance, safety, aesthetic, and environmental considerations across a wide variety of conditions and environments. As with any plan, a lighting plan provides a vision and objectives for lighting, and sets out the technical, organizational, and budgetary frameworks necessary for implementation. The benefits of a formal lighting plan are being acknowledged by more and more cities, as well as commercial districts and campuses.

The following benchmark cities are renowned for their built heritage, a concern for sustainability, and an overall heightened sense of design. Lyon, France is considered the pioneer in urban lighting with its 1989 lighting plan, which focused on monuments and buildings. Quebec City, Canada is the first North American city to develop a Lighting Plan that highlights both cultural and natural features. Helsinki, Finland is considered to have created the first city-wide lighting plan in 2000 that considers special sites as well as streets, public spaces, and buildings. And in 2005, Eindhoven, The Netherlands updated its Lighting Master Plan with a focus on the symbolic aspect of lighting with regard to its industrial heritage and current economic focus on technological development and cultural/event applications.

As the examples demonstrate, a lighting plan provides an opportunity to link urban lighting schemes to other development goals, such as cultural, economic, environmental, and quality

of life initiatives. Each of these cities has something in common with Pittsburgh, from topography and a rich built heritage to an industrial past and a desire to be a part of a technology-driven economy.

› **Lyon, France: Plan lumière (1989)**

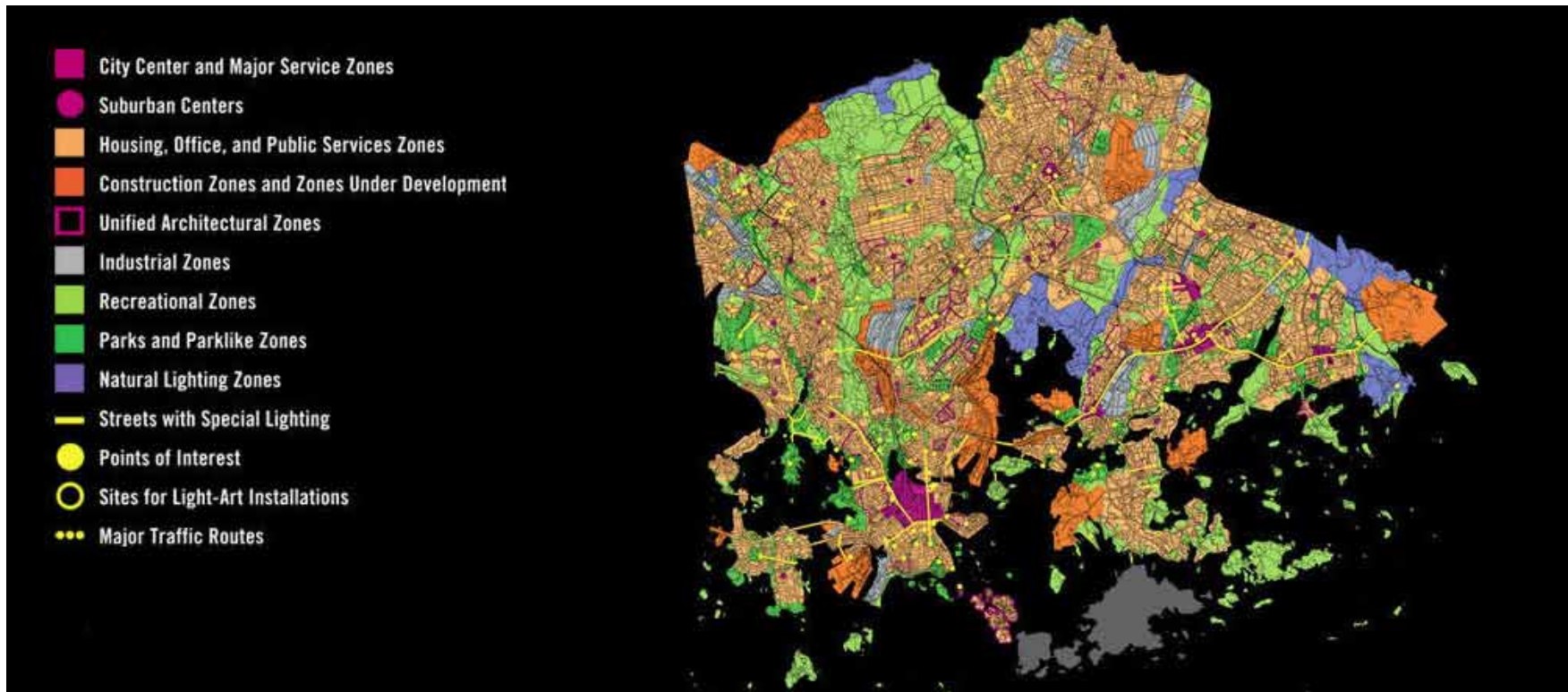
Lyon, France is the first city to have implemented a lighting plan (1989) that focuses on the urban design merits of light, with a focus on monuments. Since 1989, 150 sites have received special lighting treatment. In 2004, the Lighting Plan was updated and its scope broadened to include natural features such as rivers and hills, silhouettes, and major roadways. On the strengths of its experience, the City of Lyon created LUCI (Lighting Urban Community International), a network of cities and lighting professionals using light as a tool for urban, social, and economic development within a context of sustainability.

› **Quebec City, Canada: Plan lumière (1999)**

In anticipation of the celebration of Quebec City's 400th anniversary in 2008, the Commission de la capitale nationale du Québec (CCNQ) was commissioned by the provincial government of Quebec in 1997 to develop the city's first lighting plan. The interdisciplinary planning team focused on the illumination of 63 sites closely associated with the city's identity in four categories: natural sites; parks, gardens and public spaces; civic, religious and military architecture; and civil engineering works. Important natural and cultural landmarks that have been lit so far include the Cape Diamond, the Château Frontenac, and the waterfront Bunge grain silos in the Old Port district.



Eindhoven lighting examples



Helsinki, Finland Master Lighting Plan

› **Helsinki, Finland: Master Lighting Plan (2004)**

For northern cities like Helsinki, which is located roughly 430 miles from the Arctic Circle and averages 1 hour of sunlight from November to February, a pleasant public lighting scheme is important. The Helsinki Master Lighting Plan, developed in 2004, extends the planning scope beyond districts and special sites to include all streets, public spaces, and buildings within the city limits. The Plan's horizon is 20 years and is based on three years of research by a team comprised of municipal planning, building control, public works departments, and Helsinki Energy. The project began in 2000 with 40 special lighting installations to celebrate Helsinki's designation as European City of Culture. These proved so popular with the public that a citywide program was initiated based on 13 zoning types designated in the 2002 Helsinki Master Plan. Similar to Eindhoven, the Helsinki Master Lighting Plan focuses on creating zones of darkness so that residents can have a chance to see the dark sky.

› **Eindhoven, The Netherlands (2005)**

With a population of around 750,000, the Eindhoven region is a former industrial powerhouse and, since 1891, home of global electronics and lighting conglomerate Royal Philips Electronics. The city's second Lighting Master Plan, developed in 2005 by a team of architects, lighting designers, and artists, became an opportunity to use light as a symbol of Eindhoven's unique identity as home to Philips and as an important leader in technology and research, thus setting it apart from other Dutch and European cities.

The vision for Eindhoven covers six categories of outdoor lighting: urban lighting (streets, public areas); buildings and objects/art (indoor and outdoor); events and festivals; information; and advertising. The Master Plan considers all six types of lighting separately and holistically, and emphasizes the most sustainable practices available. To further emphasize the qualities of light, the Lighting

Master Plan vision includes a respect for darkness: in 2008, the city began requiring the dramatic reduction of advertising light in late evening. Furthermore, Strijp-S, a new 66-acre brownfield redevelopment project of the former Philips factory site, will feature specially-developed Philips LED streetlights that will sense pedestrian activity and adjust illumination levels accordingly. Streetlights will be dimmed to a super energy-saving mode when possible to balance between visibility, safety, and light pollution. Eindhoven's traditional light festival, the Lichtjesroute (Route of Lights), celebrated since 1945 to commemorate the liberation of the city at the end of World War II, has also been augmented with the GLOW festival, a forum for light in art and architecture since 2006.

Eindhoven is using new lighting technologies to not only enhance and unify public spaces, but to promote an updated and vital image for the city that promotes its heritage as much as its innovative local talent.

Reducing Street Lighting Use

Faced with budget crises, cities across the United States are looking for ways to reduce their energy costs associated with street lighting. In February 2010, Colorado Springs, CO deactivated 8,800 of its 24,500 street lights as a result of budget issues. It also instituted a "Street Light Adoption Program," in which residents could pay \$75 to adopt a street light and keep it on for a year. By November 2010, additional revenues were found and the City was able to turn them back on, but not before saving \$1.2 million. Fears that crime would increase were unfounded. Other cities, such as Rockford, IL and Rockingham, VT have also selectively turned off lights.



Dial4Light



Lunar Resonant street light



Hybrid LED street light

› **Dial4Light: Licht per Anruf (Light by Phone Call)**

In Germany, many towns turn off their less frequented street, bikeway, walkway, and recreational lighting systems from 11 pm to 6 am to save energy and reduce costs. For a town like Lemgo, Germany (population 41,000), the annual savings of this policy is around 50,000 Euro (\$71,500 US dollars/June 2011). An enterprising Lemgo resident devised a SMS-powered streetlight system which allows users, typically pedestrians, to turn on public outdoor lights via a mobile phone text application or landline connection when desired. Registered users can turn on Dial4Light routes for about 10 to 15 minutes for the cost of a text (SMS), whereas energy-intensive lighting, such as sports field floodlights, are subject to a fee. Emergency services can use the service for free. Six additional German towns have adopted the Dial4Light service.

› **Civil Twilight: Lunar Resonant Street Light**

The conceptual lunar-resonant street light is the 2007 winner of the Metropolis Magazine Next Generation Design Competition. Created by the Civil Twilight Design Collective, lunar resonant street lights are embedded with a photocell that senses the varying brightness of moonlight and adjusts the luminaire's light output accordingly. This "smart" street light relies on the unique dimming capabilities of LED technology to work in harmony with the natural context to reduce energy use and mitigate urban light pollution. The designers estimate that this approach could save as much as 80–90 percent of the energy used in street lighting.

Renewable Energy Integration

› **Hybrid LED Street Lights**

In 2010, San Francisco installed four prototype wind and solar powered hybrid LED street lights in Civic Center Plaza as part of the Civic Center Sustainability District initiative. The combination of environmentally-friendly energy generation and low-energy LED technology makes this type of street light extremely low-cost and low-emission. Street lights create the most emissions during their use phase, when they are powered by electricity, the production of which creates vast amounts of greenhouse gas emissions.

Urban Green Energy has two solar/wind powered LED street lamp models on the market. The 18-foot Boardwalk and 26-foot Sanya luminaires respectively feature a 60 and 77 W LED lamp on a standard galvanized steel pole that can be made locally or swapped with older street lamps. The wind turbine can be on a vertical or horizontal axis, and two solar panels generate up to 150 W of power in addition to the 600 W of wind power. The poles are additionally customizable to create unique luminaires.

Solar powered LED luminaires are readily available. The low energy requirements of LED lighting make them the ideal candidate for solar-powered street lights.



LED lights for pedestrian crosswalk

Overview

Focus group sessions were held formally in April 2011 with the three business district communities in this study. In addition, selected individuals were interviewed to gain their insights about new street lighting. Members of the Pittsburgh Downtown Partnership, the South Side business and residential community, and the Brighton Heights Citizens Federation participated in discussions organized around the following three questions:

- › What do you like about the present street lighting?
- › What don't you like about the present street lighting?
- › If you could have new street lighting, what would you like to achieve with the new lighting?

Focus group meetings took place over one hour and began with a brief presentation about the LED street light research project. Examples of new LED street lighting and new luminaires installed in other cities were shown. This was followed by a review of the RCI research team's preliminary findings presented to City Council. The groups were encouraged to ask questions and express their impressions and preferences.

General Consensus Items

- › All preferred the ability to control the color temperature to adjust between a warm or cool white depending on the local context.
- › The use of colored light, such as a blue or a green light for accentuating street surfaces for special events, was not considered desirable or appropriate in a designated historic district, such as East Carson Street.
- › Colored light could be acceptable on sidewalks, but only under controlled situations. However, this idea was not strongly endorsed.

- › Street lighting should project onto business district buildings for a height of at least one story, but not higher as it would affect residential occupants on upper floors. The expressed intent was to shed light into the spaces between buildings and the nooks and crannies of building facades. Most women expressed concerns about walking along business district sidewalks at night for personal safety reasons and often sought out streets with higher intensity street lighting.

Concerns Raised

- › The ability to control the dimming, intensity, and flashing of LED street lights was not met with consensus. Many did not like the idea of flashing street lights for any purpose.
- › The use of control systems raised some concerns about hacking the city system to turn off all street lights in the city, put all street lights on a flashing mode, or to generally create lighting chaos.
- › Some business owners were not in favor of street lighting projecting onto building facades due to concerns that this light trespass would “overpower” their own facade lighting or even signage.
- › A clear preference was expressed for not adding more overhead wires, even if it means better lighting.

Suggestions

- › Embed new LED lighting into the street pavement at pedestrian crosswalks as permanent markers. The embedded lights could shine or flash when a pedestrian enters the crosswalk, and solar powered embedded fixtures are already available.
- › Alternate energy sources were encouraged, such as solar or wind powered street lights.



Spot meter



Photometer

Tools for Measuring Street Lighting

› Illuminance Photometry

Illuminance is a measure of light falling on a surface (typically a horizontal surface), from 180 degrees or a semi-spherical source, composed of all lighting coming from the upper hemisphere. This measurement characterizes the total light incident at an exact position. Illuminance measurements were taken directly below luminaires and at positions between luminaires. The typical goal of street lighting with regard to illuminance is to provide about 1 footcandle as a minimum value, often with a secondary criterion for uniformity. During this measure, the illuminance photometer is held at the street level, and the body of the person measuring is positioned so as not to block any source of light. The measuring instrument was a Photo Research Spot-Mate Illuminance and Luminance Photometer.

› Luminance Photometry

Luminance is a measure of surface ‘brightness’ and is generally performed with a one-degree luminance photometer. This measurement characterizes the luminance at an exact position, with one degree of angular coverage. Luminance measurements were taken directly below luminaires and at positions between luminaires. During these measurements, the photometer was pointed at the light source of the luminaire. The intent of this measurement is to determine the value of glare from a luminaire, as glare reduces the visual effectiveness of lighting by causing the eye to adapt to the bright source rather than the visual task (walking or driving).

Most street lighting is not measured for luminance, as customarily most electrical engineers and lighting consultants do not have an adequate luminance photometer.

The typical goal of street lighting with regard to luminance is to limit the brightness of the source to minimize the need for visual adaptation to the source rather than the visual task. During this measure, the luminance photometer is held at the standing eye level, with the operator pointing the photometer at the area of interest on the street or on the light source.

› Imaging Photometry

Imaging photometry is a newer technique for measuring luminance by the use of a digital camera and lens, with an accompanying computer, that is calibrated to provide one million pixelized luminance measurements of a street scene.

Imaging Photometry was invented by the Institute for Building Research at the National Research Center / Canada in Ottawa. It was designed to be used similarly to a computerized acoustic analyzer. It allows the lighting consultant to gather multiple images of a scene that can then be analyzed at the lab to determine factors such as the brightest point in an image; the intensity of a source in the image; an average luminance for the image; and the contrast between aspects of the image. Orfield Laboratories was the world’s first user of this technology, when NRCC offered its first four CapCalc Photometers in 1989. Since that time, Orfield Labs has moved through five generations of software and hardware changes, again being the first user of their photopic -scotopic model.

Imaging photometry has particular significance in the study of street lighting because a one degree meter often cannot determine, with high resolution, the brightness of a source as that brightness may be less than one degree. Since LED light sources are generally smaller than a one-degree measurement aperture, normal spot photometry does not accurately measure the value of brightness from the LED luminaire.



Imaging photometry measuring luminance, East Carson Street

During this measure, the luminance photometer is positioned on a tripod at the standing eye level, with the operator pointing the photometer at the area of interest on the street or on the light source.

On most street lighting projects, there is just one type of measurement performance, that of illuminance in footcandles. On this research project, the measurement was enhanced by use of two types of luminance measurement: spot photometry and imaging photometry. These newer technologies were the foundation behind the most important findings of these measurements.

[Make reference to existing guides or standards for measurement. i.e. ASSIST: Alliance for Solid-State Illumination Systems and Technologies: A Method for Estimating Discomfort Glare from Exterior Lighting Systems and Recommendations for Evaluating Street and Roadway Luminaires.]

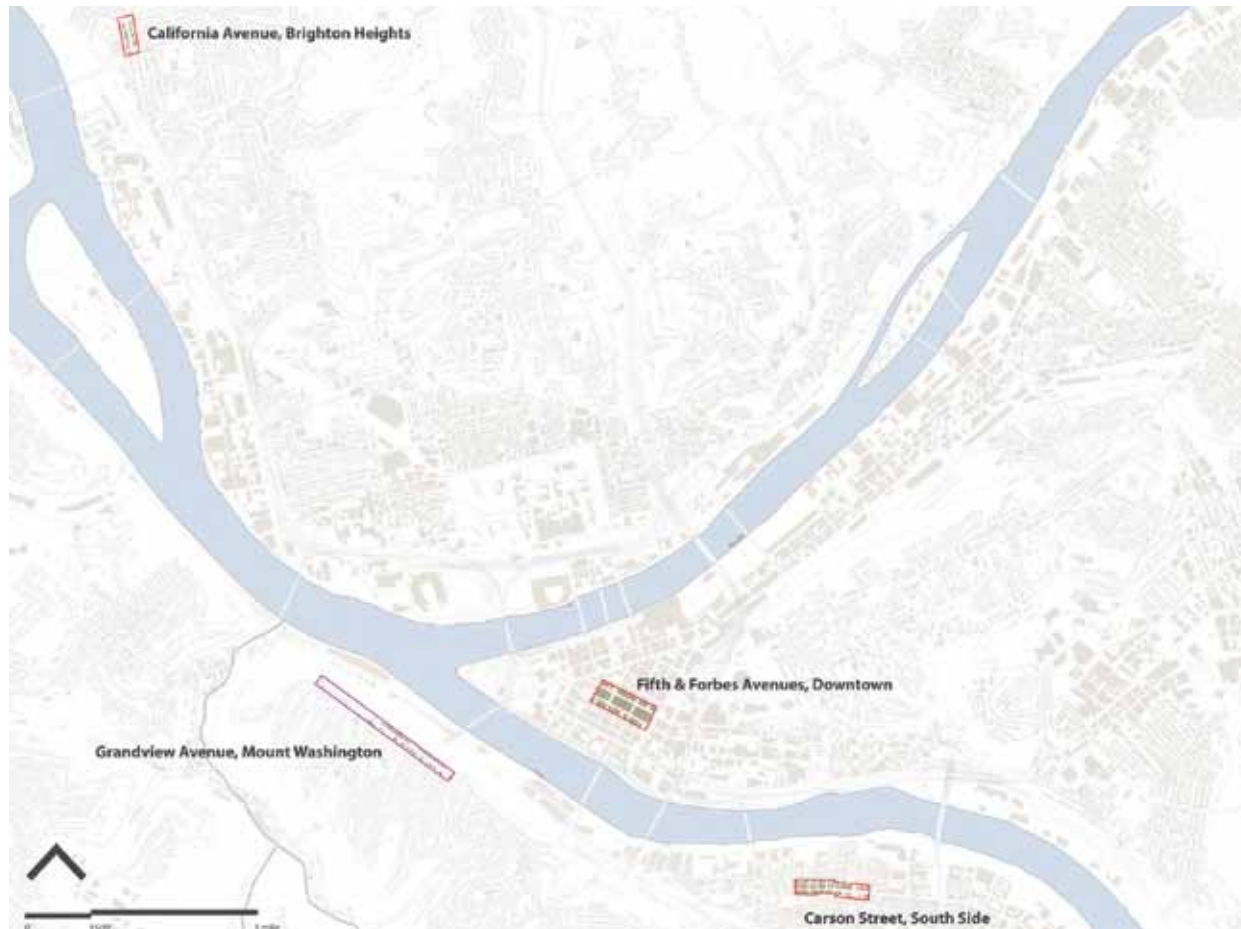
Approaches to Evaluating Public Preferences for Streetlights

Orfield Labs surveyed a series of LED projects around the United States and Canada. Typically, each project was predicated not on lighting quality but on energy savings and incentives. In order to achieve public buy-in on each project, a demonstration was generally installed next to existing lighting, placing a new LED luminaire next to an old high-pressure sodium HID luminaire. The public was surveyed about the lighting to determine which they preferred. Preference was generally in favor of the LED, as it is a much whiter light and renders colors more accurately. Lighting levels were also measured to ensure that both lights complied with the standards in place. The problem with this typical evaluation is multiple levels of bias, including surveyor shared information about LED efficiency and LED quality.

A more realistic comparison demonstration would have been to put the LED luminaire next to a metal halide HID. In many cases, the HID would have been preferred because it has lower levels of glare, but still renders colors accurately. Secondly, it is well known in research circles (cognitive psychology and academic market research) that accurate subjective testing must be indirect and must not be based on opinions. What must be measured are the feelings and associations of the public, not their opinions, as opinion-based research has little predictive value.

Comparisons of lighting can be done validly by using either real street scenes or images of those scenes. But the public ranking should be based on semantic ranking of the 'street scene', not the light, and the rankings should be based on semantics that describe important positive and negative feelings when on the streets at night. And nothing should be shared with the public about bias for LED, about 'old vs. new' lighting, etc. This type of subjective testing is technically called Perceptual Market Research.TM

Measurements should also include lighting levels as well as luminance and glare, which are strong determinants of use preference.



Testing locations



Cobra head



Shoebox



Acorn



Teardrop

Overview

In February, 2001, Minneapolis-based Orfield Laboratories visited Pittsburgh to document the range of visual performance of four of the City of Pittsburgh's standard luminaire types: HID Shoebox, HID Teardrop, HID Acorn, and HID Cobra head. Globe fixtures were excluded from this study because The City had previously created a program to replace all the deteriorating globe fixtures (lollipops) with acorn fixtures. Measurements were taken in the three existing business districts that are the focus of this research. Also tested was the new LED lighting installation which the City designed for Mount Washington's Grandview Avenue. In addition, the City sent samples of the four standard luminaires to Orfield Laboratories for testing.

Method

Measurements in this study included illuminance in footcandles and luminance in candelas per m². Three different photometers were used, including an illuminance photometer, a luminance photometer, and an imaging photopic/scotopic luminance photometer. At the same time, photographs were taken of the different sites to aid the understanding and explanation of the measurements. Many of the luminaires were high pressure sodium (HPS). The measurement process provided benchmarks for measuring and evaluating improvement on a new LED lighting system.

Results

The City's photometric specification is to maintain a 1 footcandle average at grade with a 4:1 or less ratio. These measures confirmed that there were many locations below 1 foot-candle in luminance, and the brightness of most of the current luminaires is very high, causing significant glare problems.

The RCI/CMU team visited the aforementioned three sites in Pittsburgh, plus the Mount Washington site. Illuminance was

measured below and between luminaires at the sidewalk and in the street. These measures of illuminance varied from 0.2 to 2.5 foot-candles, with many areas falling below the City's one foot-candle guideline.

Spot photometry was also measured, and the luminance of sources ranged from 1,200 to 65,000 cd/m², with a maximum luminance in a very high and troublesome visual range.

Imaging photometry was also taken, both photopically and scotopically (day and night vision). The values of luminance had typical ranges from 50,000 to 140,000 cd/m², with the maximum luminance in an even higher and more troublesome visual range. The typical range of HID was 50,000 to 90,000 cd/m², and typical LED measurements were 100,000 cd/m² or higher.

The new LED installation on Mount Washington provided benchmarking about the early use of LEDs in Pittsburgh. The luminance of these measurements initially seemed rather low, via the use of spot photometry. Using imaging photometry, the values increased dramatically, as the imaging photometer could measure individual LED cells.

Conclusions

These measures were the most intensive field measurements the RCI research team is aware of in the U.S. or Canada. Steven Orfield has investigated many cities that have installed LEDs in the U.S. and Canada. The installations have not been measured with these technologies, nor have the sites had a set of luminance (glare) measurements or luminance guidelines. Most of these cities reported selecting the LED lighting by comparing it to low pressure sodium lighting, the most common street lighting in the U.S.

Feedback from these cities included an increasing awareness of glare after the LED installations are in place, with additional concern as newer generations of LED luminaires are introduced.



Fixture examples

Recommendations

Overview

The City of Pittsburgh’s current standard fixtures types—the cobra head, shoebox, pendant, acorn, and globe—do not adequately control for glare, and most of them have very poor lighting distribution control. It is the position of the RCI research team that retrofitting any of these luminaires with LED sources would provide little benefit when compared to simply selecting new fixtures (heads) that are designed appropriately to reduce glare and work with control systems. As such, this report recommends without reservation the replacement of all fixture heads with new fixtures. It also recommends the elimination of acorn fixtures to alleviate glare and night sky pollution issues.

This report also recommends that a more rigorous second investigation be undertaken to design new LED fixtures that address the problems of glare and distribution that this investigation was unable to resolve. It also recommends that the City of Pittsburgh undertake a certification program to assure that all future LED fixtures perform as specified, that specifications are developed specifically for neighborhood street lighting in addition to business district street lighting, and that the City of Pittsburgh’s Lighting Ordinance be amended to appropriately address the attributes and qualities of LED street lighting.

Effect of the City Lighting Ordinance on the RCI Research Project

The original intention of this research was to develop recommendations and specifications for business district LED street lighting that would result in fixtures that take advantage of LED’s inherent benefits while overcoming their issues, such as glare. Suggestions for standards of spacing, height, patterning, and fixture type for different business district typologies was also part of this research.

When this study began the City of Pittsburgh did not have a lighting ordinance and it was expected that this research would lay the groundwork for LED-specific standards and regulations. Although the City had been informally following IES and ASHTO recommendations for street lighting, the research team had earlier acknowledged that these were not appropriate for addressing LED glare nor visual acuity and clarity issues. When the City adopted the new City of Pittsburgh Lighting Ordinance in March 2011 (about half-way through the project), the RCI research team modified its approach to accommodate the new ordinance with the understanding that the first phase of LED retrofitting would not be able to achieve the original goals of the project.

There were several other factors that influenced this change. City funding restrictions require the initial phase of LEDs to be placed within 12 months of the time the research project began, and recommendations of the research team were to be developed within 4 months so that bidding documents could be issued for the new street lights. As a result, the research team was unable to work with LED manufacturers to design and test new fixtures, and subsequently revisions to the recommendations that reflect the testing results are not included. The short time frame also did not allow time for the intended testing of LED fixtures already on the market to ascertain which were effective at glare reduction or adaptable to different patterning. The testing regimen was intended to modify “theoretical” recommendations with the realities of LED technology, manufacturer knowhow, and field application findings.



Fixture examples

The revised approach became one of recommending specifications for business district LED fixtures that would:

- › Meet all new Lighting Ordinance requirements
- › Improve on the LED fixtures already in place in Pittsburgh

As the City's LED street lighting program would be implemented over a period of several years, it was understood that a more rigorous design and testing of LED fixtures, certification of appropriate fixtures, and recommended LED revisions to the Lighting Ordinance would follow this initial research as a Phase II project.

Recommendations

Initial recommendations for new business district street lighting and fixtures are in three forms:

8. General criteria that convey the design and performance intent of business district LED street lighting
9. Base performance criteria for new LED fixtures, including photometrics, color, controls, and design
10. Evaluation criteria for a simplified testing procedure of manufacturer-submitted fixtures as part of the bidding selection process

In addition, upgrade recommendations are made for additional controls and accessory wayfinding lighting. With the exception of the additional controls and wayfinding recommendations, these formed the basis for the City's solicitation of 3,100 LED fixtures for 30 of the city's business districts as Phase 1 of the LED street lighting program.

The findings generated from the research modified the City's original intentions for the Phase 1 program. Originally the intention was to replace only the lamps with new LED arrays and retain the fixture housings and lenses. Because of the existing

fixture housings and reflector designs specifically for HID lamps, not LEDs, and the inability of the acorn fixture to control lighting spread, the RCI research team recommended and the City agreed to replace the entire fixture with LED-appropriate fixtures and to consider other fixtures to replace the acorns. The value of electronic controls for monitoring and addressing individual fixtures was recognized as a desired feature and City requested that the recommendations also include a control-ready requirement in the base criteria for all new LED fixtures.

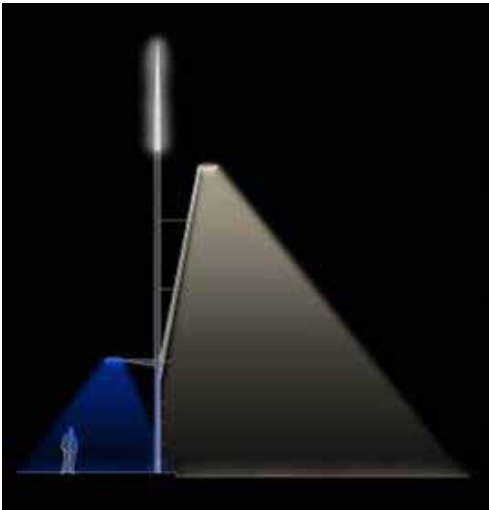
Technical and Aesthetic Performance for Business District LED Lighting

The performance of these luminaires is intended to be superior to the performance of the HID luminaires they are replacing. This is true in terms of energy consumption, but is also true in terms of visibility, glare, and more accurate color rendition. Within the criteria that are noted below, the intent is to benefit from better lighting performance and multiple tasking of street lighting, with the assumption that street lights should "illuminate but not be seen."

Although LED lighting can be very even, it is the intent of these recommendations to comply with the City's lighting regulations at the lowest acceptable evenness ratio in order to control for glare and visual clarity.

General Criteria

- › Luminaires for LED replacement are existing business district cobra head, teardrop, shoebox, acorn, and globe luminaires.
- › The entire luminaire head is to be replaced, not just the HID lamps. The luminaire is to attach to existing pendants or poles similar to existing cobra head, teardrop, shoebox, acorn and globe



Fixture example

luminaires. Manufacturers are responsible for this coordination between existing pendants or poles and new lighting heads.

- › Light color is to be white within a required temperature range noted below.
- › Under good street lighting conditions, the LED light source should not be visible to drivers or pedestrians, unless they are looking directly up.
- › Lighting that is non-uniformly distributed is better than lighting that is uniform in terms of glare, as evenness requires higher power for lighting toward the edges of the distribution pattern. This high angle glare is not acceptable.
- › The current acorn luminaire will be discontinued because of glare issues and dark sky problems and replaced with either down-firing LED cells, cut-off deflectors, and/or lenses to produce non-glare direct light, or up-firing LED cells aimed at white horizontal reflectors to produce non-glare diffused light.
- › Imaging photometry will be used to benchmark glare by measuring luminance at high resolution. Measurements will be both photopic and scotopic.
- › LED luminaires must be guaranteed for a minimum 10-year life span, defined as no more than a 30% deterioration of LED cells in each luminaire and continuous maintenance of the minimum FC illuminance within a 10 year period.
- › LED luminaires are intended to meet current City of Pittsburgh Lighting Ordinance requirements for business district lighting.

Base Criteria: Photometrics

- › Illuminance must meet a minimum of 1.5 FC as a maintained value on the roadway and a uniformity ratio of 4:1 per City of Pittsburgh Lighting Ordinance requirements for street lighting in business districts.

- › It is preferable to use lower power LED sources and higher source quantity to correct brightness.
- › The preferable lighting pattern is overlapping ovals, with adjustable cutoff angles to minimize glare. Typical 25' high street lighting (existing cobra head and teardrop luminaires) is typically spaced at 85' to 150' feet. Typical 30' high street lighting (existing shoebox luminaires at Downtown intersections only) is located atop signal light poles at all four corners of intersections. Typical 15' to 18' high sidewalk lighting (existing acorn luminaires) is typically spaced at 80' apart; however in some instances luminaires are spaced closer together and in some instances, particularly in Downtown, this is the only street lighting in mid-block locations. Typical sidewalk width is 8 feet. The vendor will be responsible for calculating spacing and angular photometric distribution as well as illuminance.
- › To control lighting brightness, luminaires should favor center brightness over edge brightness. Side shielding of optics should be considered to control side angle glare.
- › In business districts, the sidewalk backlighting should not exceed 6" (inches) in height on adjacent building facades.

Base Criteria: Color

- › The color temperature range must be within 2,800 to 5,000 Kelvin, preferably 3,500 Kelvin if only a single color temperature is to be provided.
- › Color Rendering Index (CRI) must be 80 or greater.

Base Criteria: Controls

All luminaires are to be control ready: have the ability to be individually controlled (addressed) remotely by either RF, WiFi, or hard-wired systems.



Fixture examples

Base Criteria: Design

- › Contemporary luminaire design is preferred. The accompanying illustrations of luminaires in this section of the report are examples of acceptable luminaire design and are included to provide design guidance to lighting manufacturers and vendors. They are not definitive of acceptable luminaire design and hopefully will encourage design experimentation.
- › Teardrop and acorn equivalents should be compatible with the streetscape in a historic context.
- › Manufacturers are encouraged to submit an optic that addresses the technical performance items with a variety of luminaire head designs.

Performance and Aesthetic Field Evaluation Criteria for Business District Led Lighting

Each luminaire will be observed and rated for the following characteristics:

- › Beam spread on the street based on luminaire type and typical height and spacing measurements. The beam spread on the street should meet code requirements for coverage and intensity.
- › Beam spread on the sidewalks based on luminaire type and typical height and spacing measurements. The beam spread on the sidewalk should meet code requirements for coverage and intensity.
- › Beam spread on vertical building surfaces based on luminaire type and typical height and spacing measurements. The beam spread on the vertical building surfaces should not be blinding to occupants inside the building.
- › Flexibility of color temperature control. Flexibility of dual color temperature should range between 2,800 K and 5,000 K to accommodate color preference in business districts as well as other

locations. This also allows communities the ability to create a warmer environment in winter and a cooler one in the summer. Varying color temperature specifically integrates the street lighting to the surrounding landscape.

- › Light intensity. Light intensity will meet all code requirements. Dimming the light during periods of time with low activity can create additional energy savings. Varying intensity will also allow preference of brightness in business districts and quickly identify emergency areas for police and medical personnel.
 - › Light clarity. The light should be broad spectrum for accurate color rendition and provide good visibility without glare.
 - › Elimination of glare. Glare should be eliminated from most viewing angles with the exception of looking straight up.
 - › Integration with the surrounding context. The total effect of intensity, color temperature, clarity of light, beam spreads, and luminaire design in a business district and pedestrian streetscape context where 25' high pendent-mounted and/or 15' to 18' high pole-mounted luminaires are installed should be contextual.
 - › Visual experience. The total effect of intensity, color temperature, clarity of light, and beam spreads should enhance the safety and aesthetic beauty of the landscape and be a place where people want to be.
 - › Luminaire design. The design of the luminaire should not only house the specified LED breadboards, but should be aesthetically pleasing to the surrounding architecture and streetscape.
- Evaluations will be conducted based on a rating scale of 1-to-5, with 5 being excellent and 1 being unacceptable.



Fixture examples

Evaluation Procedure for Business District LED Lighting

This process is intended to provide the City of Pittsburgh the opportunity to consider actual luminaires and their performance in a laboratory setting and “in place” on a Pittsburgh business district street in order to consider different luminaire embodiments (replacement of cobra head, teardrop, shoebox, acorn, and globe luminaires with LED equivalents) and to qualify those luminaires to be considered for purchase and installation for the City’s business district LED lighting program.

The evaluation procedure will consist of a two-part, simultaneous testing process for each luminaire submitted, consisting of:

1. Laboratory testing and observation of each luminaire using imaging photometry at a testing facility capable of measuring luminance at high resolution by both photopic and scotopic measurements, such as Orfield Laboratories in Minneapolis, MN, for the luminaire’s compliance with the recommended performance.
2. Field testing and observation of each luminaire by the City of Pittsburgh and the Remaking Cities Institute for the luminaire’s compliance with the recommended performance and aesthetics criteria.

Manufacturers will fund the testing and install each luminaire for evaluation. Each manufacturer, or their representatives, will be responsible for installing all luminaires at the selected testing laboratory and on existing street lighting pendants or poles in Pittsburgh and certify that they are working properly. The laboratory testing will be in two planes at 10 degree angles from 0 degrees to 90 degrees. Each image capture will be photopic and scotopic. The intent of this luminance measuring process is to evaluate glare at a set of fixed viewing angles. The field testing will be conducted by the City of Pittsburgh and the RCI research team. Each manufacturer will have the option of sending additional LED

“breadboard” optics for evaluation of the same luminaire for laboratory testing and for field testing. Manufacturers requesting testing of additional LED breadboard optics should send multiple luminaires with different breadboards rather than change out lamp arrays within the same fixture.

For field testing, each luminaire is to be provided with adequate control mechanisms to test variable color temperature and intensity (dimming), including the ability to individually address the luminaire. Manufacturers will be responsible for providing the control mechanism within each luminaire and remote control mechanism(s) for testing within 100’ of the installed luminaire(s).

LED testing results will be submitted to the City of Pittsburgh, who will make the determination of each luminaire’s qualification for the business district LED lighting program. The City of Pittsburgh is under no obligation to qualify any of the luminaires submitted. At their discretion, the City of Pittsburgh reserves the right to qualify fixtures that do not meet all performance specifications and evaluative criteria.

The testing laboratory would be available to manufacturers for consultation during this process. Any findings that would modify the preferred performance will be shared with each participating manufacturer. The City of Pittsburgh is aware that this may be one of the first LED applications to approach a large LED project based on optics and urban qualities, rather than simply approaching the selection based on energy and life cycle cost savings claims.



Accessory LED color fixture, acrylic tube

Upgrade Option: Basic Controls

In addition to being control ready, these optional control features will provide additional versatility for intensity and color rendition:

- › The luminaire must be capable of dimming from 6 FC to 1.5 FC (code).
- › The luminaire must be capable of adjusting the color temperature range between 2,800 and 5,000 Kelvin.

Upgrade Option: Smart Street Lighting Control System

The following list of control options provide guidance with the practical points of operation of the base criteria and with specialty scenarios like wayfinding, emergency signaling, and special event lighting. Capabilities include:

- › Wireless and/or hardwire monitoring.
- › Monitor real-time power consumptions of fixture on a daily basis.
- › Diagnose fixture problems and issues.
- › Monitor age/lamp life.
- › Strobing/flashing capability for emergency uses.
- › Evacuation route designation with chasing LED lights.
- › Integration with police, fire and 911 services.
- › Dim/control light intensity.
- › Controls dimmable from 6 FC to 1.5 FC.
- › Ability to control a street light that has two different color temperature LED arrays in them, for example 2,800 K and 5,000 K.
- › Networked connectivity.
- › 256-bit encryption or better for security.

- › Ability to control accessory wayfinding fixtures attached to street light poles.
- › Software program to control, modify and monitor all of the above areas.

Optional Upgrade: Accessory LED Color Fixture

An accessory LED color system separate from the street light luminaire can be used for wayfinding, special events, and also emergency signaling. One type of accessory LED lighting fixture was researched as part of the study: an acrylic tube capable of infinite color variations that could be attached to a light pole and powered and controlled similar to the street light luminaire. See the accompanying illustrations of this accessory fixture. Other forms of accessory lighting are available, such as accessory LED lighting built into the supporting light pole or circular LED luminaires that wrap the pole, and this upgrade is intended to apply to all accessory possibilities.

These specifications are intended to provide the overall performance criteria for any accessory LED color fixture:

- › Contain RGB LEDs (red, green, blue) to achieve a bright uniform glow throughout the fixture. The quantity of LEDs is to be determined by a prototype.
- › Capable of operating within a temperature range of 40 degrees Celsius (-40 degrees Fahrenheit) to >50 degrees Celsius (122 degrees Fahrenheit).
- › The signal information for the RGB will come through a data enabler to allow control of each color.
- › Power can be either a 120V or a 240V system.
- › Signal source will be either DMX 512 or Ethernet.
- › The fixture must be waterproof along with its connectors.



Accessory LED color fixture

- › The mounting system will be affixed to the street pole by either strapping belts or bolts, or imbedded within the light pole.
- › The control signal will be either through the street light smart control management system, an independent wireless system or a separate hard-wired system.

Upgrade Option: Light Cue

A light cueing feature located on the street light luminaire would allow a small amount of white light to be visible above the cutoff level to serve as a visual indication as to whether or not the light is on.

Additional Research and Future Recommendations

This project with the City of Pittsburgh has developed a lighting approach and set a series of initial standards for business district luminaire performance funded so far. The recommendations contained in this report are for business district street lighting and, although many of the recommendations are transferable, no research or recommendations are made for neighborhood street lighting, which encompass the remaining 37,000 fixtures throughout the city slated for new LED fixtures. No product evaluation has been included for final standardization or certification of fixtures that meet these standards or for future neighborhood street lighting.

Neighborhood Street Lighting

Street lighting in neighborhoods will differ from business district lighting in a number of aspects, including lower lighting levels, potentially different fixture designs and neighborhood-specific controls. This report recommends that the City of Pittsburgh

undertake a research project for neighborhood street lighting similar to the approach used for this project. Likewise, a similar testing and evaluation program should be undertaken and qualified fixtures be certified as recommended below.

The neighborhood street lighting project could be undertaken prior to beginning a recommended Phase II product evaluation and certification process so that business district and neighborhood street lighting fixtures could be evaluated at the same time, a more cost- and time-effective procedure.

Pittsburgh LED Product Evaluation and Certification Program

Further research and evaluation is recommended as a Phase II in order to invite the vending community to further assist in the evaluation of their products via a testing process using imaging photometry at a testing facility capable of measuring luminance at high resolution by both photopic and scotopic measurement, such as Orfield Laboratories. Field observation and evaluation would also be part of this evaluation. This would involve an invitation to lighting manufacturers to participate with the City in a more rigorous evaluation of their products so that final standards and certification would occur. Although there is a testing and evaluation procedure for the initial business district LED lighting program, at this time there is no standardized method for this type of evaluation that Phase II would provide.

Phase II would consist of two parts:

1. Initial testing for type selection.
2. Final testing after luminaire standards and Smart Street Lighting Control System are refined.

Phase II would be also be funded by those manufacturers who want to be certified to provide LED lighting systems to the City of



Accessory LED color fixture

Pittsburgh. The findings would be shared with the participating manufacturers. Exact costs would depend on the number of products that each manufacturer submits and the testing regimen in each phase.

A significant part of this process is the development of the evaluation process and its administration. There are currently no standards for imaging photometry (IP) for use in quality benchmarking of LED street lights. And most current luminance measurements appear to be incorrect. This would be the first national process to actually perform this due diligence research, and this would be the first LED application, as far as the RCI research team is aware, to approach a large LED program based on visual and urban quality, rather than simply approaching it based on energy savings claims.

The two-phased testing process is intended to provide the City of Pittsburgh the opportunity to consider actual luminaires in place in order to consider different luminaire embodiments of this approach and to finalize the details of a standard to be used to certify luminaires under Pittsburgh's LED program.

The following is an outline of the recommended Phase II evaluation and certification procedure.

› **Phase II - Part 1**

A program explanation will be sent to each manufacturer explaining the intent, process, and costs of the Pittsburgh LED Certification Program. This would include the following types of information and submittal requirements:

- › This report prepared by the RCI research team.
- › A narrative explanation of the results of the testing and results of the initial LED business district lighting program.
- › A statement of the City of Pittsburgh/RCI research team lighting philosophy.

- › A statement of objectives regarding Part 1 and Part 2.
- › An explanation of the Phase II - Part 1 process of evaluation and testing.
- › An invitation to provide the manufacturer's views and suggestions regarding this process and to provide information that would be supportive of the process and objectives.
- › An invitation to supply and install one or more street lighting luminaires for testing based on the LED lighting philosophy and report that the manufacturer feels would be good benchmarks for testing. Each manufacturer would have the option of sending additional LED "breadboard" optics for evaluation in the same luminaire. Manufacturers or their representatives would install all luminaires at the testing laboratory and certify that they are working properly.
- › An opportunity, at the City's option, to present these luminaires to the RCI research team and City officials.
- › A timeline for participation in this process.
- › The development of a more detailed and final standard for LED fixture performance and procurement.

› **Phase II - Part 2**

A Phase II - Part 2 program explanation would be sent to each manufacturer explaining the intent, process, and costs of Part 2 of the Pittsburgh LED Certification Program. This would include the following types of information and submittal requirements:

- › A narrative explanation of the results of Part 1 and the final standard.
- › An invitation to supply and install one or more street lighting luminaires for testing based on the LED lighting philosophy and report that the manufacturer feels would meet the new performance standards.



Fixture example

- › Testing of the submitted luminaires at the testing laboratory for approval.
- › Repeated tests of luminaires that do not meet the test standard but now have been modified.
- › Analysis of results and report to the City of Pittsburgh/RCI research team.
- › Laboratory-approved luminaires to be field tested before certification. Manufacturers to provide three samples of each approved luminaire to the City, to be installed by the manufacturer or their representatives, for in-the-field evaluation by City officials and the LED research team. Field evaluation would follow the same procedure recommended for the initial LED business district lighting program. Manufacturers may be requested to make further modifications before certification.
- › Final certification to be issued by City of Pittsburgh upon successful field testing.

Modifications to the City of Pittsburgh Lighting Ordinance

It is generally acknowledged that the IES and ASHTO street lighting standards, including the City of Pittsburgh Lighting Ordinance which is based on those standards, do not adequately address LED glare. Glare has been recognized by many lighting designers and the IES as an issue, and some initial recommendations have been put forward for comments. However, imaging photometry has not been adopted or agreed as a legitimate method of measuring glare and LED luminaires continue to be manufactured without regard to the higher glare qualities of LEDs. As the RCI research team has seen, many of the European fixture designs with down-firing and up-firing LED sources have successfully addressed glare. However lighting manufacturers in this country continue to replicate HID fixtures with LED light sources,

because the market is demanding only the cost-saving qualities of LED retrofit lighting and not fixtures designed specifically to correct LED glare because of their higher costs. Manufacturers claim that municipalities are not requiring glare control.

As noted earlier in this report, uniformity of street lighting is not producing good results for visual acuity and clarity, particularly for older persons. Lighting standards and regulations now seek uniformity of lighting and many recent LED installations in other cities have exceeded the standard level of uniformity in an attempt to produce a higher quality result.

This report recommends that the City of Pittsburgh, through its LED lighting program and through the above additional research and testing, undertake a program to produce qualified LED products and subsequently revise the City of Pittsburgh Lighting Ordinance to reflect those findings and insure good LED street lighting.

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Pittsburgh Festival of Lights

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Appendices

Appendix A: Glossary

BULB: The light source within a street lighting fixture.

CANDELA: Unit of luminous intensity, describing the intensity of a light source in a specific direction.

COLOR RENDERING INDEX (CRI): A scale of the effect of a light source on the color appearance of an object compared to its color appearance under a reference light source. Expressed on a scale of 1 to 100, where 100 indicates no color shift. A low CRI rating suggests that the colors of objects will appear unnatural under that particular light source.

COLOR TEMPERATURE: The color temperature is a specification of the color appearance of a light source, relating the color to a reference source heated to a particular temperature, measured by the thermal unit Kelvin. The measurement can also be described as the “warmth” (red qualities) or “coolness” (blue qualities) of a light source. Generally, sources below 3200K are considered “warm,” while those above 4000K are considered “cool” sources.

CONTRAST: The relationship between the luminance of an object and its background.

CUT-OFF ANGLE: The angle from a fixture’s vertical axis at which a reflector, louver, or other shielding device cuts off direct visibility of a lamp. It is the complementary angle of the shielding angle.

DIRECT GLARE: Glare produced by a direct view of light sources. Often the result of insufficiently shielded light sources. (See GLARE)

DOWNFIRING: Light that is directed downward as a result of fixture type or design.

DOWNLIGHT: A type of ceiling luminaire, usually fully recessed, where most of the light is directed downward. May feature an open reflector and/or shielding device.

FIXTURE: See LUMINAIRE.

FOOTCANDLE (FC): The English unit of measurement of the illuminance (or light level) on a surface. One footcandle is equal to one lumen per square foot. Lux and footcandles are different units of the same quantity, and so it is valid to convert footcandles to lux and vice versa.

GLARE: The effect of brightness or differences in brightness within the visual field sufficiently high to cause annoyance, discomfort or loss of visual performance.

HID: Abbreviation for high intensity discharge. Generic term describing mercury vapor, metal halide, high-pressure sodium, and (informally) low-pressure sodium light sources and luminaires.

HIGH PRESSURE SODIUM LAMP: A high intensity discharge (HID) lamp whose light is produced by radiation from sodium vapor (and mercury). Casts an orange-yellow color.

ILLUMINANCE: A photometric term that quantifies light incident on a surface or plane. Illuminance is commonly called light level. It is expressed as lumens per square foot (footcandles), or lumens per square meter (lux).

INDIRECT GLARE: Glare produced from a reflective surface.

KELVIN (K): A unit of measurement for temperature, one of the seven base units in the International System of Units (SI), is assigned the unit symbol K. Used to measure color temperature.

LAMP: Device for providing light.

LIFE-CYCLE COST: The total costs associated with purchasing, operating, and maintaining a system over the life of that system.

LOW-PRESSURE SODIUM: A low-pressure discharge lamp in which light is produced by radiation from sodium vapor. Considered a monochromatic light source (most colors are rendered as gray).

LUMEN: A unit of light flow, or luminous flux. The lumen rating of a lamp is a measure of the total light output of the lamp and is not dependent on area (as is lux).

LUMINAIRE: A complete lighting unit consisting of a lamp or lamps, along with the parts designed to distribute the light, hold the lamps, and connect the lamps to a power source. Also called a fixture.

LUMINAIRE EFFICIENCY: The ratio of total lumen output of a luminaire and the lumen output of the lamps, expressed as a percentage. For example, if two luminaires use the same lamps, more light will be emitted from the fixture with the higher efficiency.

LUMINANCE: A photometric term that quantifies brightness of a light source or of an illuminated surface that reflects light. It is expressed as footlamberts (English units) or candelas per square meter (Metric units).

LUX (LX): The metric unit of measure for illuminance of a surface. One lux is equal to one lumen per square meter. One lux equals 0.093 footcandles. One footcandle equals roughly 10.764 lux. Lux and footcandles are different units of the same quantity and so it is valid to convert footcandles to lux and vice versa.

MAINTAINED ILLUMINANCE: Refers to light levels of a space at other than initial or rated conditions. This term considers light loss factors such as lamp lumen depreciation, luminaire dirt depreciation, and room surface dirt depreciation.

MERCURY VAPOR LAMP: A type of high intensity discharge (HID) lamp in which most of the light is produced by radiation from mercury vapor. Emits a blue-green cast of light. Available in clear and phosphor-coated lamps. Color temperature of 6500K.

METAL HALIDE: A type of high intensity discharge (HID) lamp in which most of the light is produced by radiation of metal halide and mercury vapors in the arc tube. Available in clear and phosphor-coated lamps. Color temperature range of 3000K to 20,000K.

NADIR: A reference direction directly below a luminaire, or “straight down” (0 degree angle).

PLACEMAKING: A term used by urban designers, architects and planners to describe the process of creating attractive and distinctive public places, such as public squares, commercial districts and streets.

PHOTOMETRY: The science of the measurement of light, in terms of its perceived brightness to the human eye.

PHOTOPIC VISION: The vision of the eye under well-lit conditions. (See SCOTOPIC VISION)

PUBLIC REALM: In urban design, a concept referring to any publicly-owned and occupied space, such as streets, sidewalks and right-of-ways, parks, pathways, publicly-accessible open spaces and public or civic buildings.

SCOTOPIC VISION: The vision of the eye under low light conditions. (See PHOTOPIC VISION)

UPFIRING: Light that is directed upward as a result of fixture type or design.

WAYFINDING: A process of orienting oneself and navigating from place to place.

› **LUCI (Lighting Urban Community International)**

LUCI was formed in 2002 by the City of Lyon as an international network bringing together cities and lighting professionals focused on leveraging light for urban, social and economic development. LUCI has nearly 100 members, comprising around 63 cities covering four continents and 35 associated members (international companies, lighting designers and architects, universities, independent lighting professionals, etc.). The LUCI Charter on Urban Lighting integrates principles for urban lighting with concerns for sustainable development, addressing the cultural and social dimensions of lighting, maintenance, recycling, light pollution, energy efficiency and quality of life.

› **BLISS (Better Lighting in Sustainable Streets)**

BLISS is a European project which was set up to achieve a reduction in street lighting energy consumption. The project participants are St. Helens in the UK, Eindhoven in the Netherlands, Interleuven in Belgium and Kaiserslautern in Germany. Together, these four European local councils intend to drastically reduce street lighting costs by using new cutting-edge technologies. BLISS is looking for bright ideas for Planet Earth.

› **LED City®**

Created by Cree, Inc., LED City® is an industry-driven partnership program focusing on the energy and maintenance cost savings of LED lighting for municipalities. Since 2007, LED City has worked with participating cities to develop evaluation methodologies and funding opportunities for LED retrofit programs. Pioneering LED cities include Raleigh, NC; Ann Arbor, MI; Anchorage, AK; Los Angeles, CA; Torraca, Italy; and Toronto, Canada.



Burj Dubai Street Column



Buchanan Street, Glasgow

Sorento Streetlight, Cambridge, UK

Speirs + Major collaborated with product designers Priestman Goode to create a new LED street light. The Sorento, designed for lighting group DW Windsor, was originally created for use in an urban lighting project in Cambridge, but has since been commercialized for use in other public spaces.

The street light was developed in response to the lack of lighting products suitable for historic areas. A success of this product is that it works in a historic context.

Burj Dubai Street Column, Dubai, UAE

This project called for specially designed public lighting, specifically a column that could be applied to both street and pedestrian lighting within an area encircled by Emaar Boulevard.

The design led to the production of 190 highway columns and 270 shorter pedestrian columns, installed on primary routes. A key aim was to respond to the proportions of the tower. The street light versions have two luminaires with 150W metal halide lamps providing warm white light. In the early morning hours one lamp switches off to save energy, and the luminaires alternate so that the lifespan for each remains balanced. The pedestrian-scale lamp has one luminaire. The result is a refined and carefully detailed design which fully reflects the prestige of its setting.

Scarborough Harbour Streetlight, Scarborough, UK

In order to reduce the dominance of the road, the design team decided to avoid using conventional highway light columns.

The landscape consisted of horizontal elements. The only vertical elements within the composition are the masts of the boats in the harbor which became the inspiration for a new streetlight that

could simultaneously light both pedestrian spaces and the road.

The new design consists of a tapering timber column rising from a black steel base sleeve. At the top is a 1.8m 'finial' of light, lit by low-energy LED. At night these form a row of beacons which reflect in the water of the harbour. Two steel arms emerge from the column, supporting separate luminaires – one lights the road with warm white light while the other lights the pedestrian areas in a contrasting cool blue.

Buchanan Street, Glasgow, UK

Objectives included the creation of a safe, but distinctive, environment and the concept sought to distinguish Buchanan Street, a pedestrian street, from the surrounding streets that were still lit in orange sodium.

The design challenged conventional highway lighting practice and demonstrated how low levels of lighting and even the use of color could create a vibrant and uplifting environment, while differentiating the pedestrian and highways routes.

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