New Lighting Technologies and Roadway Lighting:

An Informational Brochure

Developed by the **Lighting Research Center (LRC) at Rensselaer Polytechnic Institute**

Project Sponsors:
New York State Energy Research and Development Authority (NYSERDA)
New York State Department of Transportation (NYSDOT)

Lighting is an important element of roadway safety. Evidence suggests that roadway lighting is usually associated with reductions in nighttime crashes. After several decades of relatively slow and gradual change, light source technologies for roadway lighting are evolving rapidly. Many new options for roadway lighting are available, and there is more information about how light interacts with the human visual system. This informational brochure provides some information about these developments and how they might be incorporated into lighting practices for several types of roadways and locations in New York State. The focus is on replacement of older roadway lighting systems near the end of their useful lives, and on maintaining or improving visibility and safety while minimizing energy use and associated costs.

Types of Roadways Discussed

Roadways in New York State range from residential streets to freeways. This brochure focuses on three types of roadways.

Parkways

These are usually highways with designed landscaping and limited access control. They often carry traffic at fairly high speeds (greater than 40 mph) but are not built to the same standards as most freeways. Parkways may have more winding turns and changes in elevation than typical freeways; lighting might assist drivers in identifying and responding to these roadway features safely. Many parkways are considered historic or scenic in character, and maintaining this character is often an important lighting design consideration.

Residential streets

In many residential areas, the focus of lighting is more on nighttime pedestrian activity than traffic safety. Many residential street lighting systems are mounted on existing utility poles, which are located for the purpose of carrying utility lines, and not with lighting in mind. Providing light for pedestrian visibility often needs to be balanced against concerns for light pollution, especially light trespass onto residential windows that can disturb occupants.

Rural intersections

Most rural roadways are unlighted. When lighting is present, it is often in the form of isolated illumination of conflict areas such as intersections, and may consist of only one or two lights at a given location.

Technologies

Most roadway lighting in New York State presently uses high pressure sodium (HPS) lamps. HPS lamps produce a "yellowish" color of illumination, and are popular because of their relatively low initial cost, their efficiency (expressed in terms of luminous efficacy, or lumens per watt), their long useful lives, and their ability to maintain relatively high light output throughout their lives (called lumen maintenance). All of these factors combine to produce efficient, long-lasting and predictable lighting system performance.

In the past decade or so, several alternatives to HPS have emerged:

- **Metal halide (MH) lamps.** These lamps are similar in construction and operation to HPS lamps, but the ma-

Distinctive lighting along a parkway.

terials inside the lamp discharge produce "whiter" light. MH lamps have actually been available for several decades, but until recently their efficiency, useful lives and lumen maintenance were substantially poorer than HPS. Newer MH lamps with ceramic arc tubes and new methods of starting have much increased efficiency, life and lumen maintenance. Lighting systems using MH lamps are similar in appearance and luminaire (fixture) types to those using HPS lamps.

- **Fluorescent and induction lamps.** Fluorescent lamps are not usually thought of for roadway lighting, but a number of fluorescent roadway lighting systems are available. And more recent fluorescent lamp types known as induction lamps, which use radio frequencies to stimulate the material in the lamp to produce light (unlike conventional fluorescent lamps, which use electrodes at either end of the lamp tube), are becoming more widespread. Induction lamps have similar color as conventional fluorescent lamps and share their diffused appearance, but do not require the longer tubular shape of most fluorescent sources. Although they are somewhat more compact than conventional fluorescent lamps, induction lamps are still relatively large in size compared to HPS and MH lamps, and as a result, induction roadway lighting fixtures often need to be large to provide a uniform distribution of light on the roadway, or else they can produce light patterns with greater variations in light level.
- **Light-emitting diode (LED) sources.** Recent advances in solid-state lighting technologies have resulted in LED sources that produce white light, mainly by using short-wavelength LEDs that produce blue light in combination with phosphors that convert some of the blue light to yellow light, with the resulting mixture appearing white. LED roadway lighting systems are approaching and sometimes exceeding the efficiency of HPS systems. As solid-state devices, LED lighting systems potentially have very long rated lives–perhaps double that of HPS systems, and can exhibit good lumen maintenance, when fixtures are designed with proper heat management. Initial costs have been relatively high but are decreasing rapidly as this technology advances.

	High Pressure Sodium (HPS)	Metal Halide (MH)	Fluorescent Induction	Light Emitting Diode (LED)
Efficacy (lumens/watt)	80-120	60-110	60-90	70-120
Power (watts)	35-400	70-400	55-200	55-300
Operating Life (hours)	24,000-30,000	10,000-20,000	60,000	30,000-100,000
Correlated Color Temp. (kelvins)	2100 (yellowish)	2800-4200 (white/cool white)	2700-6500 (warm white/ bluish white)	3000-8000 (white/ bluish)

In general, each of these sources produces a "whiter" illumination color often judged superior to that of HPS illumination. The long operating lives and relatively high efficiency of these sources can make them suitable replacements or alternatives to HPS for roadway lighting.

Visual Efficacy

As lighting technologies have advanced, so has our understanding of the potential benefits, and drawbacks, of using these newer technologies for roadway lighting. One issue that stems from the use of "white" light sources like MH, induction fluorescent and LED lighting systems is the eye's sensitivity to light at nighttime light levels. Standards and recommendations for roadway lighting are given in terms of photometric quantities such as footcandles (fc) or lux (lx; 1 fc ≈ 10 lx), which are based on the eye's sensitivity to light at interior or daytime levels experienced in offices, schools and homes. The eye's sensitivity at nighttime levels actually shifts so that "blue" or "green" portions of the visible spectrum are relatively more effective than under daytime conditions, especially for seeing objects in the visual periphery.

Since "white" light contains energy in all parts of the visible spectrum while illumination from HPS lamps is concentrated in the "yellow" and "red" portions of the spectrum where the eye is relatively less sensitive under nighttime levels, visibility under "white" light sources may be under-estimated by conventional fc or lx relative to HPS. A growing number of experimental studies has shown that visibility under "white" light sources can be equivalent to HPS even if the measured

Images: LRC

A local road illuminated by high pressure sodium (left) and by fluorescent induction (right) systems.

light level is lower than under HPS, and international standards bodies are beginning to recognize these findings. The use of "visual efficacy" rather than "luminous efficacy" to quantify the usefulness of illumination for roadway lighting provides a way to maintain visual effectiveness under any light source, whether the "yellow" illumination from HPS, or the "white" illumination from MH, fluorescent induction, or LED sources.

Replacement Scenarios

Parkways

New York State has an extensive parkway system. Many of these roads were designed to have scenic qualities integrated with the landscape along which they are located and lighting is often an element of this design. It is not unusual for parkways to be lighted with historic luminaires mounted on wooden poles. Several of these systems are relatively old and in need of replacement.

In New York State, parkway lighting operating and maintenance costs are borne by NYSDOT in certain regions (NYSDOT Regions 8 and 10), and ornamental or decorative lighting intended to replicate a historic appearance along a historic parkway can be incorporated into a special specification in order to pay for such lighting. Ornamental or decorative lighting installation costs in other locations are borne by the municipality requesting it.

The most common luminaires used by NYSDOT are semi-cutoff luminaires using HPS lamps. Treating a parkway as a principal arterial roadway located along parks or vacant land, and assuming low pavement reflectance (i.e., asphalt) is used, the average recommended illuminance for a parkway would be approximately 0.9 fc based on guidelines from the American Association of State Highway and Transportation Officials (AASHTO) and the Illuminating Engineering Society (IES). The National Lighting Product Information Program (NLPIP) determined that for commercially available LED luminaires available in 2010, existing standards for lighting could be achieved with LED luminaires resulting in an average energy reduction compared to HPS lighting. (Initial costs tended to be higher because of higher equipment costs.) The average wattage of LED luminaires to meet existing standards was about 172 W(watts), or 7% lower than the wattage of a 150-W HPS lamp system (which uses 185 W once the ballast power is included).

Of course, every LED roadway luminaire has a very different optical distribution and design, so simply replacing existing HPS luminaires with LED ones may not provide sufficient uniformity of illumination. Specific luminaires should be checked in specific roadway scenarios to determine whether replacing an HPS with LED in existing mounting locations will conform to AASHTO and IES guidelines.

An average illuminance of 0.9 fc, assuming asphalt pavement, corresponds to a luminance of 0.3 candelas/square meter (cd/m²). At this luminance, an LED system with a correlated color temperature (CCT) of 4300 kelvins (K) would produce 35%-40% higher visual effectiveness (based on visual efficacy) than HPS. In theory, equal visual effectiveness could be achieved with a lower measured light level from a "white" LED source than under the "yellow" illumination from HPS, but current AASHTO and IES guidelines for continuous roadway lighting, such as is installed along many parkways, do not take visual efficacy into account.

Roadway Application	Base Case Lighting	Measured Light Level	Replacement Alternative
Parkways	150 W HPS (185 W total)	0.9 fc (average)	172 W LED (4300 K CCT or higher)

Residential Streets

A very common lamp type for local residential roads is the 100 W HPS lamp. AASHTO and IES recommend an illuminance of 0.4 fc when designing continuous lighting on local roads in residential areas. However, most residential street lighting systems are mounted to existing utility poles rather than dedicated lighting poles. As a consequence, residential streets might meet the average illuminance criterion of 0.4 fc but are not likely to meet other criteria such as uniformity.

Therefore, AASHTO and IES criteria are generally not limiting factors underlying the layout of most residential street lighting systems. Because pedestrians might be more likely to require peripheral vision in order to be seen while driving along a residential street, a residential street lighting retrofit of an HPS system could feasibly be deployed using a source with greater short-wavelength ("blue") spectral output and a lower photopic (light meter-measured) light level.

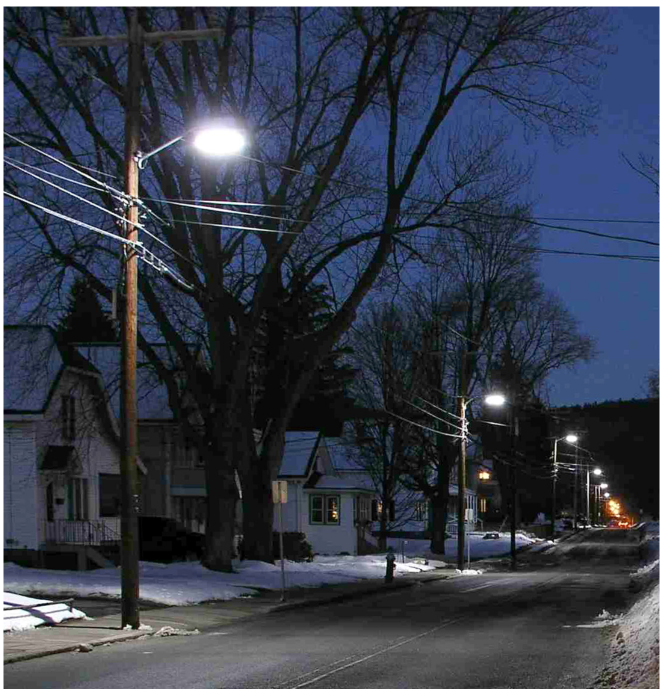

Image: LRC

Street lighting on utility poles in a residential neighborhood.

Assuming an average asphalt pavement luminance of 0.14 cd/m² when the average illuminance is 0.4 fc, a 4300 K CCT LED and a 5000 K CCT fluorescent induction luminaire would both produce the same unified luminance with a (photopic) illuminance of 0.2 fc. The efficiencies of LED and induction fluorescent street lights (evaluated by NLPIP in 2010) are similar to those of 100 W HPS luminaires. The total power used by a 100 W HPS system is 127 W (because of power required by the ballast in HPS systems). It is estimated that an LED or induction street light with a power of about 65 W could replace 100 W HPS luminaires, to achieve the same average visual effectiveness. Higher wattages would result in lower energy savings, but increase visual effectiveness even more relative to the HPS system.

Field evaluations of induction lighting systems replacing HPS luminaires on residential streets have confirmed that residential street lighting systems using 30% to 50% less energy could produce equivalent apparent visibility (as judged by residents of the streets) as HPS systems.

Roadway Application	Base Case Lighting	Measured Light Level	Replacement Alternative 1	Replacement Alternative 2
Residential streets	100 W HPS (127 W total)	0.4 fc (average)	65 W LED (4300 K CCT)*	65 W induction fluorescent (5000 K CCT)*

** - To provide equivalent visual effectiveness as the base case at the measured light level.*

Rural Intersections

A common method for illuminating rural roadway intersections is to use one or two luminaires at the intersection location, where the likeliest vehicle-to-vehicle conflicts would be expected to occur. AASHTO and IES guidelines are silent regarding illuminance recommendations for isolated intersection lighting systems. According to AASHTO and IES, illuminances at the intersections of continuously lighted roadways should be equal to the sum of the recommended light levels for the intersecting roadways. Assuming a local roadway intersects with a collector roadway in a rural area (and that both were continuously illuminated), the recommended illuminance would be 1 fc in the intersection conflict area and this is a reasonable light level for the conflict area at the intersection of two unlighted roadways. An illuminance of 1 fc could be achieved, for example, with two 100 W HPS luminaires, or with a single 150 W HPS luminaire.

A recent analysis of benefits and costs associated with rural intersection lighting in the state of Minnesota identified the necessary traffic volume required to achieve the break-even point between the cost of the lighting system (i.e., poles, luminaires, lamps, energy and maintenance) and the benefits in terms of the value of avoided nighttime crashes (in terms of avoided injury and property damage costs). A daily traffic volume of nearly 1900 vehicles/day through the busier roadway in the intersection was needed to break even, based on Minnesota data. While specific costs based on New York State costs and lighting practices would differ, such a method could be applied to rural intersections in New York State as well. Many intersections with low traffic volumes might not recover the costs of lighting because the benefits would be low in terms of the number of nighttime crashes reduced in a given time period (such as a year).

As described for parkways, LED luminaires for roadway lighting can meet AASHTO and IES recommendations with an average 7% reduction in power. Using the 150 W HPS lamp system as a base case for rural intersection lighting (having a total power of 185 W), LED luminaires with a power of 172 W would be expected to provide an illuminance of approximately 1 fc at rural intersections.

Image: Chris Phan

Rural intersection lighting.

The discussion to this point has focused on locations where vehicle-to-vehicle crashes are the predominant type of crash experienced during the night. At rural intersections where pedestrian-related crashes are of special concern and where detecting pedestrians relies on peripheral vision, it may be possible to take advantage of the higher visual effectiveness produced by "whiter" lamps producing lower conventionally measured light levels. For example, the same visual effectiveness as produced by 1 fc of HPS illumination (with an average asphalt pavement luminance of 0.32 cd/m²) could be achieved from either a 4300 K CCT LED system or a 5000 K CCT induction lamp system having 35% lower power than the equivalent to a 150 W HPS system, corresponding to 112 W for an LED system or 120 W for an induction fluorescent lamp system (compared to 185 W from the 150 W HPS system).

Roadway Application	Base Case Lighting	Measured Light Level	Replacement Alternative 1	Replacement Alternative 2
Rural intersection	150 W HPS (185 W total)	1 fc (in conflict area)	172 W LED (4300 K CCT) [112 W LED 4300 K CCT)]*	185 W induction fluorescent (5000 K CCT) [120 W induction fluorescent (5000 K CCT)]*

** - Alternatives in square brackets are to provide equivalent visual effectiveness as the base case at the measured light level if pedestrian detection through peripheral visibility rather than vehicle-to-vehicle crashes is of primary concern.*

Resources

The following resources contain helpful technical information about roadway lighting practices in New York State, lighting technologies, and visibility under nighttime conditions:

Roadway Lighting Guidelines and Recommendations

- *American National Standard Practice for Roadway Lighting,* Illuminating Engineering Society, 2000: http://www.ies.org/store/product/roadway-lighting-1028.cfm
- *Highway Design Manual: Chapter 12, Highway Lighting,* New York State Department of Transportation, 1995: http://www.dot.ny.gov/divisions/engineering/design/dqab/hdm/hdm-repository/chapt_12.pdf
- *How-to Guide to Effective Energy-Efficient Street Lighting for Municipal Elected/Appointed Officials,* New York State Energy Research and Development Authority, 2002: http://www.rpi.edu/dept/lrc/nystreet/how-to-officials.pdf
- *How-to Guide to Effective Energy-Efficient Street Lighting for Planners/Engineers,* New York State Energy Research and Development Authority, 2002: http://www.rpi.edu/dept/lrc/nystreet/how-to-planners.pdf
- *Policy on Highway Lighting,* New York State Department of Transportation, 1979: http://www.dot.ny.gov/divisions/operating/oom/transportation-systems/repository/policylight.pdf
- *Roadway Lighting Design Guide*, American Association of State Highway and Transportation Officials, 2005: http://bookstore.transportation.org/Item_details.aspx?id=320
- *Street Lighting as Part of NYSDOT Region 1 Construction Contracts: An Informational Booklet*, New York State Department of Transportation, 2008: http://www.dot.ny.gov/regional-offices/region1/repository/Street_Lighting_An_Informational_Booklet_NYSDOT_R1Desig1.pdf

Lighting Technologies

- *ASSIST Recommends: Recommendations for Evaluating Street and Roadway Luminaires,* Alliance for Solid State Illumination Systems and Technologies, 2011: http://www.lrc.rpi.edu/programs/solidstate/assist/pdf/AR-RoadwayEvaluation.pdf
- *Specifier Reports: Parking Lot and Area Luminaires,* National Lighting Product Information Program, 2004: http://www.lrc.rpi.edu/nlpip/publicationDetails.asp?id=900
- *Specifier Reports: Streetlights for Collector Roads,* National Lighting Product Information Program, 2010: http://www.lrc.rpi.edu/nlpip/publicationDetails.asp?id=927
- *Specifier Reports: Streetlights for Local Roads,* National Lighting Product Information Program, 2011: http://www.lrc.rpi.edu/nlpip/publicationDetails.asp?id=931

Visual Efficacy

- *ASSIST Recommends: Visual Efficacy,* Alliance for Solid State Illumination Systems and Technologies, 2009: http://www.lrc.rpi.edu/programs/solidstate/assist/pdf/AR-VisualEfficacy-Jan2009.pdf
- *Recommended System for Mesopic Photometry Based on Visual Performance*, Commission Internationale de l'Éclairage, 2010: http://www.cie.co.at/index.php?i_ca_id=788
- *Spectral Effects of Lighting on Visual Performance at Mesopic Lighting Levels,* Illuminating Engineering Society, 2012: http://www.ies.org/store/product/spectral-effects-of-lighting-on-visual-performance-at-mesopic-lighting-levels-1266.cfm

Credits

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Publication date: June 2012