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DOE Solid-State Lighting Program and Federal Highway Administration:

Roadway Lighting R&D Meeting

September 2022

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Disclaimer

DOE Solid-State Lighting Program & Federal Highway Administration, "Roadway Lighting R&D Meeting," September 2022.

This report was prepared for:

Solid-State Lighting Program
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Comments

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R&D Meeting Participants

Joe Cheung	Federal Highway Administration
Shirley Coyle	Independent Consultant
Maurice Donners	Signify
Ron Gibbons	Virginia Tech
Paul Lutkevich	WSP
Craig Marquardt	Acuity Brands Lighting
Don Mclean	DMD Consulting Engineers
Nick Mesler	Evari, GIS Audit
Jason Tuenge	Pacific Northwest National Laboratory
Don Vendetti	Evluma

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1 Introduction

On September 7, 2022, ten subject matter experts from industry, national laboratories, and universities gathered at the invitation of the Department of Energy (DOE) Solid-State Lighting Program and the Federal Highway Administration to identify critical research and development (R&D) topic areas in roadway lighting. The guidance provided by stakeholders on critical R&D areas may be incorporated into the DOE lighting technology strategy described in the DOE Solid-State Lighting R&D Opportunities document.

This year the meeting was held virtually. The meeting commenced with 'soapbox' presentations: each participant gave a short presentation describing what they believed to be the key R&D challenges for roadway lighting over the next three to five years. This was followed by a general discussion of the presentations and critical challenges hindering roadway lighting advances. The meeting format provided an opportunity for experts from the fields of lighting technology and roadway safety to exchange ideas and explore collaborative research concepts.

This report summarizes the outcome of the discussions on critical challenges and identifies corresponding R&D tasks within the existing task structure. Outlines of the participants' soapbox presentations and related remarks are included in Appendix A of the report.

2 Key Themes

The meeting format encouraged attendees to participate and present their perspectives on critical R&D challenges for roadway lighting. In the discussions that followed the soapbox presentations, several recurring themes arose regarding research areas that could lead to significant breakthroughs in technology development and implementation (in more detail below):

- Roadway lighting is a proven safety countermeasure
- Light-emitting diode (LED) technology offers the opportunity to provide 'ideal' lighting in terms of intensity, spectrum, timing, duration, and spatiality
- Considerations of driver safety, pedestrian safety, light trespass, and ecological effects need to be better understood and appropriately balanced
- There are barriers to adoption to more advanced lighting products, lighting designs, and controls

2.1 Roadway Lighting Improves Safety

The participants agreed that lighting is a proven roadway safety countermeasure for drivers and pedestrians. There are three times more roadway fatalities at night than during the day. 76% of pedestrian fatalities occur at night. Reduced visibility at night requires a longer stopping distance. Visual clutter and glare from roadway lighting and adjacent lighting and activities can further reduce visibility. Weather conditions can also reduce visibility or counteract the positive visibility effects of roadway lighting. However, there is a point of diminishing return where more light does not contribute to increased safety.

2.2 LED Source Capabilities and 'Ideal' Lighting

LED technology offers the potential to provide 'ideal' light in terms of intensity, spectrum, timing, duration, and spatiality (or optical distribution) for the specific roadway setting.

- Intensity: The modularity of LED technology enables a broad range of light outputs and target illuminance levels. LED technology is also fundamentally dimmable; intensity levels can be fine-tuned to meet the minimum target requirements to avoid energy waste and light pollution.

- Spectrum: The technology also offers a wider range of spectral power distributions through white light sources. Preliminary research has shown that white light enables better contrast detection and therefore better visibility. Studies have shown that 4000K white light enables further visibility and stopping distance than 3000K or high pressure sodium (HPS) spectral power distributions.

- Timing and duration: Because LED technology can be instantaneously dimmed and turned off and on, the use of presence sensors, timers, motion detectors, or other adaptive control elements can be readily achieved. This could greatly reduce energy waste and light pollution without affecting the intended safety function of the installed lighting. Lights would only be on when necessary for safety.

- Spatiality: Controls could also be used to make the lighting responsive to different visibility conditions. LEDs are small optical sources that can achieve precise optical control. Upward directed light, light that is off target, and light that causes glare can be eliminated or minimized with appropriate optical design.

While achieving 'ideal' roadway lighting conditions is possible, there is still debate on the definition of 'ideal' lighting. Existing research can be limited by the shortcomings of previous light source technologies that could not be readily dimmed, turned off and on instantaneously, engineered with different SPDs, or achieve good optical control.

2.3 Balancing Varied Interests

Research is necessary to better understand how to balance the impacts of LED technology on driver safety, pedestrian safety, light trespass, and ecology. Research can be conducted in controlled settings such as test roads and test ecological beds. However, given the variety of roadway settings, systematic approaches are needed to understand the role of lighting in vehicular crashes. This principle also applies to ecological research. Ecosystem-scale lighting effects need to be understood so that the benefits and drawbacks of roadway lighting can be appropriately balanced.

Post-installation follow-up reviews of performance and impacts are critical in determining the safety effects of new roadway lighting for drivers and pedestrians. Light levels, light distributions, luminance levels, glare metrics, energy consumption, crash rates, injuries, and light trespass complaints can be evaluated and reviewed after changes to a lighting situation. This information can inform future products and installations. Follow-up review of roadway lighting should be the accepted best practice for all installations. When lighting conditions can be better linked to safety and ecological outcomes, informed decisions can be made.

2.4 Barriers to LED Adoption

While new capabilities offer advanced performance and benefits, increasingly complex options can be confusing to lighting specifiers. Specifiers are often dealing with large fixture quantities covering wide areas with a broad range of setting-specific considerations. There is a 'one size fits most' approach where buyers seek to use the fewest number of variants of roadway lighting products. Buyers and specifiers also often revert to previous lighting decisions without considering the new capabilities of LED technology. There is a pressing need for improved training, education, and guidance that incorporate the new capabilities of LED technology. These capabilities can meet new performance considerations, including reduced energy consumption, reduced total light output (for ecological considerations), more targeted light, and reduced light trespass.

Appendix A: Participant Presentations

Joe Cheung, FHWA, "FHWA Lighting Research and Development"

Joe Cheung, safety engineer at the Federal Highway Administration, kicked off the presentations with his discussion of FHWA's Safe System approach. The Safe System approach is based on six key principles. These principles are that death and serious injury are unacceptable, that humans make mistakes, that humans are vulnerable, that responsibility is shared, that safety is proactive, and that redundancy is crucial. Cheung focused his talk on the last two principles, proactive safety and redundancy. FHWA is using a systematic approach to identify risks and implement measures to prevent crashes before they occur. Street lighting can provide redundancy to further reduce crashes, especially those resulting in pedestrian fatalities. This is especially important in light of the fact that the nighttime crash fatality rate is three times that of the daytime, even though much more travel occurs during the day. 76% of pedestrian related fatalities occur at night. This has important implications for equity as well, since pedestrian deaths occur at higher rates in underserved communities. FHWA recommends that agencies engage with communities to improve roadway lighting in priority areas. Cheung presented a series of findings from recent research in this topic area, including that after certain lighting levels there is no improvement in pedestrian visibility and that urban clutter can reduce driver awareness, increasing the need for lighting in these areas.

Ron Gibbons, Virginia Tech Transportation Institute, "Balancing the Good and Bad in Roadway Lighting"

Ron Gibbons, professor at Virginia Tech Transportation Institute, presented on "Balancing the Good and the Bad in Roadway Lighting." Gibbons began by stating that the goal of ideal lighting is to meet the goals of the relevant space and thus varies depending on the space and application. He then outlined 5 controllable factors for roadway lighting: intensity, spectrum, timing, duration, and spatiality. Gibbons argued that roadway lighting research should aim to determine how to put the right light when and where it is needed rather than coating light all over a space. Although safety is critical, it is important to consider the other impacts of roadway lighting, such as public perception, energy use, human health, ecological impact, and light pollution. For example, often when converting from HPS to LED lights, agencies and municipalities receive complaints that the white LEDs are too harsh. This can impact the viability of current and future conversions. Furthermore, impacts will vary in importance for different applications. Overall, Gibbons argued that roadway lighting professionals must shift focus from finding the 'perfect lighting' that can be used everywhere to finding the ideal lighting for each condition.

Paul Lutkevich, WSP, "Owners and Designers Need Clear Direction on How to Balance the Lighting Approach to Best Address Impacts in Different Settings"

Paul Lutkevich, vice president at WSP, discussed recommendations for the spectral content of roadway lighting. He said that research on this subject sometimes generates conflicting results as to how we can improve safety while minimizing environmental impact. Owners and designers need clear direction on how to balance these impacts. Designers don't know how to go about evaluating the environmental impact of their systems and thus struggle to lessen it. One way might be examining species in the area and designing the spectrum with those species in mind. However, a method for doing this has not been established. The industry needs a tool or metric to apply findings from research to systems. This tool could then be taken to the IES Roadway Lighting Committee or the AASHTO Roadway Committee. Otherwise, research findings will not be applied throughout the US.

Don McLean, DMD, "Lighting Controls"

Don McLean, senior partner at DMD Consulting Engineers, outlined barriers for controls implementation in roadway lighting. McLean argued that LEDs and controls have evolved similarly over the last 15 years. However, LEDs have achieved mass adoption, while controls lag far behind. One major barrier is the lack of standards and guidance for how to use controls to vary light levels for roadway lighting. There is liability for state DOTs and potential safety consequences if controls are implemented poorly. In addition, cost and payback are the only tools used to assess whether controls are worth the investment. Use of other metrics could

illuminate further benefits. Utility rate structures often hinder controls installation as well, since power for streetlights is often provided at a flat rate rather than on a per unit energy basis. Finally, technology remains an issue, especially from a cybersecurity standpoint. McLean noted that as the language used to describe these developments (including phrases like 'smart street lighting' or 'smart city') has evolved, the lighting piece has faded into the background. To address this, McLean suggested revision of the current lighting standard to a more flexible standard written by him and others. The new standard would examine speed, geometric configuration, and density and weight them according to importance. McLean closed by calling for better optical control and improved light quality on roadways.

Shirley Coyle, Independent Consultant, "Roadway Luminaires as a Commodity"

Shirley Coyle, an independent lighting consultant, discussed how roadway lighting is viewed as a commodity and suggested ways for the industry to emphasize that lighting quality for roadways matters. Coyle began by pointing out that in most roadway lighting projects, product selection is being done by people unfamiliar with the benefits quality lighting can bring. As a result, the lowest cost product is often chosen at the expense of important roadway outcomes. She argued that if manufacturers and roadway lighting researchers can't quantify the benefits of quality lighting, it will always have limited adoption. Coyle suggested multiple avenues for making lighting quality part of the cost/value analysis. First, she argued that IES recommendations for roadway lighting include maximum levels in addition to minimum levels. This would help avoid glare. She also recommended development of additional guidance on spectrum for pedestrian safety and environmental impact. Once glare and spectrum guidance are developed, the authors must train manufacturers, designers, agencies to implement it in their projects. Post-installation studies to highlight successes would also be helpful. Finally, communications aimed towards the public could help accelerate adoption.

Jason Tuenge, Pacific Northwest National Laboratory, "Collecting and Using Roadway Lighting System Data to Improve Design, Operation, and Maintenance"

Jason Tuenge, researcher at Pacific Northwest National Laboratory, discussed a potential structure for future research that may help fill gaps in understanding, education, and product R&D for roadway lighting. The first idea was related to the effective lifetime of LED roadway luminaires and how one will know when these luminaires need to be replaced. LEDs have decreasing light output over time. They are also still susceptible to failure. He outlined that the goal of this type of research would be to maintain safety while reducing energy consumption and costs. The key to success would involve outreach to early adopters of LED systems (reaching 10-14 years in some cases) and collecting primary data from their aging systems. Challenges in this approach would be the stakeholder willingness to share data, cost of field measurements, available calculation parameters, and uncertainty in forecasting any lumen depreciation or other mechanisms of failure. The second topic was whether roadway light levels can be safely reduced. He cited examples of studies showing that LED replacements for outdoor HID equipment was generally at lower light levels, with total light output 1/3 to 1/2 of HPS lights. However, the lower lumen output may be acceptable, particularly if the quality of lighting is higher, providing better visual acuity. This type of research could also support reduction in energy consumption while minimizing light pollution and other side effects. Starting with early adopters and a standardized lighting data collection process, illumination levels could be reduced to IES RP-8 recommendations. Then, if the data supports it, the illumination levels for IES RP-8 could be reduced. Challenges of this approach may be that system operators may be averse to detailed scrutiny of design and outcome data. Furthermore, there remains difficulty with limited data completeness, data quality (nominal rather than measured), and associating crashes to light levels as opposed to other factors.

Don Vendetti, Evluma, "Assessing Glare in Current LED Streetlight Offerings"

Don Vendetti noted that glare is one of the leading complaints from end-use customers, but that this is not easily defined and could be due to many factors (e.g., CCT, light trespass, discomfort glare). He presented detailed analysis of 29 luminaires from various large and small manufacturers of outdoor and roadway luminaires. The model assessed these using AGi32, with a focus on 100 W HPS Type 2 LED replacements, typically used in residential areas (~6,000 lm with roughly 50W-60W and 4000K). The analysis examined various parameters to determine if all RP-8 parameters were met. Pole spacings varied widely from 150 to 220

ft. Major limiting factors were max-to-min uniformity ratio and the veiling luminance ratio. To further parse the data, the team used 150 ft spacing as the control variable. At this pole spacing, there was a 2.75x spread for best-to-worst ratio for uniformity and 1.7x spread for best-to-worst veiling luminance ratio. Most specifications in the industry are illuminance based and they only look at average luminance and average-to-min ratio instead of max-to-min ratio or veiling luminance. However, this modeling showed that moving from using average-to-min ratio to max-to-min ratio changed the failure rate from 14% to 48%. He noted that one potential downside of controlling glare can be lowered efficacy, with roughly 11% reduction in efficacy in the luminaires analyzed. He closed by emphasizing the need to balance efficacy goals with higher quality of light, incentives for manufacturers and end-users to acquire lower glare models, and to standardize and publish glare ratings.

Maurice Donners, Signify, "Striking a Balance and Road Lighting Research Topics"

Maurice Donners described how European outdoor lighting faces similar challenges as in the United States: a need to strike a balance between budget, energy, safety, and user satisfaction. Recent research has piqued new interest in how light, particularly outdoors, impacts the environment and people (light trespass). He also noted there is a growing concern in lighting regarding the sustainability of lighting products, including limited material usage and recyclability. Further understanding of discomfort glare is one of the most important research topics, as this should be an observer-based metric. Correlating glare with a physiological response may be necessary rather than just measuring glare at the source of light. Other research topics could include how lighting impacts alternative transportation modes such as cyclists and pedestrians, as well as studying lighting in inclement weather. For controls, more research is needed on dimming based on traffic density or composition, as well as lighting based on road surface conditions. Development of better metrics, particularly with glare, are essential to adoption and implementation of better lighting solutions. Even if product performance is improved by manufacturers, new products will not enter the market if the metrics are not well developed.

Craig Marquardt, Acuity Brands Lighting, "Roadway Safety, Reduced Glare, Higher Vertical Illumination with Tailored Distributions"

Craig Marquardt opened by explaining the misuse of lighting distributions in the field for an intended roadway or outdoor lighting application. He showed that the applications of residential, commercial, and infrastructural street lighting are incredibly varied, with each requiring different optical distributions needed to promote safety and reduce glare and light trespass. However, because of an overemphasis on B-U-G ratings and lack of customer education or expectations, the same type of distribution is being applied across the board to meet minimum numbers required. As an example, he showed an analysis of two Type 2 luminaires of the same lumens and wattage with radically different distributions that would be fit for different applications (one more urban, and one more rural). He presented another example of two Type 3 lights with the same lumens and efficacy, but with drastically different distributions: one being standard, and the other with a strong curb line cutoff. He concluded by emphasizing the need to develop a system to teach stakeholders specifying these distributions about how they can be applied to each specific end-use and application. He stated that it is proven the lighting industry can design any distribution today, so it is paramount that we design or select it for the proper application.

Nick Mesler, Evari GIS Consulting, "Twilight Safety"

Nick Mesler provided some background on EVARI and their data work on 3 million LED replacements across the United States. He posited that current interpretation of collision data may be incorrect, and that the industry needs to reindex the data to the appropriate natural lighting conditions. Although dusk/dawn is reported as 5% of collisions, dusk/dawn accounts for up to 25% because twilight is often misreported as night. Twilight accounts for 12-18% of a 24-hour period, but accounts for 25% of all collisions. Personal interpretations of dusk or dawn is subjective, and thus the reporting for collisions may not indicate the exact conditions under which the crash occurred. Instead, he proposed analyzing by time of collision, then using the geographic location by coordinate, alongside time and date, to evaluate the actual natural light levels of the collisions. Currently, funding is available from FHWA for safe street designs. Street lighting is now a proven safety

countermeasure, with collision reduction potential of up to 42% (larger than any other traditional transportation safety improvements). He concluded by explaining that vehicle collisions are highly related to celestial conditions (angle of the sun) rather than time (e.g., rush hour). Furthermore, there are spatial relationships to collisions and the incidence of daytime and nighttime collisions occur at distinct locations. Particular environments could be causing these collisions alongside their different lighting conditions.

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