

GATEWAY

Demonstrations



Trial Demonstration of Area Lighting Retrofit

Host Site: Yuma Border Patrol, Yuma, Arizona

December 2014

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Prepared by:

Pacific Northwest National
Laboratory

Yuma Border Patrol Area Lighting Retrofit Trial Demonstration

Final Report prepared in support of the DOE Solid-State Lighting Technology
GATEWAY Program

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Pacific Northwest National Laboratory
U.S. Department of Energy

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Preface

The GATEWAY Program

This document is a report of observations and results obtained from a lighting evaluation project conducted under the U.S. Department of Energy (DOE) GATEWAY Program. The program supports evaluations and demonstrations of high-performance solid-state lighting (SSL) products in order to develop empirical data and experience with in-the-field applications of this advanced lighting technology. The DOE GATEWAY Program focuses on providing a source of independent, third-party data for use in decision-making by lighting users and professionals; this data should be considered in combination with other information relevant to the particular site and application under examination. Each GATEWAY evaluation compares SSL products against the incumbent technologies used in that location. Depending on available information and circumstances, the SSL product may also be compared to alternate lighting technologies. Though products used in the GATEWAY program may have been prescreened for performance, DOE does not endorse any commercial product or in any way guarantee that users will achieve the same results through use of these products.

Acknowledgements

The assistance of the following individuals was critical in the development of the following report:

- Harry Hart, Customs and Border Protection
- Heather Santiago, Customs and Border Protection
- Bob Smith, PE, Eaton's Cooper Lighting
- Dale Stolzenburg, Eaton's Cooper Lighting

These individuals assisted with various aspects of this report, from providing technical information to reviewing and commenting on the report. Their efforts are greatly appreciated.

Executive Summary

The Yuma Sector Border Patrol Area is a high luminous flux lighting application in a high temperature environment, presenting a formidable challenge for light-emitting diodes (LEDs). The Yuma Sector lighting retrofit was documented to better understand LED technology performance in high temperature environments. This retrofit is an Energy Savings Performance Contract ENABLE project under the U.S. Department of Energy (DOE) Federal Energy Management Program.

The LED lighting system selected for the retrofit is expected to reduce energy consumption 69% compared to the incumbent quartz metal halide (QMH) lighting system. The annual maintenance cost savings was not permitted to be included in the economic analysis for this project; however, includes considerable reductions in maintenance visits required by the contractors and Customs and Border Protection's (CBP's) internal time and resource savings. The retrofit includes a 24 ft reduction in pole height, which would further savings due to reduced lift and labor costs. The advanced optical system of the selected luminaires improved the uniformity of illumination despite the reduction in pole height. The pole height reduction also considerably reduced stray light.

Night is when the most activity occurs in the Yuma Sector Border Patrol Area, so it was important to ensure the lighting system would help the border patrol agents perform their duties. The LED lighting system installed for the trial demonstration confirmed LED technology's ability to improve lighting quality and reduce energy consumption. The design target was equal or greater maintained illuminance compared to the incumbent QMH system, which the LED system met. The initial output of the LED system and the maintained output of the QMH system—which had been operating for an unknown number of hours—were measured at the time of the trial demonstration. The average illuminance was comparable between the two systems. The average illuminance was greater for the LED system than the QMH system for all horizontal measurements taken between the primary fence (along the U.S.-Mexico border) and the secondary fence (125 ft back from the primary fence), and horizontal and vertical measurements on the primary fence side of the pole (located 45 ft from the primary fence). The vertical illuminance on the primary fence increased by more than 100% relative to the QMH system. The average horizontal and vertical illuminance on the secondary fence side of the pole was slightly lower for the LED system. The LED system delivered equal or better uniformity than the QMH system.

The lighting system installed for the trial demonstration had been on the market less than 2 years, yet at the time of the installation an upgraded system that incorporated a newer generation LED package was going to be released to the market in the coming months. The upgraded lighting system provided improved efficacy and optical distributions, resulting in the expected energy savings of 69%.

Lumen and color maintenance, luminaire efficacy, and luminaire component lifetimes are all significant concerns when LED luminaires are exposed to high ambient temperatures. If high luminous flux LED technology performs well in a region with high ambient temperature and solar radiation, it can perform well in most outdoor environments. The design process for the Yuma retrofit has already provided valuable knowledge to CBP and DOE. If the LED lighting system is installed, we will continue to document and disseminate information regarding the installation and long-term performance so that others may also gain valuable knowledge from the Yuma Sector Border Patrol Area lighting retrofit.

Acronyms and Abbreviations

A	ampere(s)
APS	Arizona Public Service
CCT	correlated color temperature
CBP	U.S. Customs and Border Protection
CRI	color rendering index
DOE	U.S. Department of Energy
ESCO	energy service company
ESPC	Energy Savings Performance Contract
FEMP	Federal Energy Management Program
HID	high-intensity discharge
IP	ingress protection
IES	Illuminating Engineering Society
IGA	investment grade audit
kWh	kilowatt-hour(s)
LED	light-emitting diode
LLF	light loss factor
lm	lumen(s)
lm/W	lumen(s) per watt
lx	lux
MH	metal halide
NEMA	National Electrical Manufacturers Association
POE	port of entry
QMH	quartz metal halide
SOW	scope of work
SSL	solid-state lighting
TWh	terawatt-hour(s)
TMY2	Typical Meteorological Year 2

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1. Introduction

High luminous flux applications in high temperature environments present a formidable challenge for light-emitting diodes (LEDs). Lumen and color maintenance, luminaire efficacy, and luminaire component lifetimes are all significant concerns when LED luminaires are exposed to high ambient temperatures. These challenges are among the reasons why the Yuma Sector Border Patrol Area lighting retrofit on the U.S.-Mexico border was documented by the U.S. Department of Energy (DOE) Solid-State Lighting (SSL) GATEWAY program. This border lighting application also presented an opportunity to save energy and improve lighting quality.

A border lighting application is unique; however, high luminous flux and/or high temperature applications in the United States are not unique. Applications include high security exterior lighting, such as correctional facilities and military bases, and more generally street and area lighting. DOE estimates that annual federal outdoor lighting electricity consumption is approximately 5.0 terawatt-hours (TWh), with 66% attributed to roadway and area lighting.¹

The retrofit is a DOE Federal Energy Management Program (FEMP) Energy Savings Performance Contract (ESPC) ENABLE project administered through the General Services Administration. The program provides a process for small federal facilities to quickly implement energy conservation measures using pre-established procurement and technical tools and qualified energy service companies (ESCOs). Through this process an ESCO was selected, and Eaton's Cooper Lighting Business (Cooper) supported the ESCO by designing the lighting system and manufacturing the luminaires.

Several steps were required in the ESPC ENABLE scope of work (SOW), including an investment grade audit (IGA), which according to the SOW is "validation by contractor of the survey/evaluation information performed utilizing FEMP-provided survey tools." The SOW required that a sample of luminaires be installed on three sequential poles as a trial demonstration of the proposed design solution for CBP approval prior to the task award. This report summarizes the results of the IGA and selection of a final design solution.

This Phase 1 report is the first in a planned series that documents the installation of the LED luminaires that were selected by CBP for their superior photometric performance and 69% energy savings compared with the incumbent quartz metal halide (QMH) luminaires. If the luminaires are installed, future reports will summarize the performance at the time of installation and the long-term performance of the LED luminaires in the high ambient temperature environment.

- **Yuma Phase 1 Report: Investment Grade Audit Trial Demonstration:** Describes the Yuma Sector Border Patrol Area and focuses on the IGA trial demonstration including development of the lighting system design and photometric measurements taken during the IGA trial demonstration.
- **Yuma Phase 2 Report: Initial Assessment of Installation (Pending):** Will summarize the installation and initial performance of the lighting system. Our plans include sample photometric, thermal, and energy measurements, and the results of initial testing of several luminaires prior to installation for later follow-up testing to evaluate field condition impacts.

¹ U.S. Department of Energy. 2012. Outdoor Solid-State Lighting Potential at Federal Sites. Prepared by Federal Energy Management Program.

- **Yuma Phase 2 Updates (Pending):** Will review the results of ongoing data collection, including field illuminance measurements of the overall lighting system and individual laboratory testing of lumen depreciation and color shift for a sample of the luminaires.
- **Yuma Phase 3 Report: Long-term Assessment of Installation (Pending):** Final report that will encapsulate 30 months of data collection, providing an overview of the data collection and analysis of the effects of the desert environment on the LED system.

2. Background

The Yuma Sector Border Patrol Area, near the Yuma San Luis Port of Entry (POE), spans 9 miles south of Yuma, AZ, along the U.S.-Mexico border. The goal of the retrofit was to replace the existing luminaires lighting the area along the border to achieve a minimum energy savings of 50% while maintaining existing light levels. The area of interest was between the primary fence marking the U.S.-Mexico border and a secondary fence set back 125 ft from the primary fence. The terrain and lighting system design for the 1.8 miles west of the POE varies along the border, while 7.2 miles east of the POE the terrain, lighting system design, and fence spacing are consistent. This report focuses on the 7.2 miles east of the POE, shown in Figure 1.



Figure 1. U.S.-Mexico Border East of San Luis POE: Area Between Primary (left) and Secondary (right) Fences. Photo taken from the east end of the 7.2 mile area, looking west. The QMH Nighthawk luminaires are mounted on the poles at a height of 64 ft.

2.1 Application Description

This tactical border application was a challenge for LED luminaire technology because it required high luminous flux in a region with high ambient temperature and solar radiation. The 180 ft pole spacing and 125 ft spacing between the primary and secondary fences required each LED luminaire to cover approximately 11,250 ft², with an approximate average illuminance of 25 lux (lx) at a 40 ft mounting height. The higher the flux from a luminaire, the more difficult it can be to properly dissipate the heat to prevent damage to the luminaire electronic components and LED packages. Dissipating heat is even more difficult in high temperature environments. For a typical year, as determined from Typical Meteorological Year 2 (TMY2) data sets², the maximum temperature at sunset in this area is approximately 38°–44°C (101°–112°F) and the minimum is approximately 2°–6°C (36°–43°F)³.

² U.S. Department of Energy. National Solar Radiation Data Base. Produced by the National Renewable Energy Laboratory. http://rredc.nrel.gov/solar/old_data/nsrdb/1961-1990/tmy2/.

³ A TMY2 data set was not available for Yuma, so the ranges reflect data from Phoenix and Tucson, Arizona.

The border patrol area east of the POE is 125 ft wide, split by the pole line with 45 ft between the pole line and the primary fence and 80 ft between the pole line and secondary fence. The 14 ft corrugated metal primary fence blocks visibility through the fence; however, the 12 ft metal mesh secondary fence allows border patrol agents to easily see objects through the fence. A schematic of the border patrol area is illustrated in Figure 2.

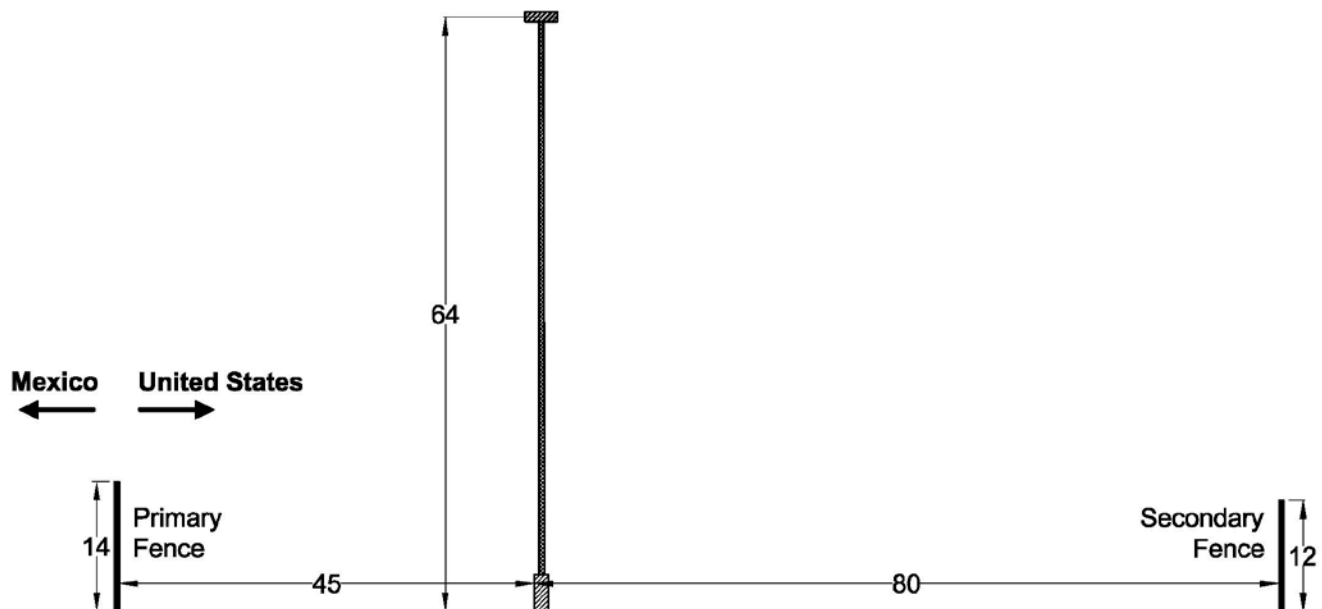


Figure 2. Schematic Elevation of the Yuma Sector Border Patrol Area East of the San Luis Port of Entry. The figure is representative, and does not indicate the exact dimensions along the entire 7.2 mile border area east of the San Luis POE. All dimensions are in feet. The elevation near the secondary fence was approximately 2-4 ft higher than the base of the concrete pole pedestal.

The 7.2 miles east of the POE requires continuous surveillance by border patrol agents, and the role of the lighting is to allow the border agents to perform their job tasks equally well day or night. The Illuminating Engineering Society (IES) does not currently have specific recommendations for a border security application. Chapter 25, *Lighting for Emergency, Safety and Security*, in the *IES 10th Edition Lighting Handbook* does not list recommendations for any security applications and instead directs readers to IES G-1, *Guidelines for Security Lighting for People, Property, and Public Spaces*. The IES G-1-03 recommendations for the applications most similar to the border are listed in Table 1. The guarded facilities recommendations do not directly apply because the border is not an entrance or an area of inspection, furthermore, maintaining 100 lx is environmentally and financially unsustainable. The unoccupied spaces application is similar, but again deviates from the border lighting application because of the high security nature of the border. As of the writing of this report, it is our understanding that the next revision of IES G-1 will include recommendations for patrolled and/or guarded exterior lighting applications.

Table 1. IES G-1-03 Recommendations for Security Applications Similar to a Border Lighting Application. The table lists three of the 41 applications listed in G-1, ranging from senior housing to fast food restaurants.

Application	Average	Avg/Min Ratio
Unoccupied spaces - storage yards, industrial equipment area and container terminals	5-20 lx	8 (horizontal)
Guarded facilities - entrances and gatehouse inspection	100 lx	3 (horizontal)
Facial identification	5-8 lx	4 (vertical)

2.2 Incumbent System Design

Two hundred and five poles were spaced 180 ft apart along the 7.2 miles east of the POE. The incumbent design consisted of three Cooper Lighting Lumark Nighthawk QMH luminaires per pole, each with a nominally 1000 W QMH lamp and a National Electrical Manufacturers Association (NEMA) 7×6 beam spread.⁴ According to the as-built drawings from December 2008, the center floodlight was to be oriented in the direction of the primary fence and tilted 61° from nadir. The two end luminaires were to be oriented 85° east and west from the direction of the primary fence and tilted 55° from nadir. All luminaires were to be mounted on a tenon at a height of approximately 64 ft. Bronze visors (i.e., shields) were added to the QMH Nighthawk luminaires to mitigate stray light.

When five of the poles were surveyed by Cooper in December 2013, the tilt of the end luminaires ranged from 43°–51° with an orientation ranging from 85°–90°. The center floodlight tilt ranged from 32°–43° with no deviation from perpendicular relative to the fence. The luminaires were lamped with 1000 W probe start QMH lamps manufactured by Technical Consumer Products, Inc., with a mean lumen rating of 64,400. Each floodlight consumed approximately 1080 W, increasing slightly over time as the lumen output of the lamp depreciated. The center floodlight was disconnected for all 205 poles, which was indicated on the December 2008 as-built drawings. The reason the luminaires were initially disconnected was to reduce energy use due to funding constraints; however, the center luminaire may have never been switched on due to the perception of adequate lighting from the two end luminaires on each pole.

Maintenance of the luminaires occurred consistently, with spot re-lamping and bi-annual cleaning. Cleaning is also scheduled after rainfall if funds are available. The maintenance, re-lamping, and cleaning costs totaled over \$200,000 annually during 2012 and 2013. This cost is only contractor costs, and does not include internal CBP costs for maintaining the luminaires.

The border area east of the POE was divided into eight sections, each with 23 to 27 poles that were operated by two photocells aimed northward. The luminaires in each section were turned on simultaneously by the photocells and had no dimming capability. The only non-lighting loads on the system were gates on the secondary fence. CBP did not maintain a record of lamp outages; however, every month the CBP program manager would drive the entire 9 mile length of the Yuma Sector Border Area to verify the operation of the luminaires. Photocells, ballasts and lamps were replaced monthly as needed by the contractor.

⁴ For further information read section 3.3.3 of IES RP-6-01.

3. Retrofit System Design Process

An ESCO⁵ was selected to provide services for the ESPC ENABLE Yuma Sector Border Lighting Retrofit. The ESCO led communication, organized the financing of the project, and completed required documentation. Eaton's Cooper Lighting Business supported the ESCO through technical and design expertise and manufacturing of the luminaires. FEMP provided advisory and technical assistance to CBP through the ENABLE program. The GATEWAY program documented the design process, and the following details the design process for the IGA.

3.1 Design Requirements and Parameters

A lighting project on the U.S.-Mexico border has unique characteristics; however, the parameters and constraints of this project are similar among government projects, exterior area lighting applications, and high ambient temperature conditions. The design process for the Yuma Sector Border Area Lighting retrofit began with initial information gathering and computer simulations that varied as the parameters of the project varied, and continued beyond the field demonstration of the lighting system. The design process included weekly meetings and continuous discussions between the ESCO, Cooper, CBP, and DOE representatives to meet the design objectives of the retrofit.

3.1.1 Initial CBP Design Restrictions and Requirements

The SOW outlined several restrictions and requirements for the retrofit, including meeting Border Patrol Facilities and Tactical Infrastructure Standards. The restrictions aimed to protect the environmental conditions of the area, safety of the occupants, and the quality of the human environment. There was also concern about the lighting system's impact on migratory birds, so environmental protection specialists were consulted throughout the design process. The requirements focused on the characteristics of the lighting system and were as follows:

1. In-situ temperature measurement test⁶ at 45°C (113°F), representing the maximum nighttime temperature for the Yuma Border Sector.
2. Average illuminance greater than or equal to 30 lx, with a maximum to minimum ratio less than or equal to 20.
3. Correlated color temperature (CCT) between 4000 and 5000 K.
4. Efficacy that met or exceeded the FEMP-designated performance level for outdoor pole/arm-mounted area and roadway luminaires of greater than or equal to 65 lumens per watt (lm/W).

The SOW did not specify if the average illuminance was initial or maintained; however, it is assumed that it was intended to be maintained illuminance on the horizontal plane. The SOW targeted 50% energy savings and the target payback for the project was 15 years or less. All changes to the existing lighting were required to happen during the day, so that the luminaires on all poles were operational before sundown. The IGA trial demonstration of the proposed design was also mandatory.

⁵ As of this writing, the project is not proceeding with the original contractor, so the contractor is not identified in this report.

⁶ U.S. Energy Protection Agency. 2012. ENERGY STAR Program Requirements Product Specification for Luminaires (Light Fixtures) Eligibility Criteria Version 1.2. Prepared by Office of Air and Radiation.
http://www.energystar.gov/ia/partners/product_specs/program_reqs/Final_Luminaires_V1_2.pdf?5ed0-1202.

3.1.2 Revised CBP Design Requirements

Cooper led the discussions regarding the selection and layout of the luminaires, and the design requirements established by CBP in the SOW were refined during these discussions. Cooper completed an initial audit of the incumbent lighting system, including taking illuminance measurements. After Cooper completed and shared results of the initial computer simulations and spot measurements of the incumbent QMH Nighthawk lighting system, it was determined that meeting or exceeding the light levels provided by the incumbent lighting system—in its depreciated luminance state—was acceptable. The results of Cooper’s initial lighting measurements of the incumbent lighting system, listed in Table 2, served as the baseline that was to be met or exceeded by Cooper’s LED luminaire design solution.

Table 2. Initial QMH Lighting System Illuminance Measurements [Cooper]. The illuminance levels were measured between poles 199 and 200 during Cooper’s initial audit of the lighting system. The horizontal illuminance in the area was measured on a 10 x 10 ft grid. Not every grid point was measured. The vertical measurements occurred at 3, 6, and 9 ft high on the fence.

Location	Average (lx)	Max (lx)	Min (lx)	Max/Min Ratio
Poles to Primary Fence (45 ft) - Horz	23.8	69.4	6.5	10.7
Poles to Secondary Fence (80 ft) - Horz	14.7	61.1	2.0	30.6
Primary Border Fence - Vert	9.2	19.0	4.8	4.0

The LED Galleon-AA⁷ area and site luminaire was selected from Cooper’s product line as the luminaire that could best meet the needs of the application. The LED Galleon-AA provided scalable lumen packages and customizable optics, allowing for design flexibility and optimization. The luminaire lumen package could be scaled by altering the number of light squares⁸ in the luminaire—with a corresponding change in the size of the luminaire housing—and a different optic package could be used for each light square.

Cooper’s initial simulations of the border area showed that it was possible to lower the height of the pole and improve uniformity with the LED Galleon-AA due to superior optical control. Lowering the pole height decreased the required number of light squares from 10 to 8, reducing the power consumption by 20% and delivering similar illuminance levels. There was concern that the decrease in pole height would increase vandalism; however, after discussion of the construction and durability of the LED Galleon-AA and examples of the ability of other LED luminaires to withstand vandalism, CBP agreed on a height of 40 ft for the IGA trial demonstration. Each square of the Galleon-AA is powered by two separate circuits, so if one circuit opens due to damage, the other half of the LEDs within the square will continue to operate, and other squares within the luminaire will be unaffected. A ballistic shield was considered, but it increased the cost, decreased the light output, changed the distribution and did not provide a substantiated increase in durability.

3.2 Design Solution

Two LED Galleon-AA luminaires mounted on each pole at a height of 40 ft and spaced 180 ft apart was the final solution selected for the trial demonstration based on computer simulations. The LED Galleon-AA was specified with eight light squares, six directed toward the primary fence and two directed toward the secondary fence. Figure 3 shows the LED Galleon-AA solution with eight IES Type III distribution light squares. Two of the light squares had the same distribution directed in the opposite direction because these light squares illuminated the 80 ft distance between the poles and secondary fence. The remaining six light squares illuminated the area

⁷ AA is notation used by Cooper to indicate the generation of the LEDs used in the luminaire.

⁸ Light squares, bars, and packages are terms used by luminaire manufacturers to describe the scalable lumen output characteristic of their luminaires.

between the pole and primary fence, a distance of 45 ft. The primary fence and the 45 ft between the pole and the primary fence required higher levels of illumination because the primary fence and the sand-covered ground close to the primary fence were the main focus of the border patrol agents at night. The border patrol agents often drove along the secondary fence, with a spot-light mounted on the vehicle providing additional light in the area near the secondary fence.

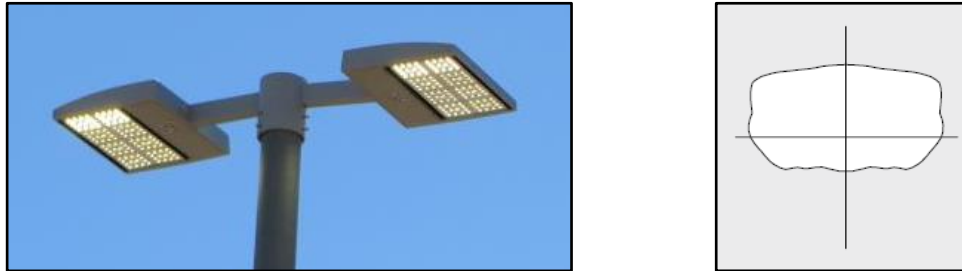


Figure 3. LED Galleon-AA IGA Design Solution (left) and the Asymmetric Distribution of the Light Squares [Photos: Cooper]. In the photo at the left, two light squares in each luminaire appear brighter than the other six due to their different orientation. These two light squares are oriented within the luminaire to illuminate the area between the poles and the secondary fence. All eight light squares in each luminaire provide the same output and exhibit the same IES Type III asymmetric distribution.

According to Cooper, the LED Galleon-AA 480 V luminaires drew 398 W of input power and produced approximately 31,200 lumens (lm).⁹ Philips Lumileds LXML-PWN2 LED packages were used in the Galleon-AA light squares and operated at a 1 A drive current. The results of the LXML-PWN2 IES LM-80 test showed lumen maintenance at or slightly above 100% at 10,000 hours for all three case temperatures (55°, 85°, and 105°F). The TM-21 report provided by Cooper estimated lumen maintenance of 95.7% at 60,000 hours. The in situ temperature testing was conducted at ambient temperatures of 25°C and 50°C and interpolated to 40°C for the TM-21 report. The lighting system was initially designed with a 0.95 light loss factor (LLF). Cooper determined that it was not necessary to include luminaire dirt depreciation factor as part of the LLF because of the ingress protection (IP) 66 rating¹⁰ and the low possibility of environmental film on the luminaire optic due to the arid conditions at the site. According to the IES LM-79 test report provided by Cooper, the color rendering index (CRI) of the LED Galleon-AA was 66 for the 4000 K CCT option.

Networked controls were considered by CBP because of the capability to record outages and to save energy, but such a control system was not installed for the IGA trial demonstration. The use of motion sensing was briefly discussed; however, CBP decided all luminaires needed to remain at the same output during dusk-to-dawn operation. There was a serious concern about the potential of the motion sensing system to distract agents through diversionary tactics by transgressors, false-triggers due to wildlife, or not function as desired by the agents. A motion-controlled lighting system would require a significant paradigm shift from using light as a trespass deterrent to light as an indication of trespass. There were too many unknowns associated with the paradigm shift, and further demonstration of the technology was needed before employing the technology. A significant shift would also require research, broader discussion, and acceptance throughout CBP.

⁹ Watts based on bench-top testing performed by the manufacturer. Lumens based on assumption that output at 480 V is equal to output at 277 V.

¹⁰ International Electrotechnical Commission Ingress Protection Standard 60529 indicates an IP66 enclosure is a dust tight enclosure that can withstand powerful water jetting.

4. Investment Grade Audit

The IGA trial demonstration was an important opportunity for CBP and DOE representatives to understand the quantity and quality of light that could be delivered with LED luminaires. The IGA presentation and trial demonstration occurred on the evening of Feb. 4, 2014. Seventeen representatives from the ESCO, Cooper, CBP, and DOE were present. DOE gave a brief presentation concerning the technical characteristics of LED lighting systems and an overview of the GATEWAY program. Cooper presented information comparing the QMH Nighthawk lighting system to the LED Galleon-AA lighting system, followed by the trial demonstration of the LED Galleon-AA luminaires.

4.1 Trial Demonstration

Poles 203, 204, and 205 were cut to approximately 36 ft from the top of the concrete pedestal for the IGA so the total height of the pole plus the pedestal would be at 40 ft above grade, illustrated in Figure 4. Two LED Galleon-AA luminaires were installed per pole with a custom tenon mount, pictured in Figure 5, replacing the three QMH Nighthawk luminaires. The only required electrical modifications occurred at the top of the pole. When removing the incumbent QMH Nighthawk, it was noted that the wind had bent the top of the pole and caused it to bow. According to Cooper, there were no unexpected issues when retrofitting the QMH Nighthawk to the Galleon-AA.

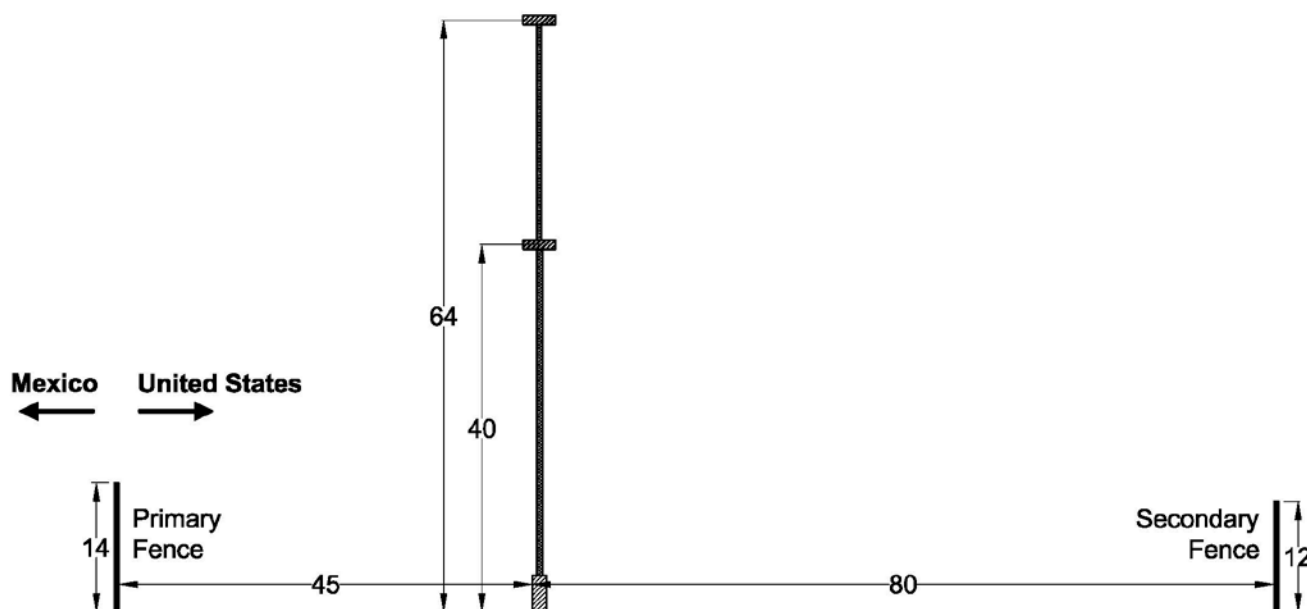


Figure 4. Schematic Elevation of the Yuma Sector Border Patrol Area East of the San Luis Port of Entry: 64 ft and 40 ft Pole Heights. The dimensions are not exact; however, are representative of the 7.2 mile border area east of the POE. All dimensions are in feet. The elevation near the secondary fence was approximately 2-4 ft higher than the base of the concrete pole pedestal.

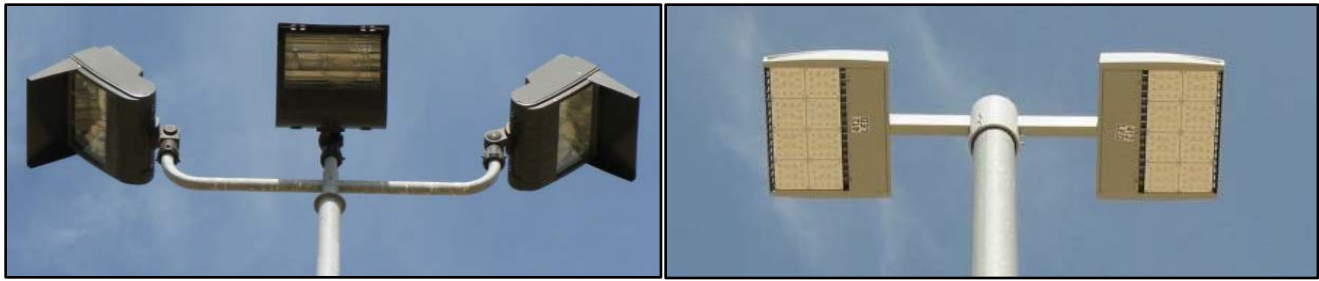


Figure 5. Incumbent QMH Nighthawk Luminaires (left) and LED Galleon-AA Luminaires (right). A custom tenon was necessary to fit the diameter of the pole after the pole was cut to 40 ft, because the diameter of the tapered pole narrowed as the height increased. The QMH Nighthawk luminaires were originally installed with visors to minimize stray light.

4.1.1 Comparison of QMH Nighthawk and LED Galleon-AA

The 17 representatives from the ESCO, CBP, and DOE traveled from the presentation site to the border site for the trial demonstration, stopping a few miles away from the border to observe the difference between the LED and the QMH system from a distance, represented in Figure 6. There was consensus among the group that the LED Galleon-AA solution was not as noticeable at the QMH Nighthawk, which clearly indicated the location of the border. The reduction in stray light was so drastic that there was concern about the border no longer being easy to recognize; however, consensus was that the lack of stray light was not a problem because the stray light did not deter illegal border crossings. The difference in height is also visible in both Figure 7 and Figure 8.

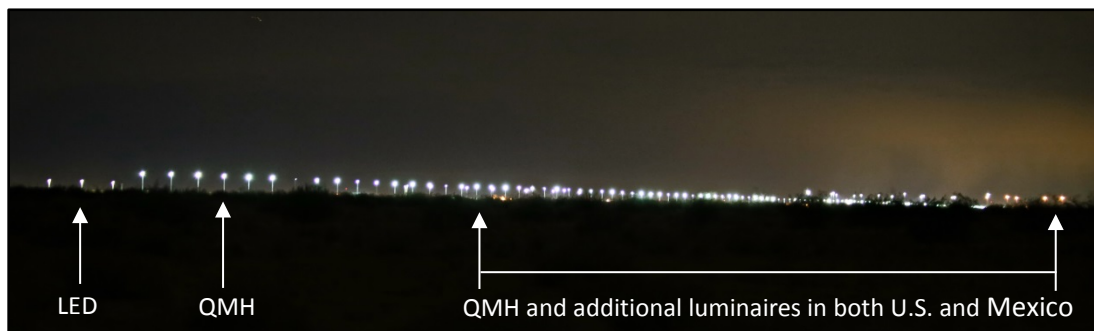


Figure 6. Yuma Sector Border Area at Night from the U.S. The photo was taken a few miles north of the U.S.–Mexico border. The photo is representative of the observed visual difference between the QMH luminaires mounted at 64 ft and the LED luminaires mounted at 40 ft. The apparent brightness of the Galleon-AA compared to the QMH varied at different viewing angles because of the differences in luminaire orientation and photometric distribution.

Upon arriving at the trial demonstration site, the ESCO and Cooper representatives gave a brief review of the similarities and differences between the two systems, which had already been discussed during the presentation. The LED Galleon-AA system was initially dimmed to 60% power, unbeknownst to CBP. After observation of the dimmed system compared to the QMH Nighthawk system, the LED Galleon-AA system power was increased to 100%. The exercise helped CBP understand the role of the human visual system in perceiving light levels in an environment that is otherwise very dark, and to determine the desired level of light. There were mixed opinions regarding the level of lighting necessary, some thought 60% was sufficient while others preferred 100%. It was later determined that light levels near 100% were required.



Figure 7. IGA Trial Demonstration Site - Nighttime: QMH Nighthawk vs. LED Galleon-AA. The 24 ft difference in height is visible in this image. The primary fence is on the left and the secondary fence is on the right, but is barely noticeable in this image due to the relatively low light level on the fence.



Figure 8. IGA Trial Demonstration Site - Daytime: QMH Nighthawk vs. LED Galleon-AA. The 24 ft difference in height is visible in this image. The primary fence is on the left and the secondary fence is on the right.

Night is when the most activity occurs on the border, so it was important to ensure the lighting system would help the agents perform their duties, which include preventing/detering illegal border crossings. The improved uniformity of the LED Galleon-AA lighting system was one benefit noted by CBP. The identification of footprints in the sand was of particular concern, and the improvement in uniformity did not hinder the identification of footprints. Additionally, the mounting height and durability of the luminaires continued to be discussed. The incumbent QMH Nighthawk luminaires in the Yuma Border Sector Area had not been broken; however, the luminaires in other border sectors were commonly hit by slingshots and small caliber firearms. One of the benefits mentioned for lowering the height was that the luminaires would be less expensive to maintain at 40 ft

than at 64 ft. During both the presentation and demonstration, Cooper discussed the benefits of a wireless control system and encouraged CBP to seriously consider incorporating controls. Cooper also encouraged the use of the newest generation light square, the “AE,” instead of the currently proposed and installed “AA” light square. The AE was not available at the time of the IGA, but was available a couple of months after the trial demonstration and offered a 27% improvement in efficacy.

4.2 Measurements

Immediately following the group review of the IGA mock-up installation, GATEWAY researchers measured the horizontal illuminance on the ground and the vertical illuminance on the primary and secondary fences under both the QMH Nighthawk and the LED Galleon-AA lighting systems. The measurements were taken from the middle of the primary face of the concrete pole pedestal at 15 ft intervals in all four cardinal directions for both systems. The horizontal measurements were taken approximately 9.5 in. above the ground and the illuminance meter was leveled for each measurement with a tripod head. This was necessary because of the unevenness of the sandy terrain. Vertical measurements were taken at a height of 4 ft and 8 ft at the fence, along the same column as the horizontal measurements. The illuminance meter was not leveled for each vertical measurement.

The Konica Minolta T-1 Illuminance Meter was used (serial number: 207839, calibrated June 25, 2013). The temperature varied between 56°–58°F and there was no rain or noticeable wind at ground level.

4.2.1 QMH Nighthawk Measurements

For the existing QMH Nighthawk system, 225 horizontal measurements and 100 vertical measurements were taken between poles 199 and 201, centered on pole 200. The poles closest to the retrofitted poles were selected, as illustrated in Figure 9. The luminaires had been operating over 4 hours when the initial measurements were taken. The total operating hours since installation of the QMH lamps and last luminaire cleaning was unknown at the time of measurement. The luminaires are cleaned bi-annually at a minimum, with cleaning scheduled after rainfall if funds are available. Cooper estimated through field measurements, computer simulations, and knowledge of the QMH Nighthawk system that the system was delivering 65% of the light of a new lamp and optical system. Generally, over a 2 year period the light output of a QMH luminaire is between 60% to 100% of the initial value, depending on the time since the last re-lamping and cleaning.

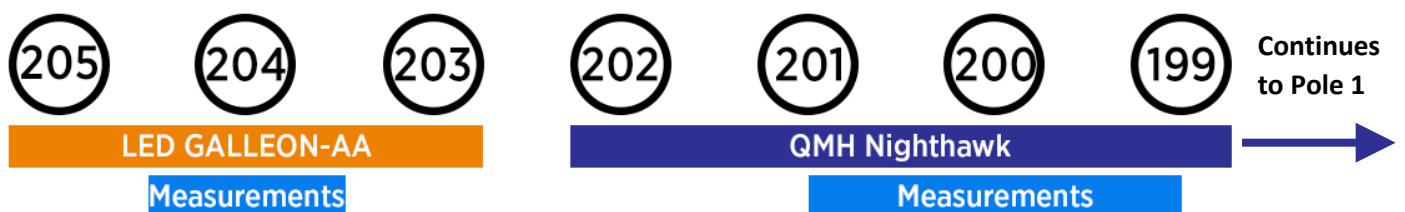


Figure 9. Schematic of Pole Layout: Luminaire and Measurement Location. Measurement of the LED Galleon-AA system was limited to half the distance between the poles on either side of pole 204 due to time constraints. Measurement of the QMH Nighthawk system extended from pole 201 to pole 199.

A subset of the QMH system measurements is presented in Figure 10 and the full set of measurements is detailed in Appendix A. The central hotspot near the pole is evident in the measurements; however, the measurements do not completely capture the non-uniform distribution of the QMH Nighthawk lighting system. The visors on the QMH Nighthawk luminaires caused stripes on the ground that were sometimes parallel and sometimes crossed; however, these stripes are not evident in the measurements because the stripes were small and fell between measurement points. The stripes of light moved on the ground as the wind moved the luminaires.

	Pole 200												QMH (lx)			
8'	7.5	7.9	7.9	7.8	8.6	6.9	6.1	7.3	8.1	7.9	8.0	9.0	8.9	7.8	Avg	Secondary Fence - Vertical
4'	7.2	7.7	8.0	7.7	8.6	6.6	6.3	6.8	7.7	8.2	8.1	8.3	8.6	9.0	Max	
Secondary Fence														6.1	Min	
	6.0	6.6	7.3	6.5	7.6	5.7	6.2	5.5	6.5	6.7	6.7	6.5	7.1	11.9	Avg	3 Rows Closest to Secondary Fence - Horizontal
	8.1	9.1	11.1	10.9	10.8	9.8	20.3	9.1	9.4	10.4	10.6	9.6	9.2	53.6	Max	
	10.4	11.3	14.4	14.3	14.2	20.3	53.6	19.0	21.8	20.0	18.7	12.3	11.2	5.5	Min	
	13.1	13.7	18.5	17.2	19.5	39.9	80.2	29.9	28.0	25.9	20.8	14.4	13.0	21.0	Avg	All - Horizontal
	14.1	17.5	24.8	20.9	27.4	35.6	87.0	37.9	33.2	29.4	24.1	16.9	15.4	101.0	Max	
	15.3	16.2	26.1	21.7	23.9	32.6	101	43.0	36.9	32.7	26.7	16.7	15.3	5.5	Min	
	14.8	15.0	21.8	19.9	22.2	32.2	89.0	43.5	30.7	26.4	22.2	15.4	14.5	22.2	Avg	3 Rows Closest to Primary Fence - Horizontal
	12.7	13.3	20.8	18.4	20.6	24.6	67.2	34.1	23.6	21.9	18.2	13.6	13.0	89.0	Max	
	11.0	11.2	15.2	12.4	14.6	16.4	23.9	17.9	17.3	17.5	15.2	12.5	11.9	11.0	Min	
Primary Fence														12.2	Avg	Primary Fence - Vertical
4'	8.9	8.9	11.2	11.1	11.2	12.3	18.0	13.8	14.2	14.8	12.3	10.3	9.5	18.0	Max	
8'	9.8	9.7	11.0	12.7	9.9	12.4	17.1	13.9	14.7	14.8	13.0	10.9	10.2	8.9	Min	

Figure 10. IGA Horizontal and Vertical Illuminance Measurements: QMH Nighthawk Lighting System. The horizontal measurements were taken at 9.5 in. above ground and the vertical measurements were taken at 4 ft and 8 ft above ground at the base of the fence. The horizontal measurements were taken from the middle of the primary face of the pole pedestal at 15 ft intervals in all cardinal directions for both the QMH and LED systems. The black solid line indicates measurements greater than or equal to 30 lx, and the white solid line indicates measurements greater than or equal to 20 lx. The square color represents the relative measured illuminance quantity: Green – low horizontal; Purple – high horizontal; Orange – low vertical; Yellow – high vertical.

4.2.2 LED Galleon-AA Measurements

For the new LED Galleon-AA system, 81 horizontal and 52 vertical measurements were taken between poles 203 and 205, centered on pole 204, and are shown in Figure 11. The luminaires had been installed for less than a week when the measurements were taken, and had not been operated prior to installation. The number of horizontal measurements was limited due to sunrise, so approximately one quarter of the measurements were estimated west of the pole based on the measurements east of the pole. The five measurements directly between the pole and secondary fence were taken between 6:40 and 6:50 a.m. Civil twilight occurred at 7:04

a.m. and sunrise was at 7:30 a.m. The reduction of the pole height, in addition to the change in mounting and luminaire design, resulted in no noticeable stripes on the ground or movement of the pole due to wind.

	Pole 204													LED (lx)		
8'	4.3	4.3	4.6	5.0	5.7	6.5	6.7	6.7	6.1	5.2	4.6	4.6	4.8	5.7	Avg	Secondary Fence - Vertical
4'	4.7	4.8	5.1	5.7	6.7	7.4	7.7	7.6	7.1	6.2	5.7	5.6	5.9	7.7	Max	
	Secondary Fence													4.3	Min	
	3.8	3.9	4.0	4.1	4.2	4.4	4.6	4.4	4.2	4.1	4.0	3.9	3.8	8.4	Avg	3 Rows Closest to Secondary Fence - Horizontal
	6.7	6.7	6.9	7.0	7.4	7.9	8.1	7.9	7.4	7.0	6.9	6.7	6.7	15.4	Max	
	13.5	13.5	13.0	13.3	14.1	15.2	15.4	15.2	14.1	13.3	13.0	13.5	13.5	3.8	Min	
	20.0	21.4	22.7	22.7	24.6	26.3	26.3	26.3	24.6	22.7	22.7	21.4	20.0	22.0	Avg	All - Horizontal
	25.9	26.7	27.6	28.1	33.8	40.1	42.1	40.1	33.8	28.1	27.6	26.7	25.9	45.5	Max	
	27.7	29.6	29.7	31.7	34.2	37.5	45.5	37.5	34.2	31.7	29.7	29.6	27.7	3.8	Min	
	28.0	28.6	29.6	30.7	34.6	39.0	41.6	39.3	36.5	33.3	32.7	30.8	28.3	28.5	Avg	3 Rows Closest to Primary Fence - Horizontal
	27.1	27.7	27.9	27.9	28.8	30.2	30.2	30.7	30.7	29.1	30.8	29.9	27.3	41.6	Max	
	23.1	23.8	22.3	22.0	23.5	24.0	24.5	24.9	24.0	22.5	23.0	22.7	21.1	21.1	Min	
	Primary Fence													29.3	Avg	Primary Fence - Vertical
4'	25.0	26.3	28.0	29.2	30.8	33.1	31.8	32.2	30.3	26.7	28.4	26.1	24.2	36.8	Max	
8'	21.4	23.6	27.8	32.5	33.7	36.5	36.8	36.5	34.5	32.0	28.8	23.4	21.5	21.4	Min	

Figure 11. IGA Horizontal and Vertical Illuminance Measurements: LED Galleon-AA Lighting System. The horizontal measurements were taken at 9.5 in. above ground and the vertical measurements were taken at 4 ft and 8 ft above ground at the base of the fence. The horizontal measurements were taken from the middle of the primary face of the pole pedestal at 15 ft intervals in all cardinal directions for both the QMH and LED systems. The black solid line indicates measurements greater than or equal to 30 lx, and the white solid line indicates measurements greater than or equal to 20 lx. The area within the dashed white and black line was not measured and was estimated by mirroring the corresponding measurements on the other side of the pole. The square color represents the relative measured illuminance quantity: Green – low horizontal; Purple – high horizontal; Orange – low vertical; Yellow – high vertical.

4.2.3 Measurement Comparison

The measured illuminance values and calculated uniformity metrics for the QMH and LED systems are listed in Table 3. The design target for the LED Galleon-AA lighting system was to deliver equal or greater maintained illuminance compared to the incumbent system. This comparison is the initial output of LED system and the maintained output of the QMH system, which had been operating for an unknown number of hours. The average illuminance was comparable between the two systems. The average illuminance was greater for the

LED system than the QMH system for all horizontal measurements taken between the primary and secondary fence, and the horizontal and vertical measurements on the primary fence side of the pole. The vertical illuminance on the primary fence increased by more than 100% relative to the QMH system. This increase was not requested by CBP, but was viewed as beneficial. The average horizontal and vertical illuminance on the secondary fence side of the pole was slightly lower for the LED system. The LED system delivered equal or better uniformity than the QMH system, and easily met the tactical requirement of a maximum to minimum horizontal illuminance ratio of less than or equal to 20.

Table 3. IGA Horizontal and Vertical Illuminance Measurements: QMH vs. LED. The table summarizes the measured illuminance values for five different areas between the primary and secondary fence. The horizontal measurements were taken approximately 9.5 in. above the ground and the vertical measurements were taken at 4 ft and 8 ft above the ground along the fences.

Area	Source	Avg (lx)	Max (lx)	Min (lx)	Max/Min Ratio	Avg/Min Ratio
Secondary Fence - Vertical	QMH	7.8	9.0	6.1	1.5	1.3
	LED	5.7	7.7	4.3	1.8	1.3
3 Rows Closest to Secondary Fence - Horizontal	QMH	11.9	53.6	5.5	9.7	2.2
	LED	8.4	15.4	3.8	4.1	2.2
All Horizontal	QMH	21.0	101.0	5.5	18.4	3.8
	LED	22.0	45.5	3.8	12.0	5.8
3 Rows Closest to Primary Fence - Horizontal	QMH	22.2	89.0	11.0	8.1	2.0
	LED	28.5	41.6	21.1	2.0	1.4
Primary Fence - Vertical	QMH	12.2	18.0	8.9	2.0	1.4
	LED	29.3	36.8	21.4	1.7	1.4
Primary Corridor (7 Rows) - Horizontal	QMH	24.6	101.0	10.4	9.7	2.4
	LED	26.7	45.5	13.0	3.5	2.1

The LED system generally delivered better uniformity than the QMH system. The secondary fence was the only measurement area where QMH system uniformity was better than the LED system. The secondary fence was also one of the first areas where a border patrol agent commented on a perceived improvement in uniformity with the LED system during the IGA. The difference in uniformity between the two systems was not initially evident; however, the border patrol agent – who regularly spends time looking down the length of the fence – quickly noticed the improvement. One reason for the difference between perception and measurements was the measurements did not capture the striations on the fence caused by the QMH Nighthawk luminaire. The measurements were taken every 15 ft along only 320 ft of the total 38,000 ft (7.2 miles) of fence. When looking along the secondary fence, a human observer with normal vision would see multiple stripes of light, increasing in frequency as distance increased. A measurement grid finer than 15 × 15 ft was needed to capture the stripes of light caused by the visors, but was not feasible for this project.

The calculated uniformity metrics generally agreed with the observed uniformity; however, the max/min and avg/min uniformity ratios (i.e., quotients) did not always corroborate. The max/min ratio seems to better reflect the observed uniformity differences than avg/min. The avg/min ratios for the QMH and LED are both 2.2 for the three rows of horizontal measurements closest to the secondary fence, while the QMH max/min ratio of 9.7 is more than twice the LED max/min ratio of 4.1. For the three rows closest to the primary horizontal fence, the QMH system max/min ratio of 8.1 is four times the LED system ratio of 2.0; however, the avg/min ratio only differs by 0.6. The avg/min ratio for all of the horizontal measurements is greater for the LED system at 5.8 than the QMH at 3.8, while the max/min ratio is greater for the QMH system at 18.4 than the LED at 12.0.

5. Energy Savings and Economics

While the Yuma Sector Border Patrol Area initially seems to be an uncommon lighting application, the same concerns of any lighting retrofit still apply: Will the retrofit maintain or improve the lighting quality? How much energy will the retrofit save? What are the economic benefits of the retrofit? The final installed costs for the new LED lighting system had not been determined as of this writing, and some of the economic details of the project are proprietary, so a full economic analysis is not possible. The costs savings from the energy reductions made possible by the proposed system are discussed in this section.

The cost of high luminous flux LED technology is not insignificant, and even more so in high temperature environments where well-designed thermal management is critical. The cost of additional luminous flux from LED luminaires also does not decrease in the same manner as incumbent technologies, including metal halide (MH). MH higher output products typically provide more lumens per dollar expended than lower output products, while for LED products typically the lumens per dollar does not vary considerably with output. This is further examined in the Discussion section of this report.

During the IGA presentation, Cooper revealed that an upgraded LED light square, AE, would soon be available for the Galleon luminaire, offering increased energy savings, lower initial luminaire cost, and more optical distributions and drive current options. The Galleon-AE was expected to cost less than the Galleon-AA because it has fewer light squares, which also decreases the overall size of the luminaire. The lighting system design that had been finalized and installed for the IGA demonstration had to be redesigned because of the change in optical distribution and luminous flux between the Galleon-AA and Galleon-AE luminaires.

As of the writing of this report, the final system has not been selected. The following analysis assumes that two LED Galleon-AE 480 V luminaires with six light squares driven at 1050 mA will be mounted on the 204 poles along the 7.2 miles of border east of the POE. A single luminaire with eight light squares is assumed to be mounted on the first pole (closest to the POE) because the surrounding area is smaller. The total annual energy cost savings was estimated to be 69%, detailed in Table 4.

Table 4. Cost and Energy Savings Summary. This is an initial example summary using the LED Galleon-AE luminaire, and does not represent the final costs associated with the Yuma retrofit. The first pole of the 205 poles only required one eight light square luminaire, therefore the wattage is less for the first pole.

		Energy Rate (\$/kWh)	Demand Charge (\$/kW)	Power Per Pole (W)	Total System Power (W)	Annual Energy Consumption (kWh)	Annual Energy Cost	Annual Demand Cost	Total Annual Cost
QMH	Poles 1 - 205	\$0.05444	\$18.62	2151	440,955	1,858,890	\$101,198	\$98,527	\$199,725
LED	Poles 2 - 205	\$0.08064	\$8.41	677	138,564	584,130	\$47,104	\$13,991	\$61,096
	Pole 1			456					
Savings	Difference Percentage				302,391 68.6%	1,274,759 68.6%	\$54,094 53.5%	\$84,536 85.8%	\$138,629 69.4%

The electrical utility service is provided by Arizona Public Service (APS). Utility bills between January 2012 and December 2013 report an average annual energy usage of 1,858,800 kilowatt-hours (kWh), and a monthly average demand of 441.0 kW. The estimated annual operating hours was 4,216 hours, averaging 11.5 hours per day. APS charged a rate of \$0.05444/kWh prior to the retrofit and was expected to charge \$0.08064/kWh after. The less favorable rate was due to the expected demand decreasing below 400 kW. The calculated watts per pole was 2151 W, and is expected to decrease by 69% to 677 W after the retrofit. The expected annual energy cost is expected to decrease by 53% despite the 67% increase in the electricity rate. The demand charge is also expected to decrease from \$18.62/kW to \$8.41/kW after the retrofit, resulting in an 86% savings in annual demand cost.

Controls were not included in the calculation in Table 4; however, it was estimated by Cooper that including the controls would decrease energy consumption by an additional 20%. The initial energy savings calculation for controls included reducing power to 50% for an hour at both dusk and dawn and lumen maintenance dimming. The controls were expected to maintain an average illuminance of approximately 25 lx during the initial 50,000 to 60,000 hours of operation, which equates to 12 to 14 years. With the controls, the luminaire power can initially be reduced—reducing lumen output—and then over time as lumen degradation occurs the power can be increased, maintaining consistent light output throughout the life of the system while also saving energy initially. After this initial period, the luminaire would operate at full power for the remaining life of the system. Lumen depreciation is expected to continue after the initial 12 to 14 years, reducing the average illuminance below 25 lx.

Implementation of controls on this project would have increased the energy and demand savings and extended the life of the LED lighting system; however, would have increased the initial costs. As of this writing, the implementation of controls was not planned for the project due to the increased costs. Beyond savings from dimming, the proposed control system would have reduced the need for CBP to drive along the border to make sure the lights were operational and the routine inspections by a CBP contractor, but these maintenance savings were not included in the economic analysis.

6. Discussion

Numerous factors were considered during the design process for the Yuma Sector Border lighting retrofit, including quality and cost. Once the basic requirements of a project are met, continued design efforts focus on optimization: How much can the quality improve? At what cost?

6.1 Quality Factors

Design efforts to maximize quality while minimizing cost are even more difficult when technology rapidly changes, as is the case with LED. The number of choices tends to increase with changes, as was the case for this lighting retrofit. Given the relative newness of the technology, these additional choices require the manufacturer and specifiers to devote time to educating clients and may involve changing expectations. LED technology can improve upon the lighting quality delivered by incumbent technology, and in the case of the Yuma sector both uniformity and color improved with the use of the LED Galleon-AA lighting system.

6.1.1 Uniformity

One of the biggest benefits beyond energy and maintenance savings for the Yuma Sector was the improvement in uniformity. Max/min uniformity ratios indicated that the LED system produced a more uniform pattern of illuminance than the QMH system, and the on-site perceived uniformity of the two systems aligned with these data. There are practical limitations on how fine of a grid can be used for photometric measurements, particularly in large areas. For this project, the differences in uniformity between the QMH Nighthawk and LED Galleon-AA lighting system were not fully conveyed because the observed stripes of light that moved along the ground due to the wind were not fully captured in the measurements due to grid spacing.

In the case of the vertical measurements on the secondary fence, the measured uniformity ratios did not align with the observed uniformity. The vertical measurements showed that the QMH system was more uniform, which contradicted the conclusion of the border patrol agent visually comparing the QMH and LED systems previously mentioned. The secondary fence was one of the first areas this border patrol agent noted an improvement in uniformity with the LED system during the IGA trial demonstration. This finding demonstrates the importance of having the typical occupants of spaces evaluate systems for uniformity and other nuances—such as the ability to detect footprints in the sand—that might be important to their job duties. The optimization of uniformity required additional design time, including computer simulations, to determine the best optical design for the application.

6.1.2 Color

There is a fundamental tradeoff between efficacy and CRI for typical LED packages.¹¹ For an outdoor lighting application where color rendering is not critical to the tasks performed, increased efficacy is often chosen over high CRI. The incumbent QMH lamp had a CRI of 65—the same as the Galleon-AA and lower than the 72 CRI of the Galleon-AE, and is generally considered acceptable in outdoor lighting. CRI is an indicator of color quality; however, visual evaluation is also important for applications where color rendition is a concern. CRI does not predict shift in color over time, which QMH lamps are known to do. LEDs can also shift in color, although the

¹¹ For further information download the LED Color Characteristics Technology Fact Sheet developed by the DOE SSL Program: <http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/led-color-characteristics-factsheet.pdf>.

color shift is currently difficult to predict and varies greatly across LED products.¹² Color shift was not a concern for the Yuma retrofit, and it was assumed that the color shift with the LED luminaires would be less than the incumbent QMH luminaires. The spectral power of the QMH and LED luminaires sources was not measured during the IGA; however, the QMH luminaires had a green hue and the LEDs had a red hue when compared side by side.

6.2 Cost Factors

The costs associated with an energy saving retrofit are always important, particularly when financing a retrofit. The initial cost factors include system design, product cost, and installation. In the short-term, utility rebates help to offset initial costs, and energy and maintenance cost savings offset the cost in the long-term.

6.2.1 Utility Rebates

Utilities often offer incentives for significant reductions in electricity use, typically in the form of a rebate based on projected electricity savings. APS offered a rebate for the retrofit of high-intensity discharge (HID) to LED at a rate of \$0.09 per annual kilowatt-hours savings for up to 75% of the incremental cost. For the 205 poles west of the POE, we estimate that this would result in a savings of \$114,728.

6.2.2 LED Technology

Understanding rebates for LED technology and how lighting quality varies between LED and HID luminaires is important, and so is understanding how the price and lumen output vary between LED and HID. A premium is often associated with new technology and LED technology is not immune to this trend. There is also a higher price associated with higher luminous flux LED technology, required for this project. Table 5 compares the relative price and output of MH and LED.

Table 5. Price and Lumen Output: MH vs. LED. The luminaire efficiency for the Online Example was obtained from the luminaire manufacturer's website and for the DOE 2010 Sample was assumed to be 0.700. The luminaire price ratio in the third column was determined by dividing the price of the luminaire by the price of the lower wattage luminaire in the pair or sample. The price-weighted output listed in the seventh column was calculated by dividing the luminaire output by the luminaire price ratio to get the price-weighted output for each luminaire. The price-weighted output ratio was calculated by dividing the price-weighted output of the higher wattage luminaire by that of the lower wattage luminaire.

Luminaire Category	Nominal Watts (W)	Luminaire Price Ratio	Initial Lamp Output (lm)	Luminaire Output (lm)	Efficacy (lm/W)	Price-Weighted Output	Price-Weighted Output Ratio
Metal Halide							
Online	250	1.00	22000	15290	61.2	15290	1.87
Example	400	0.99	40000	28400	71.0	28584	
DOE 2010	250	1.00	22000	15400	61.6	15400	1.48
Sample	400	1.16	37900	26530	66.3	22854	
LED							
Galleon-	264	1.00	---	25652	97.2	25652	1.17
AE	421	1.37	---	41134	97.7	30024	

¹² For further information download the LED Color Stability Technology Fact Sheet developed by the DOE SSL Program: http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/color-shift_fact-sheet.pdf.

The increase in lumen output per dollar between nominally 250 W and 400 W MH luminaires was calculated using two different methods. The first method—shown as Online Example in Table 5—obtained price information for a single luminaire, which included the lamp, from a national electrical supplier’s website that published the pricing online. The luminaire selected was the only outdoor pole-mounted luminaire identified that was available in two different wattages. The luminaire efficiency was found in the photometric report posted on the luminaire manufacturer’s website. The initial lamp output used is the same output assumed by the photometric report. There was little difference in luminaire price or efficiency between the two wattages; however, the lumen output was nearly double for the 400 W luminaire.

The second method used average values from a 2010 DOE sampling of MH luminaires.¹³ The average initial luminaire output and price were obtained from this survey, and the luminaire efficiency was assumed to be 70% for both wattages. These methods obtained similar lumen output values; however, there was a difference in the price-weighted output ratio due to price. The Online Example method compared different wattage versions of a single luminaire, while the DOE Sample method compared average values from several different luminaires of each wattage, which may explain the different ratios.

The relative pricing information for the LED Galleon-AE luminaire was obtained from a Cooper sales representative who was not aware of the reason for the inquiry; this information is not specific for the Yuma project. The difference in wattage is due to a different number of light squares, five squares for the 264 W and eight squares for the 421 W. The luminaire housing size and number of drivers increase for the eight squares versus five squares, and the size increase also affects packaging and transportation costs. An important difference is that the lumen output and efficacy are considerably higher for the LED luminaires than for the MH luminaires.

The price-weighted output is listed in the seventh column was calculated by first dividing the luminaire output by the luminaire price ratio to get the price-weighted output for each luminaire. The price-weighted output ratio listed in the last column was calculated by dividing the price-weighted output of the higher wattage luminaire by that of the lower wattage luminaire. This ratio was 1.17 for the LED Galleon-AE, with the price per lumen not decreasing substantially between the 264 W and 421 W luminaires. This is a clear contrast to the Online Example luminaires. The lumen output nearly doubles between the 250 W and the 400 W versions for the same price, which explains the price output ratio of 1.87 for this luminaire pair. The DOE 2010 Sample falls between the LED Galleon-AE and the Online Example luminaire pairs, with a price-weighted output ratio of 1.48.

The premium associated with high flux LED technology is one reason that these types of LED systems have not yet been adopted to the extent that other types of LED systems have been. The high price can be unexpected in an industry that is accustomed to paying noticeably less per lumen as wattage increases for MH and other source technologies.

6.2.3 Controls Technology

Controls can increase energy savings and extend the life of LED luminaires. Driving the LEDs at a lower current simultaneously reduces energy consumption, increases lumen maintenance, and may extend system life. The thermal management of a system is important, particularly in the Yuma Border Sector area. Lowering the current also lowers the heat within the system, which generally increases luminaire component life and

¹³ [DOE] U.S. Department of Energy. 2010. 10 CFR 431 High-Intensity Discharge Lamps Proposed Determination Analytical Spreadsheets. <http://www.regulations.gov/#!documentDetail;D=EERE-2006-DET-0112-0020>.

potentially system life. But as the system wattage decreases through the use of higher efficacy systems, there is less opportunity to save money with controls, which can make it harder to justify installing controls.

Another potential advantage of the control system for the Yuma Border Sector was additional maintenance savings. Creating a punch list of the QMH Nighthawk luminaires that need to be serviced includes turning on each section during the day by covering the photocells and then further inspecting any non-operational luminaires, requiring a lift. This often necessitates three days of effort. With a control system, information on the energy consumption of each luminaire would be provided, so if there were a big change in energy consumption, CBP would know the luminaire had failed. This time savings was not included in the calculation of maintenance savings costs; however, it could be considered for future installations.

6.2.4 Redesign

The design process for this retrofit included the redesign of the entire lighting system due to a significant improvement in LED technology that occurred after the initial design was completed. Redesign is increasingly common because of the rapid changes in LED technology. In the case of the Galleon luminaire, the LED Galleon-AA had been commercially available for less than 2 years when the next-generation LED Galleon-AE was released. The LED Galleon-AE offered a 27% improvement in efficacy, new optical distributions designed to reduce the perception of glare, and improvements in optical and driver efficiency. The CRI also improved from 66 to 72. The design and redesign of a system can require considerable time, as in the case of the Yuma retrofit, but is often considered a valuable effort because the improvements in LED technology deliver better light quality and additional cost savings.

7. Conclusions

The Yuma Sector Border Patrol Area lighting retrofit was documented to better understand LED technology performance in a high ambient temperature and solar radiation environment. High luminous flux and/or high temperature applications in the United States are not unique, and if high luminous flux LED technology performs well in a region with high ambient temperature and solar radiation, it can perform well in most outdoor environments. The design process and the IGA mock-up for the Yuma retrofit have already provided valuable knowledge to CBP and DOE, and if the project moves forward, we will continue to document and disseminate information regarding the installation and performance over time.

The Yuma retrofit is expected to reduce energy consumption 69%. If the annual electricity consumption of all federal outdoor lighting—including area, roadway, parking and exterior buildings—were similarly reduced 69%, the electricity consumption would drop from 5.0 TWh to 1.55 TWh.¹⁴ This reduction is equivalent to eliminating current federal outdoor roadway and area lighting energy use. The other significant benefit of the retrofit is reduced maintenance, but these savings were not included in related economic analyses.

One reason for the higher initial cost of the retrofit was cutting the pole height from 64 ft to 40 ft. This initial cost reduced stray light and furthered energy savings, due to a reduction in required lumen output at a lower height. The reduction in stray light was so noticeable that initially there was concern about the location of the border no longer being as easily recognizable at night. The reduction in pole height contributed to the projected cost savings, and was also expected to decrease annual cleaning costs due to reduced lift and labor costs.

Night is when the most activity occurs on the border, so it was important to ensure the lighting system would help the agents perform their duties, which include preventing illegal border crossings. The design criteria were not initially clear, and no recommendations from the IES were available for an application similar to border lighting. As of the writing of this report, the next revision of IES G-1 will include recommendation regarding patrolled and/or guarded exterior lighting application.

One reason LED technology has garnered so much attention is because of the rapid improvements in efficacy, color, controllability, and lumen maintenance, which can also lead to confusion, delays, and frustration. This rapid advancement creates challenges for everyone from the buyer to the component supplier, and the Yuma Sector Border Patrol Area lighting retrofit was not immune to these challenges. The availability of an upgraded lighting system less than 2 years after the launch of the original system demonstrates just how quickly LED technology is changing and potential energy savings is increasing. The LED Galleon-AE lighting system is expected to provide 69% energy savings over the incumbent QMH Nighthawk lighting system. The Yuma Sector Border Patrol Area lighting retrofit trial demonstration displayed the potential of LED technology to improve lighting quality and reduce energy consumption.

¹⁴ U.S. Department of Energy. 2012. Outdoor Solid-State Lighting Potential at Federal Sites. Prepared by Federal Energy Management Program.

Appendix A: IGA QMH Illuminance Measurements

The full set of QMH illuminance measurements are detailed below. A partial set of these measurements along with LED measurements are detailed and discussed in Section 4.2.

	199	11	10	9	8	7	6	5	4	3	2	1	200	1	2	3	4	5	6	7	8	9	10	11	201
8'	5.5	6.2	7.1	7.4	7.4	7.8	7.5	7.9	7.9	7.8	8.6	6.9	6.1	7.3	8.1	7.9	8.0	9.0	8.9	8.7	8.2	9.0	9.5	7.0	5.6
4'	5.3	5.9	6.8	7.4	7.4	7.0	7.2	7.7	8.0	7.7	8.6	6.6	6.3	6.8	7.7	8.2	8.1	8.3	8.6	8.6	7.8	8.0	9.4	6.6	5.3
	4.7	5.0	5.7	6.2	6.0	6.0	6.0	6.6	7.3	6.5	7.6	5.7	6.2	5.5	6.5	6.7	6.7	6.5	7.1	7.4	7.0	6.3	6.4	5.7	4.4
	8.5	8.4	8.5	8.8	9.9	8.4	8.1	9.1	11.1	10.9	10.8	9.8	20.3	9.1	9.4	10.4	10.6	9.6	9.2	10.1	10.8	11.7	10.6	9.9	8.4
	27.9	17.4	16.6	14.9	19.1	12.6	10.4	11.3	14.4	14.3	14.2	20.3	53.6	19.0	21.8	20.0	18.7	12.3	11.2	12.3	14.7	17.4	21.1	25.1	31.8
	78.0	32.0	27.0	22.9	24.0	16.5	13.1	13.7	18.5	17.2	19.5	39.9	80.2	29.9	28.0	25.9	20.8	14.4	13.0	14.4	17.3	21.3	27.3	36.2	61.1
	92.0	40.9	28.8	23.7	23.5	16.6	14.1	17.5	24.8	20.9	27.4	35.6	87.0	37.9	33.2	29.4	24.1	16.9	15.4	17.5	23.5	25.6	37.6	42.2	78.3
	103	44.1	33.1	29.0	28.9	18.9	15.3	16.2	26.1	21.7	23.9	32.6	101	43.0	36.9	32.7	26.7	16.7	15.3	17.0	24.0	28.1	33.0	40.0	93.0
	101	56.6	37.3	27.3	25.8	20.4	14.8	15.0	21.8	19.9	22.2	32.2	89.0	43.5	30.7	26.4	22.2	15.4	14.5	16.0	21.4	24.3	28.7	38.4	92.8
	80.3	42.8	24.7	20.3	17.8	14.2	12.7	13.3	20.8	18.4	20.6	24.6	67.2	34.1	23.6	21.9	18.2	13.6	13.0	15.2	23.1	29.2	29.3	31.0	68.5
	40.3	22.0	19.6	17.5	14.8	12.9	11.0	11.2	15.2	12.4	14.6	16.4	23.9	17.9	17.3	17.5	15.2	12.5	11.9	12.6	15.0	14.4	13.9	16.8	35.5
4'	26.3	14.4	15.6	14.7	12.5	10.7	8.9	8.9	11.2	11.1	11.2	12.3	18.0	13.8	14.2	14.8	12.3	10.3	9.5	10.5	12.1	12.1	11.8	11.6	25.7
8'	25.0	14.5	16.7	16.5	13.2	10.5	9.8	9.7	11.0	12.7	9.9	12.4	17.1	13.9	14.7	14.8	13.0	10.9	10.2	10.8	11.7	13.0	12.4	12.2	22.6
199	11	10	9	8	7	6	5	4	3	2	1	200	1	2	3	4	5	6	7	8	9	10	11	201	