Illuminating ENGINEERING SOCIETY

IES Street and Area Lighting Conference

LEDs, Earth, and Light at Night

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LEDs, Earth, and Light at Night

Learning Objectives

My hope is that participants will be able to:

1. Identify the primary global drivers of increased use of light at night.
2. Compare different lighting characteristics in terms of their relative contributions to the appearance of light in the night sky.
3. Describe the various levers the community has at its disposal for addressing light in the night sky.
4. Analyze the best paths forward from where we are today.

Electric Light Remains a Precious Commodity for Much of the World

Not the World's Standard by a Large Margin

Upward Radiance from Earth Increased 2.2% Per Year 2012-2016

SCIENCE ADVANCES | RESEARCH ARTICLE

ENVIRONMENTAL SCIENCES

Artificially lit surface of Earth at night increasing in radiance and extent

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A central aim of the "lighting revolution" (the transition to solid-state lighting technology) is decreased energy consumption. This could be undermined by a rebound effect of increased use in response to lowered cost of light. We use the first-ever calibrated satellite radiometer designed for night lights to show that from 2012 to 2016, Earth's artificially lit outdoor area grew by 2.2% per year, with a total radiance growth of 1.8% per year. Continuously lit areas brightened at a rate of 2.2% per year. Large differences in national growth rates were observed, with lighting remaining stable or decreasing in only a few countries. These data are not consistent with global scale energy reductions but rather indicate increased light pollution, with corresponding negative consequences for flora, fauna, and human well-being.

INTRODUCTION

Continued improvement in the luminous efficacy of light sources and increases in gross domestic product (GDP) have resulted in tremendous growth in artificial light use over several centuries (*1*). Historically, lighting has been subject to a strong rebound effect, in which increases in luminous efficacy result in correspondingly greater light use rather than energy savings (*2*). Regardless of historical or geographical context, humans tend to use as much artificial light as they can buy for ~0.7% of GDP (*3*). Outdoor lighting became commonplace with the introduction of electric light and grew at an estimated rate of 3 to 6% per year during the second half of the 20th century (*4*). As a result, the world has experienced widespread "loss of the night," with half of Europe and a quarter of North America experiencing substantially modified light-dark cycles (*5*).

A critical question for sustainable development is whether the use of outdoor light will continue to grow exponentially or whether developed countries are nearing saturation in demand (*3*). In addition to the possibility that the existing light levels are already sufficient for any desired visual task, factors that reduce demand include greater public recognition of the unintended ecological (*6*) and astronomical (*5*, *7*) impacts of outdoor light pollution, official warnings that overexposure to artificial light may be affecting human sleep and health (*8*), efforts to transition to a sustainable society with decreased electricity demand (*9*), the desire of local governments to reduce the costs of lighting (*10*), and the establishment of protected "dark-sky" areas (*11*). If demand saturation has not been reached, then the increasing luminous efficacy made possible by the solid-state lighting revolution (*12*) will increase light emissions instead of saving energy.

Changes in outdoor lighting can be measured on the global scale only via Earth-observing satellites, but no calibrated satellite sensor has made global observations of night lights until recently. The well-known older images of Earth at night (*13*) were based on an uncalibrated sensor from a defense satellite [Defense Meteorological Satellite Program (DMSP)], which had frequent and unrecorded changes in sensor gain. Despite this drawback, there have been attempts to use statistical methods to try to intercalibrate the time series. These methods sometimes rely on questionable assumptions, such as the assumption that Sicily experienced no changes in lighting over a 15-year period (*14*). In addition to the lack of an on-board radiance calibration, DMSP experienced saturation in cities and had low (8 bit) radiometric resolution and an intrinsic spatial resolution of 5 km (*15*). Nevertheless, the inherent connection between artificial light and human activity means that DMSP data display strong correlations with many socioeconomic factors (*16*).

Although considerable research has been done using DMSP time series, most analyses have been focused on other remotely sensed factors [for example, human settlement, socioeconomic activity, and detection of fishing vessels (*17*)] and have not reported on trends in lighting itself. The few lighting studies that have done so were on the national [for example, 4% annual increase in Spain (*18*)] or continental scale [for example, (*19*)] or else examined only a specific class of lighting [for example, (*14*)]. The official radiance-calibrated DMSP time series of the National Oceanic and Atmospheric Administration (NOAA) showed little change in the sum of lights of several large cities, but the intercalibration was based on the assumption that the lights of Los Angeles did not change over the period of 1996–2010 (*20*). In contrast, a recent analysis using a different methodology found an increase in global lights of a factor of 2 from 1992 to 2013 (~ 3.5% per year) (*21*). However, because of the limitations of the DMSP, and particularly the saturation in city centers, many analyses have been limited to change in lit area rather than change in radiance.

The Visible Infrared Imaging Radiometer Suite Day-Night Band (VIIRS DNB) came online just as outdoor use of light-emitting diode (LED) lighting began in earnest (*22*). This sensor provides the first-ever global calibrated nighttime radiance measurements in a spectral band of 500 to 900 nm, which is close to the visible band, with a much higher radiometric sensitivity than the DMSP, and at a spatial resolution of near 750 m (*15*). This improved spatial resolution allows neighborhood (rather than city or national) scale changes in lighting to be investigated for the first time (*23*).

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"Historically, lighting has been subject to a strong rebound effect, in which increases in luminous efficacy result in correspondingly greater light use rather than energy savings... Regardless of historical or geographical context, humans tend to use as much artificial light as they can buy for ~0.7% of GDP…"

Some Media Responses were Predictably “Overstated”

The Switch to Outdoor LED Lighting Has Completely Backfired

George Dvorsky
11/22/17 2:00pm • Filed to: LIGHT POLLUTION

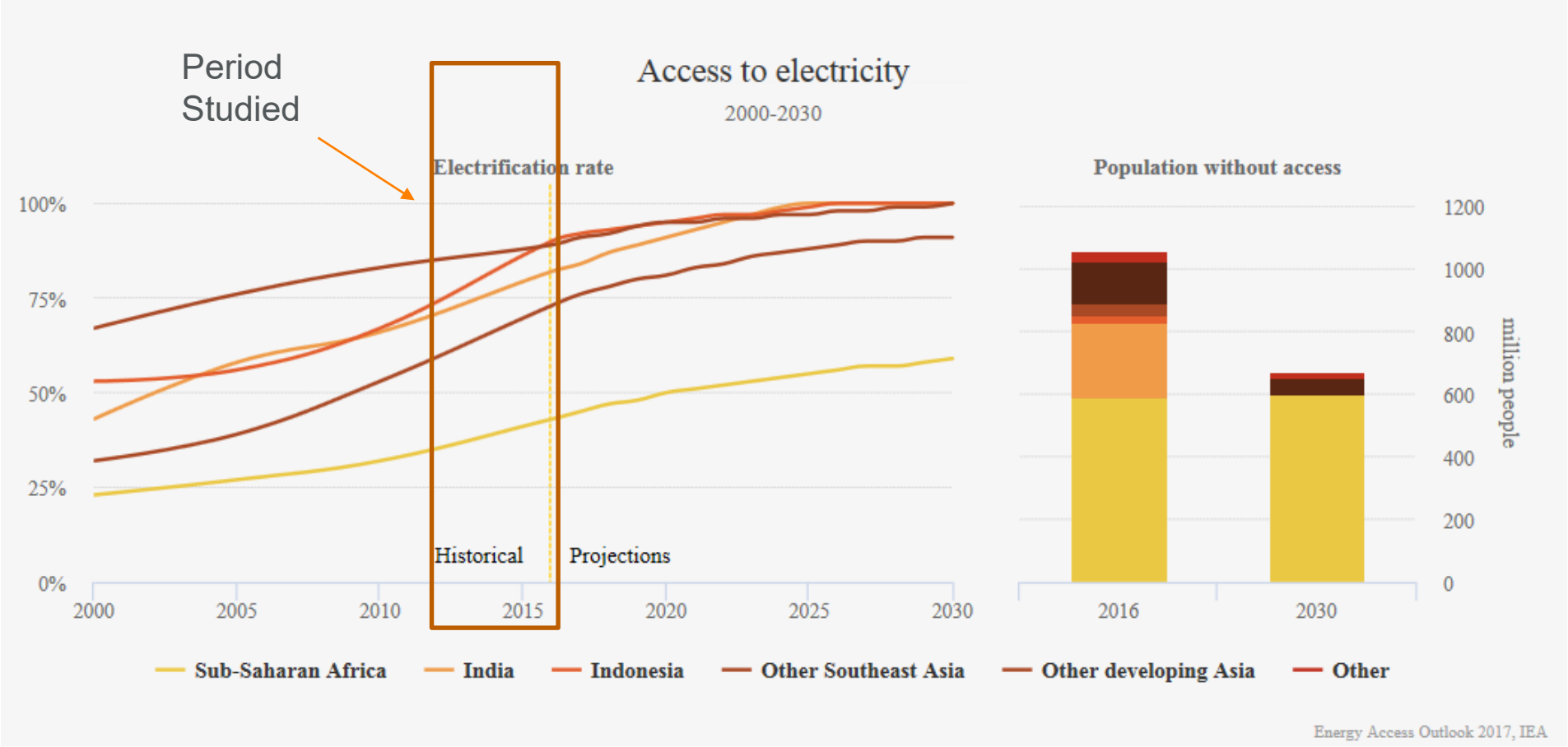
494 18

Florida at night. (Image: NASA/JSC)

Source: Gizmodo.com

Not only is the title inaccurate, the photo has virtually nothing to do with the study or LED lighting either.

Global Electrification is Occurring at a Rapid Rate



Source: IEA, Energy Access Outlook 2017

Projected Growth, 2017 – 2030

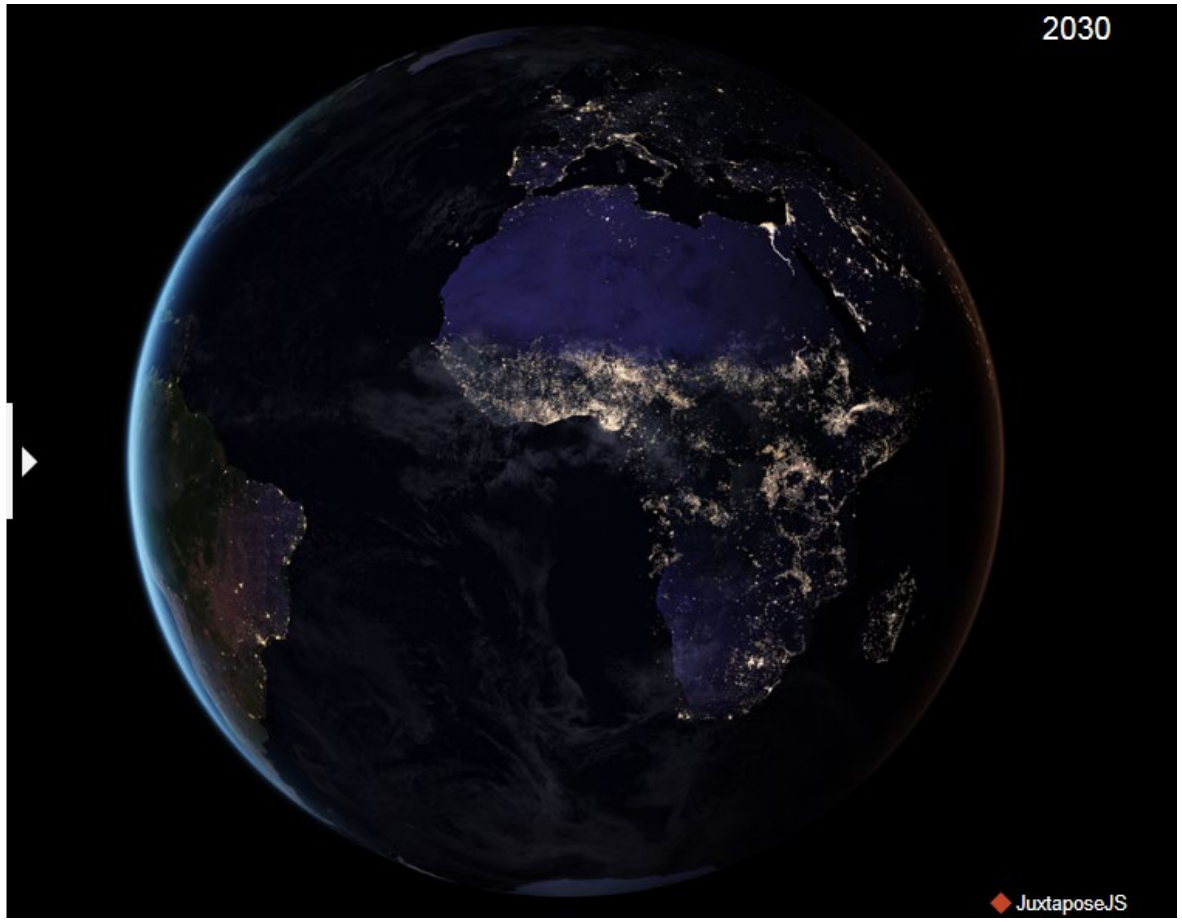
Africa in 2017

Source: IEA, Energy Access Outlook 2017

Projected Growth, 2017 – 2030

Africa in 2030

“The IEA's geographic analysis shows what the night sky over Africa would look like by 2030 compared to today with affordable, reliable, sustainable and modern energy for all”



Source: IEA, Energy Access Outlook 2017

Light at Night Concerns are Also Increasing

AMA

Education Life & Career Practice Management Delivering Care About U

AMA Adopts Guidance to Reduce Harm from High Intensity Street Lights

For immediate release: Jun 14, 2016

CHICAGO - Strong arguments exist for overhauling the lighting s
U.S. roadways with light emitting diodes (LED), but conversions t
improper LED technology can have adverse consequences. In re
physicians at the Annual Meeting of the American Medical Assoc
(AMA) today adopted guidance for communities on selecting amo
lighting options to minimize potential harmful human and environ
effects.

SCIENCE

The Milky Way Is Disappearing

A new "dark sky atlas" suggests that light pollution is drowning out the stars faster than ever.

LED Streetlights Are Giving Neighborhoods the Blues

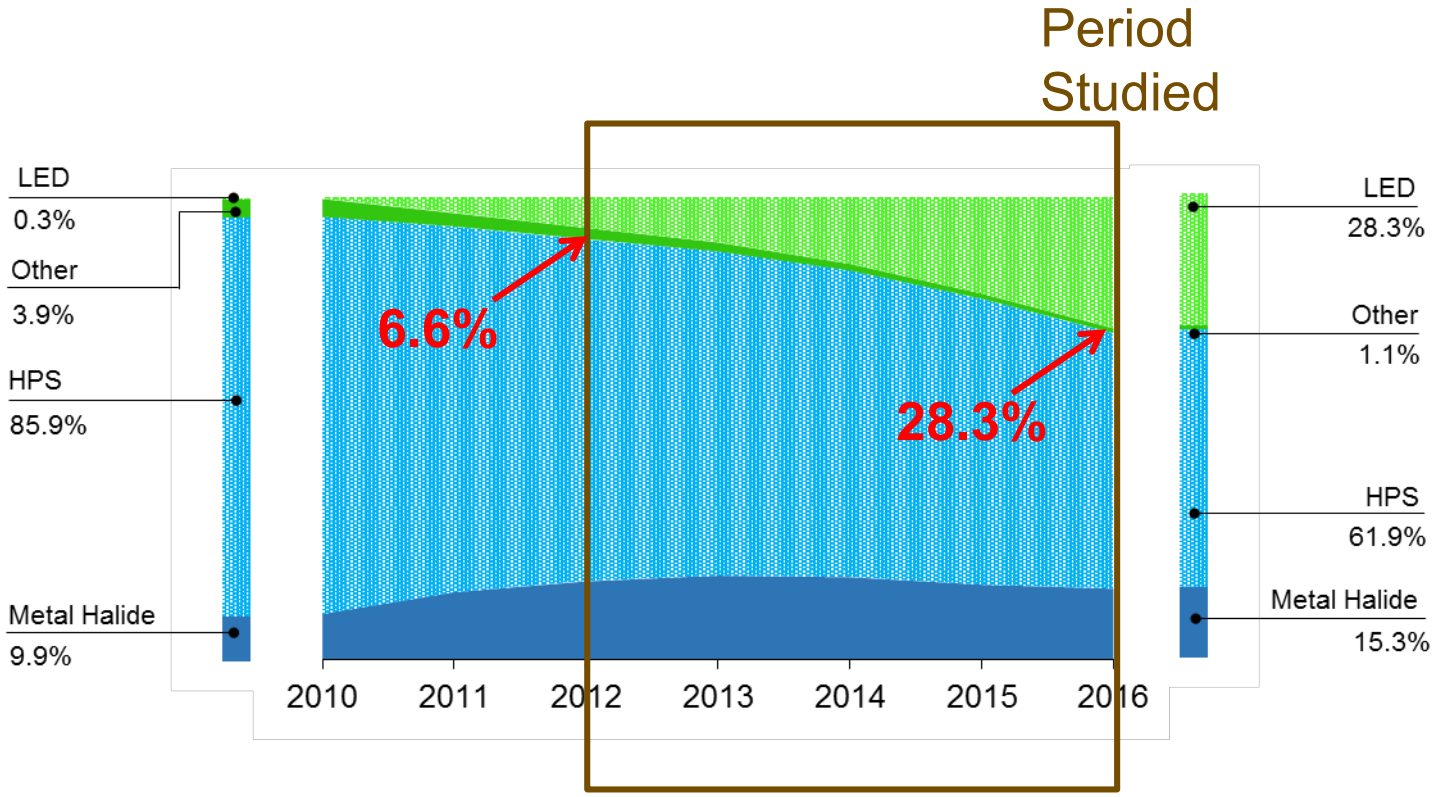
Early adopters of LED street lighting are struggling with glare and light pollution

Photo: Bob O'Connor

IEEE Spectrum

The Atlantic

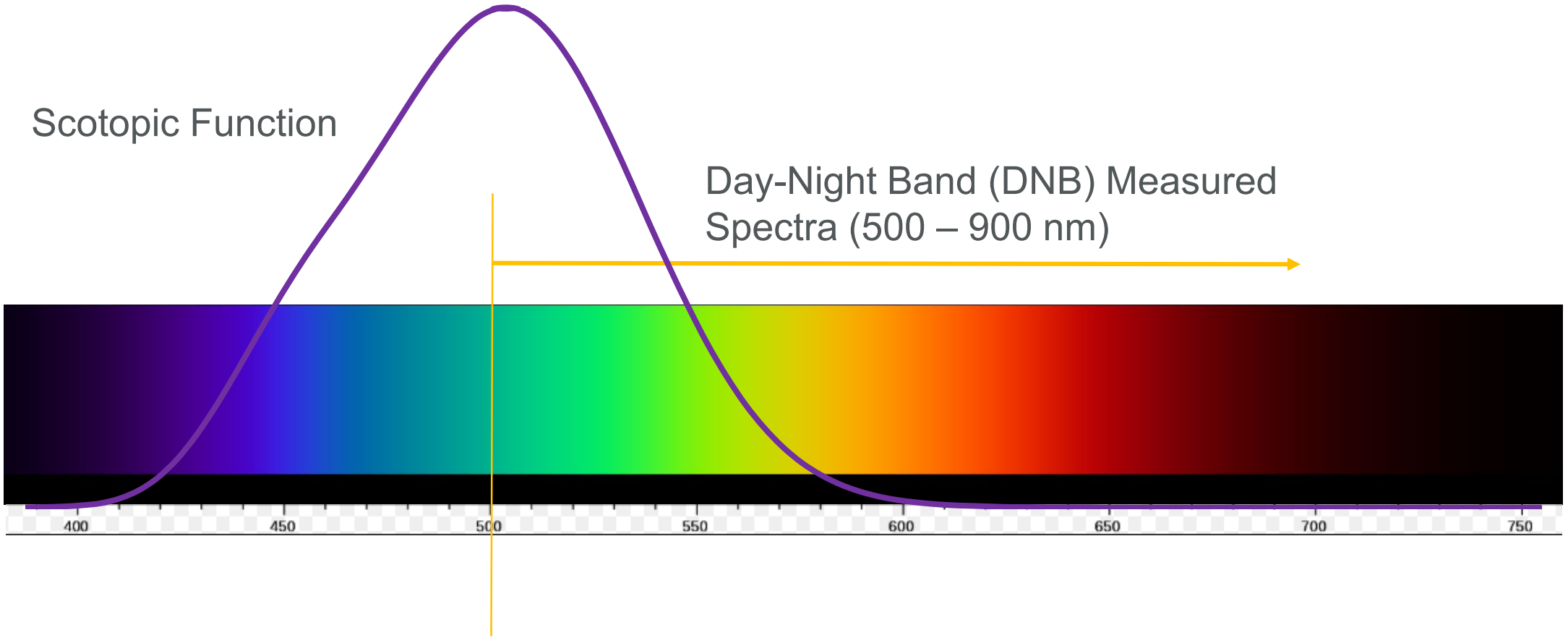
U.S. Street/Roadway Installed Stock Penetration from 2010 to 2016



Source: Navigant, LED Adoption Report, July 2017

LEDs in the installed stock increased significantly during this period, comprised mostly of 4000 K, yet U.S. upward radiance was reported as “stable”

Complexity: Most “Blue” Wavelengths Not Measured by DNB



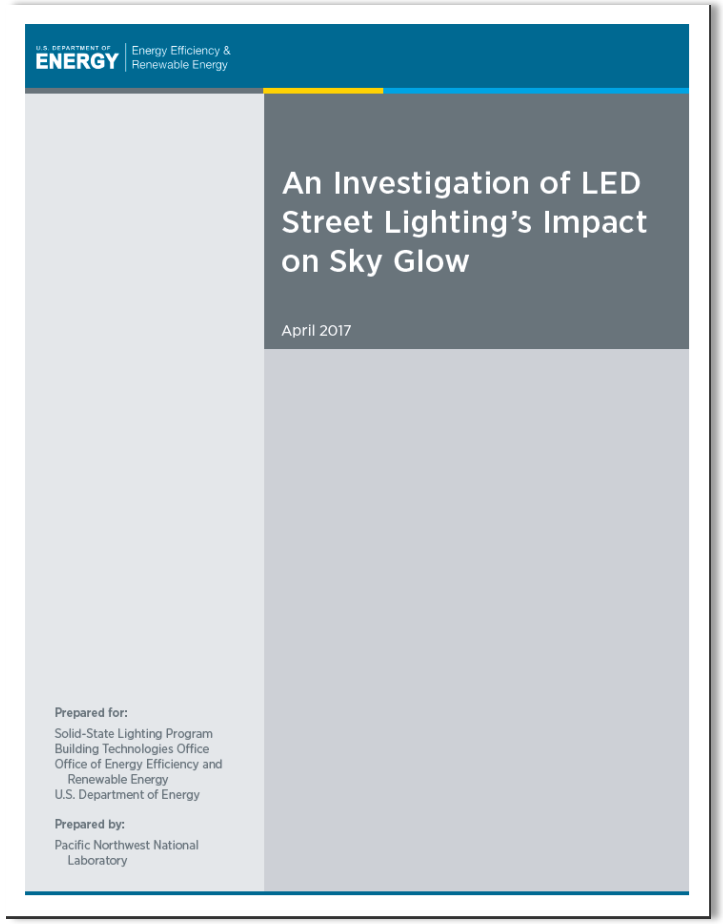
Complexity: Light in the Sky Includes All Direct and Reflected Sources

Photo: Caribb on Flickr

Photo: Chris Devers on Flickr

Photo: Chris Kyba

DOE Sky Glow Investigation – General Findings

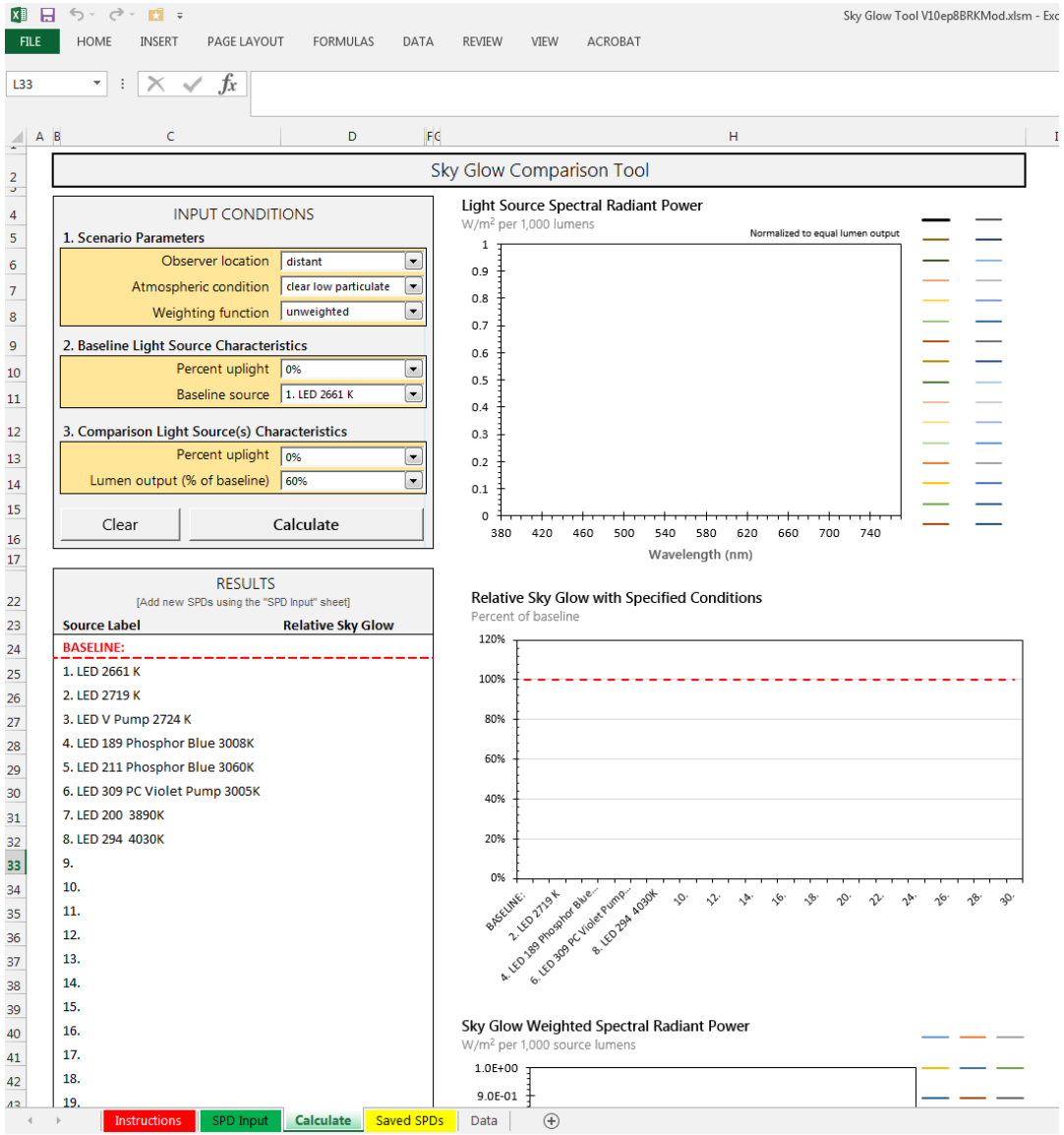


Order of effectiveness in reducing contribution to sky glow (while still maintaining a white light source):

1. Eliminate uplight
2. Reduce light output
3. Change spectral content

The Sky Glow Comparison Tool

- Spreadsheet developed from the results of 215,000+ runs of an existing sky glow model
- One set modeled the entire visible spectrum in 5 nm increments under all the other conditions specified
- The Comparison Tool essentially interpolates within the multidimensional matrix of results, for any input SPD
- For more info see posted webinar at ssl.energy.gov



Comparison Tool Outputs

- This slide compares a range of sources, 0% uplight baseline with equal lumen outputs, distant observer position, results unweighted for scotopic vision

Sky Glow Comparison Tool

INPUT CONDITIONS

1. Scenario Parameters

Observer location	distant
Atmospheric condition	clear low particulate
Weighting function	unweighted

2. Baseline Light Source Characteristics

Percent uplight	0%
Baseline source	1. HPS Example

3. Comparison Light Source(s) Characteristics

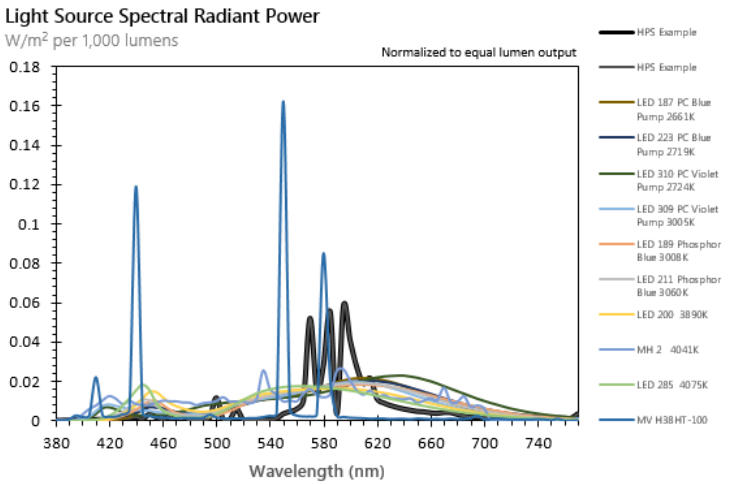
Percent uplight	0%
Lumen output (% of baseline)	100%

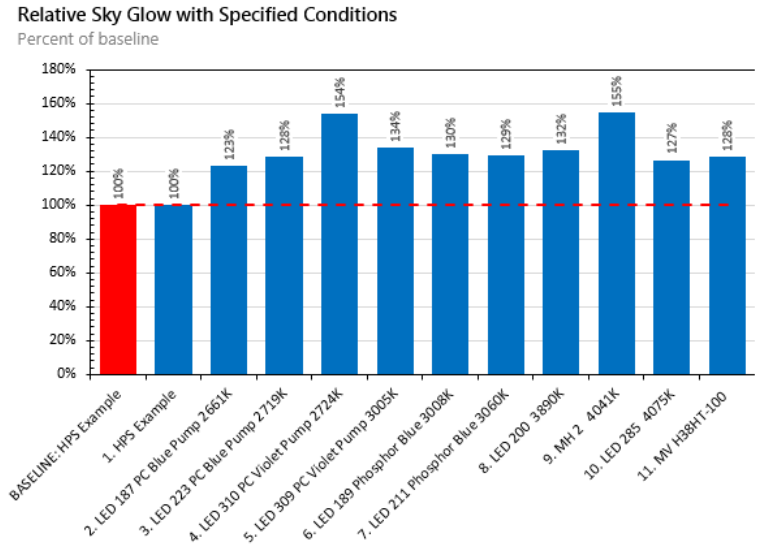
Clear | Calculate

RESULTS

[Add new SPDs using the "SPD Input" sheet]

Source Label	Relative Sky Glow
BASELINE: HPS Example	1.00
1. HPS Example	1.00
2. LED 187 PC Blue Pump 2661K	1.23
3. LED 223 PC Blue Pump 2719K	1.28
4. LED 310 PC Violet Pump 2724K	1.54
5. LED 309 PC Violet Pump 3005K	1.34
6. LED 189 Phosphor Blue 3008K	1.30
7. LED 211 Phosphor Blue 3060K	1.29
8. LED 200 3890K	1.32
9. MH 2 4041K	1.55
10. LED 285 4075K	1.27
11. MV H38HT-100	1.28





Comparison Tool Outputs

- Making this more representative of a relevant situation:
  - ➢Scotopically weighting results to specifically account for the sensitivity of the human eye
  - ➢Reducing the lumen package of replacement products to 60% of baseline
- Impacts slightly increase in variability and relative magnitude

Sky Glow Comparison Tool

INPUT CONDITIONS

1. Scenario Parameters

Observer location	distant
Atmospheric condition	clear low particulate
Weighting function	scotopic

2. Baseline Light Source Characteristics

Percent uplight	0%
Baseline source	1. HPS Example

3. Comparison Light Source(s) Characteristics

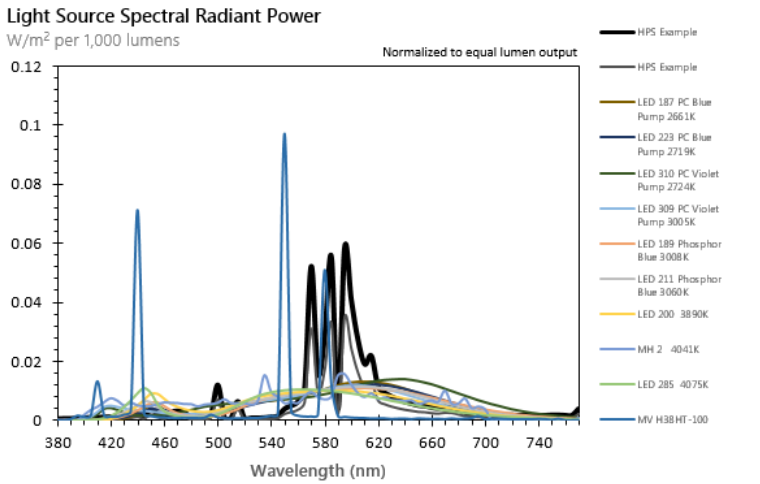
Percent uplight	0%
Lumen output (% of baseline)	60%

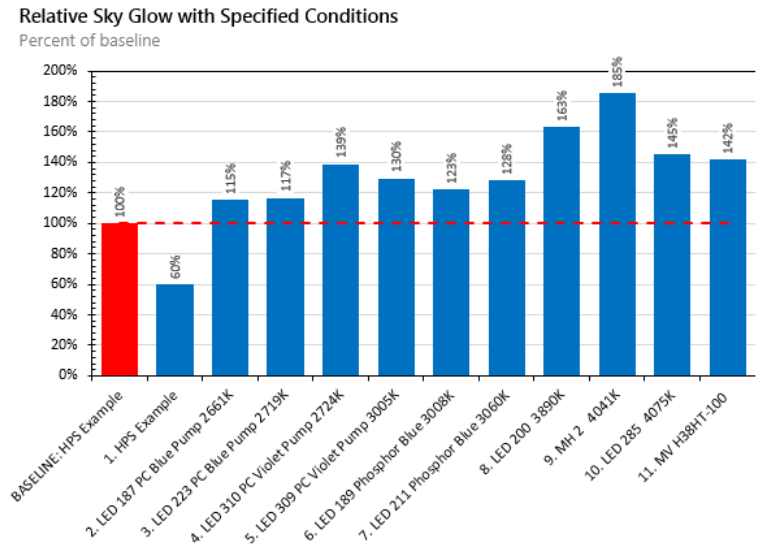
Clear | Calculate

RESULTS

[Add new SPDs using the "SPD Input" sheet]

Source Label	Relative Sky Glow
BASELINE: HPS Example	1.00
1. HPS Example	0.60
2. LED 187 PC Blue Pump 2661K	1.15
3. LED 223 PC Blue Pump 2719K	1.17
4. LED 310 PC Violet Pump 2724K	1.39
5. LED 309 PC Violet Pump 3005K	1.30
6. LED 189 Phosphor Blue 3008K	1.23
7. LED 211 Phosphor Blue 3060K	1.28
8. LED 200 3890K	1.63
9. MH 2 4041K	1.85
10. LED 285 4075K	1.45
11. MV H38HT-100	1.42





Comparison Tool Outputs

- Showing the effect of uplight at distance by introducing it to the baseline (and thus eliminating it in the subsequent comparisons)
- In comparison with uplight, both fixture light output and spectrum are only influencing sky glow at the remaining margins => getting rid of uplight is number one!

Sky Glow Comparison Tool

INPUT CONDITIONS

1. Scenario Parameters

Observer location	distant
Atmospheric condition	clear low particulate
Weighting function	scotopic

2. Baseline Light Source Characteristics

Percent uplight	2%
Baseline source	1. HPS Example

3. Comparison Light Source(s) Characteristics

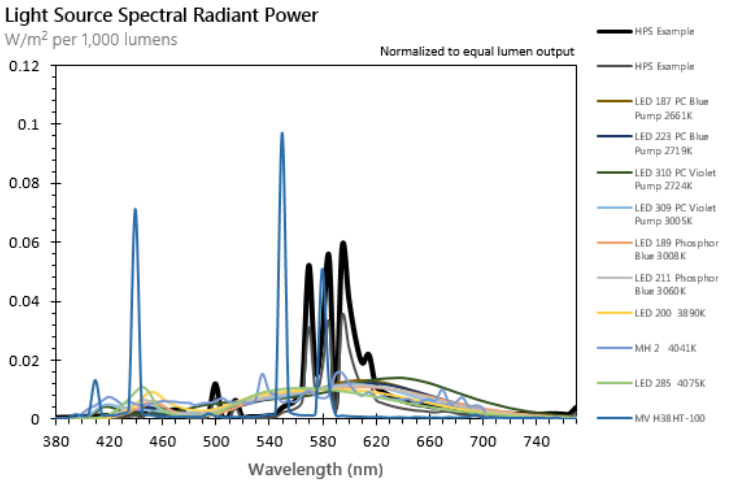
Percent uplight	0%
Lumen output (% of baseline)	60%

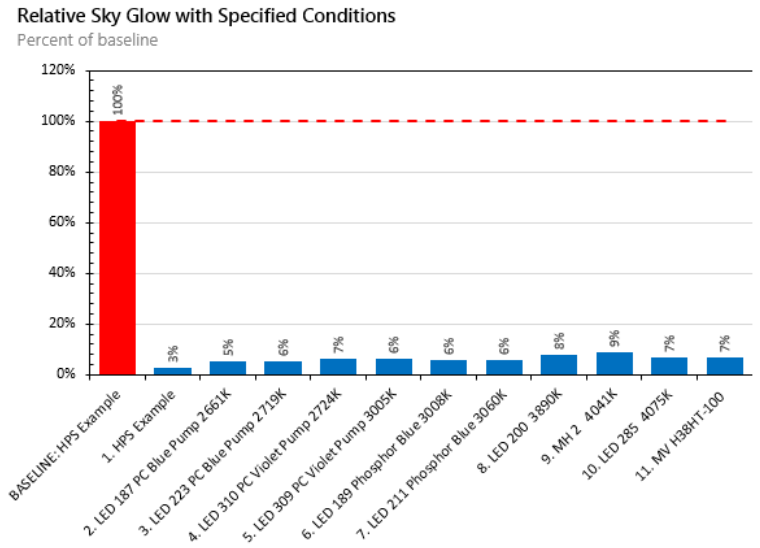
Clear | Calculate

RESULTS

[Add new SPDs using the "SPD Input" sheet]

Source Label	Relative Sky Glow
BASELINE: HPS Example	1.00
1. HPS Example	0.03
2. LED 187 PC Blue Pump 2661K	0.05
3. LED 223 PC Blue Pump 2719K	0.06
4. LED 310 PC Violet Pump 2724K	0.07
5. LED 309 PC Violet Pump 3005K	0.06
6. LED 189 Phosphor Blue 3008K	0.06
7. LED 211 Phosphor Blue 3060K	0.06
8. LED 200 3890K	0.08
9. MH 2 4041K	0.09
10. LED 285 4075K	0.07
11. MV H38HT-100	0.07





Comparison Tool Outputs

- Older incumbents eliminated to better show variation among LEDs at various CCTs
- Added an amber LED
- Other characteristics equalized to create apples to apples conditions
- Shorter wavelengths in the reflected light scatter in the immediate area of the lights; amber is missing those wavelengths so plays well in this comparison

Sky Glow Comparison Tool

INPUT CONDITIONS

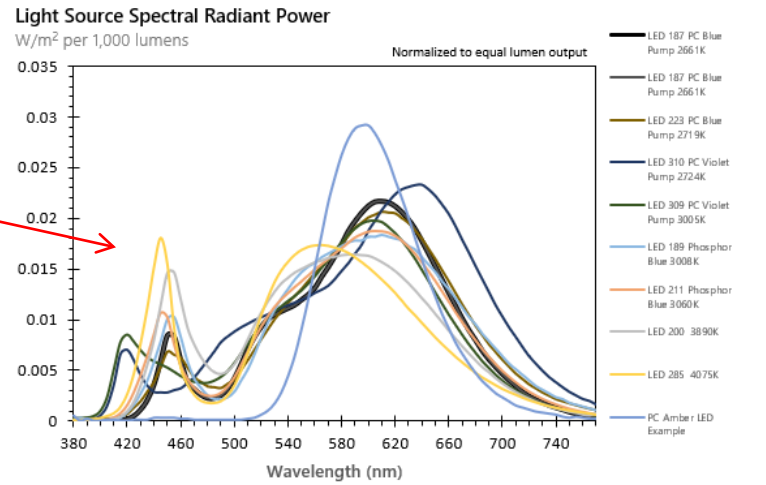
1. Scenario Parameters
   - Observer location: near
   - Atmospheric condition: clear low particulate
   - Weighting function: scotopic
2. Baseline Light Source Characteristics
   - Percent uplight: 0%
   - Baseline source: 1. LED 187 PC Blue Pum
3. Comparison Light Source(s) Characteristics
   - Percent uplight: 0%
   - Lumen output (% of baseline): 100%

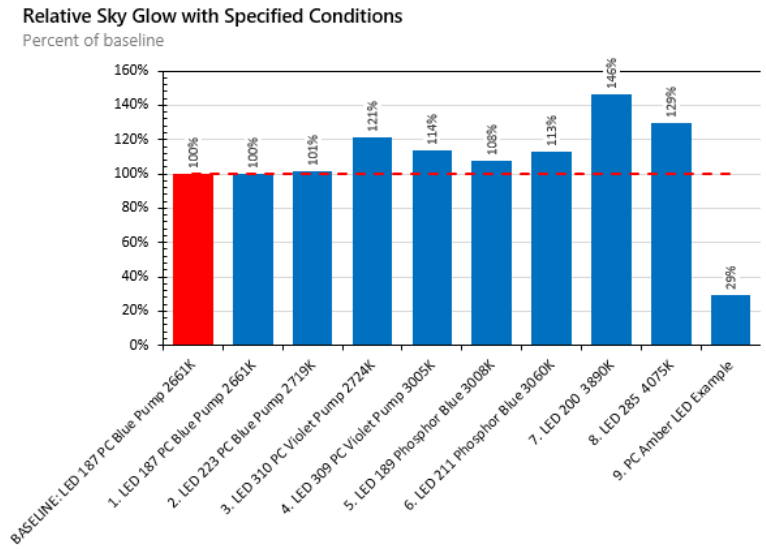
Clear | Calculate

RESULTS

[Add new SPDs using the "SPD Input" sheet]

Source Label	Relative Sky Glow
BASELINE: LED 187 PC Blue Pump 26	1.00
1. LED 187 PC Blue Pump 2661K	1.00
2. LED 223 PC Blue Pump 2719K	1.01
3. LED 310 PC Violet Pump 2724K	1.21
4. LED 309 PC Violet Pump 3005K	1.14
5. LED 189 Phosphor Blue 3008K	1.08
6. LED 211 Phosphor Blue 3060K	1.13
7. LED 200 3890K	1.46
8. LED 285 4075K	1.29
9. PC Amber LED Example	0.29





Comparison Tool Outputs

- Reducing light output has a scalar effect, so dimming by, e.g., 50% greatly exceeds the variations among the white light products and saves energy in the process
- The narrowed spectrum of the amber source offers further reductions, which the local community may want to consider against other likely tradeoffs, e.g., visual acuity, color quality, energy use

Sky Glow Comparison Tool

INPUT CONDITIONS

1. Scenario Parameters

Observer location	near
Atmospheric condition	clear low particulate
Weighting function	scotopic

2. Baseline Light Source Characteristics

Percent uplight	0%
Baseline source	1. LED 187 PC Blue Pum

3. Comparison Light Source(s) Characteristics

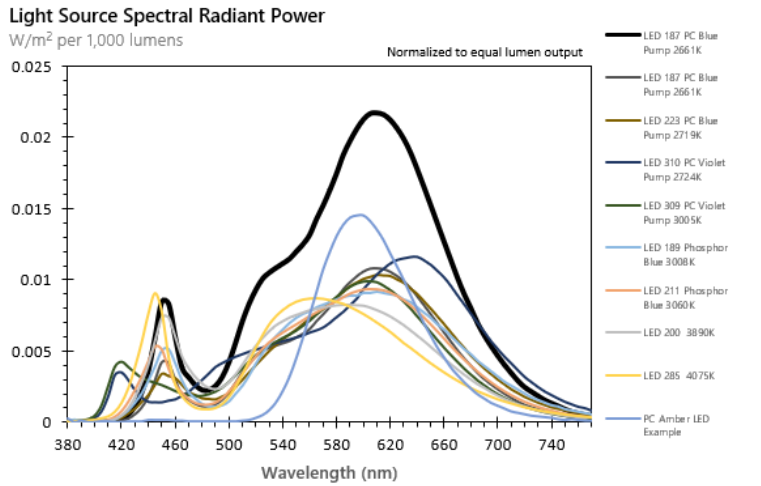
Percent uplight	0%
Lumen output (% of baseline)	50%

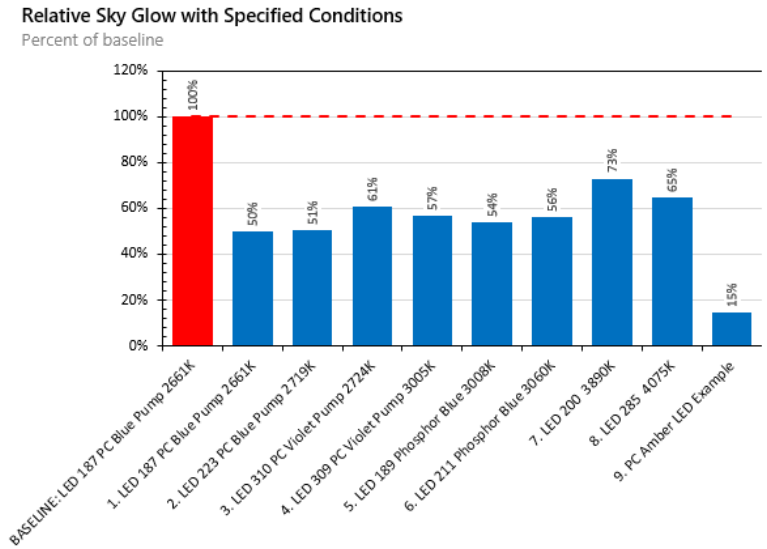
Clear | Calculate

RESULTS

[Add new SPDs using the "SPD Input" sheet]

Source Label	Relative Sky Glow
BASELINE: LED 187 PC Blue Pump 26	1.00
1. LED 187 PC Blue Pump 2661K	0.50
2. LED 223 PC Blue Pump 2719K	0.51
3. LED 310 PC Violet Pump 2724K	0.61
4. LED 309 PC Violet Pump 3005K	0.57
5. LED 189 Phosphor Blue 3008K	0.54
6. LED 211 Phosphor Blue 3060K	0.56
7. LED 200 3890K	0.73
8. LED 285 4075K	0.65
9. PC Amber LED Example	0.15





Conclusions

- Continued growth in the global use of lighting is a virtual certainty
- To be likely accompanied by concerns over associated adverse effects
- The only viable approach for avoiding associated growth in potential adverse effects first involves improving the technology – both lighting sources and controls
- Also essential are better definitions of when lighting is needed, and when and where it isn't, along with more complete understanding of the various tradeoffs between lighting's benefits and potential adverse effects
- This knowledge needs to be shared, and implemented, on a global scale

Thank you

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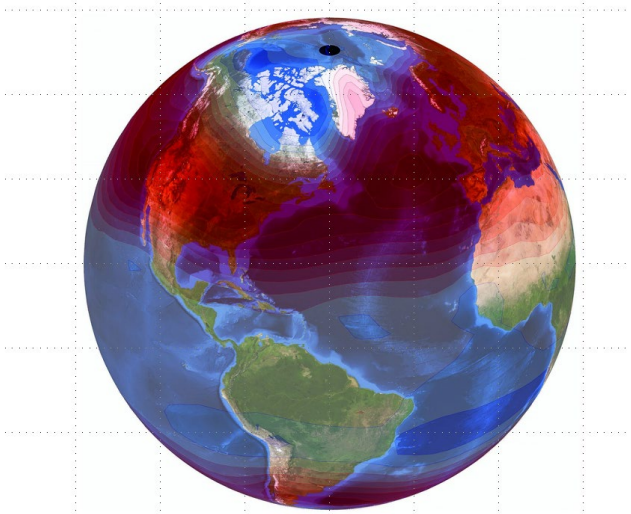
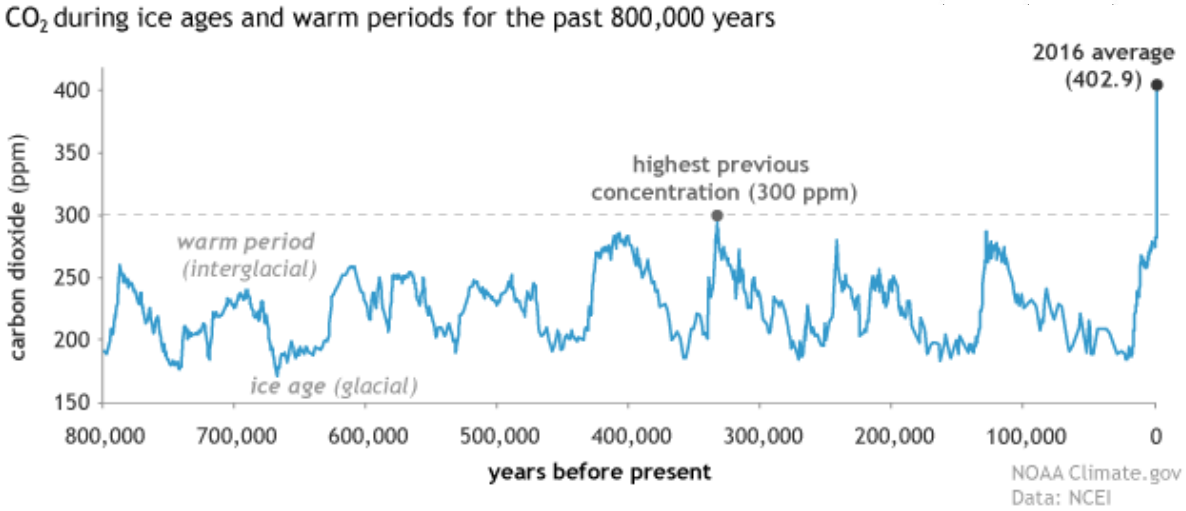


Benjamin D. Santer et al. Science 2018;361:eaas8806



Source: NOAA

Street light pole in St. Croix, USVI, 2017, following Hurricane Irma